Coral reef rehabilitation on Koh Tao, Thailand

Assessing the success of a Biorock Artificial Reef

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Abstract

Coral reefs are diverse and productive ecosystems, which play a vital role in global ecosystem health and in many human economies. Reefs are threatened by both natural and anthropogenic influences that severely reduce the ecosystem's resilience, especially in the face of climate change. On Koh Tao, Thailand, active measures have been taken to restore damaged reef area´s faster than would occur naturally. The Biorock artificial reef structure in Hin Fai, Koh Tao uses low voltage direct electrical current to stimulate calcium carbonate deposition, hereby strengthening the coral skeleton and increasing coral growth rates. The aim of this project was to compare growth rates of corals at the Biorock to other reefs around Koh Tao, by analyzing coral photos which have been collected over three years by an ecological monitoring station. We find that corals on the Biorock structure grow up to 80% faster than corals in other reef areas when conditions are optimal. It should be mentioned that this was an exploratory study using a small data set, and that further research in this area needs to be carried out constraining more variables and using a more comprehensive data set. Therefore we have included an outline on how to conduct a coral growth rate analysis, which can serve as a tool for other marine conservation students or local community members who are interested in conducting similar projects in the future.

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Preface and Acknowledgements

Initially, I went to Thailand to do two months of volunteer work at New Heaven Dive School Reef Conservation Program (NHRCP), and to write a literature thesis for my Masters in Chemistry at the VU University. The literature thesis turned into a little research project and the two months turned into three. I would have liked to stay even longer, New Heaven is a great place where people from all backgrounds and nationalities work together to preserve the coral reefs.

For the research project I analyzed coral photos taken at different locations around Koh Tao. Since I spend most of my time learning how to work with the photo analysis program, the project itself is relatively small but I also wrote an outline for future students on how to conduct a photo analysis project.

First I would the thank Henk Lingeman and Freek Ariese for giving me the freedom and opportunity to go on an internship somewhat outside the field of Analytical Chemistry, this experience has taken me a step in the right direction for my career.

I also would like to thank Chad Scott, who basically taught me everything I know about coral reefs, answered all my questions and helped a lot with this project. I want to thank Devrim Zahir for his hospitality, moral support and for showing all the beautiful dive sites around Koh Tao. Many thanks to my fellow marine conservation divers, Shin, Margaux, Will, Pim and the rest who helped me with taking the coral photos.

Picture: Divers working one of the four Biorock domes on Koh Tao, Thailand.

1. Introduction

Coral reefs are one of the oldest, most diverse and productive ecosystems in the world. They form a habitat for over 9 million species, 25% of all marine life (Spalding 1997). Coral reefs play a vital role in global ecosystem health and in many human economies. They are an important source of income, providing food, raw materials and medicine, as well as diving and snorkeling tourism (Moberg *et al.* 1999). Reefs also serve as a natural shore protection, shielding beaches and shores form waves and storms.

Coral reefs are vulnerable ecosystems, and their health is at risk due to both natural and anthropogenic factors. Natural events like storms and hurricanes cause great damage to reefs areas but they tend to be widespread but infrequent, providing the corals time to recover. Anthropogenic influences like overfishing, pollution, increased nutrient loading and physical damage by divers, are less severe but put a constant load on the coral reef (Weterings 2011). This combination of natural and anthropogenic stresses greatly reduces the ecosystems resilience in the face of climate change. Since the last decade, climate change impacts have been identified as one of the greatest threats to coral reefs (Baker *et al.* 2008; Hoegh-Guldberg *et al.* 1999, 2007; IPCC 2007). High temperatures cause mass bleaching events followed by coral mortality all around the world. Increased concentrations of carbon dioxide cause ocean acidification; under more acidic conditions, coral calcification rates are slow down and eventually coral skeletons will start to dissolve (Kleypas *et al.* 1999).

In order to protect these ecosystems, both passive and active rehabilitation techniques are applied. Passive rehabilitation is carried out by protecting a certain reef area from fishing, pollution and diving and letting the reef come back naturally. Another way to restore damaged reef areas is by active rehabilitation; artificial reefs and coral nurseries increase reef areas and restore damaged areas faster than would occur naturally (Epstein *et al.* 2003; Rinkevich 2005). At a coral nursery, coral fragments found in the sand are provided a secure growing environment until they are large enough to be transplanted back onto a natural reef (Scott 2011). Artificial reefs are metal or concrete structures, onto which corals can be secured to provide a stable and solid place to grow, which in time will be overgrown by corals and will look like a natural reef. Biorock is a form of artificial reef which uses low voltage electric current to create an excellent growing environment for corals, and counteracting the process of ocean acidification. Corals on a Biorock grow 3-5 times faster and are more resilient with respect to natural and anthropogenic stresses (Goreau, 2003).

Koh Tao, a small island located in the Gulf of Thailand, is surrounded by coral reefs and is the most popular dive destination of Thailand. Koh Tao's economy is based entirely around diving tourism, and consequently loss or deterioration of coral reef will have great consequences. Marine conservation Koh Tao, a collaboration initiated by Koh Tao's community, has started several reef rehabilitation projects around the island including coral nurseries and artificial reefs. Since 2009, Koh Tao also has a Biorock artificial reef. An ecological monitoring station has been taking coral photo data at Biorock and other sites around the island, but this data has not been analyzed so far.

The goal of this project is to compare coral growth rates on the Biorock to other reef areas around Koh Tao by analyzing the coral photo data. This provides insight on the success of the reef rehabilitation techniques and this information can serve as a tool in decision making for future projects. A second objective was to write an outline, for local community members and marine conservation students, on how to conduct similar projects in the future.

Chapter two provides a basic explanation on carbonate chemistry of coral reefs. In chapter three, background information on Koh Tao is provided and chapter four explains the principle and applications of Biorock technology. Chapter five covers the coral photo analysis I conducted followed by a conclusion. An outline on how to conduct a coral photo analysis is provided in the Appendix.

2. Coral reefs and Climate Change

2.1 Reef building corals

Corals are animals from the class Anthozoa of phylum Cniadaria and live in compact colonies of many identical individual "polyps". Included in this group are the reef building corals that secrete calcium carbonate ($CaCO_3$) to create a hard skeleton. Corals reefs are formed by a buildup of these coral skeletons over thousands of years. Corals obtain most of their energy and nutrients (and also their color) from photosynthetic unicellular algae called Zooxanthellae that live inside the corals tissue. Formation of the exoskeleton involves deposition of calcium carbonate by the polyps from calcium (Ca^{2+}) and carbonate (CO_3^{2-}) ions acquired from seawater (Spalding *et al.* 2001).

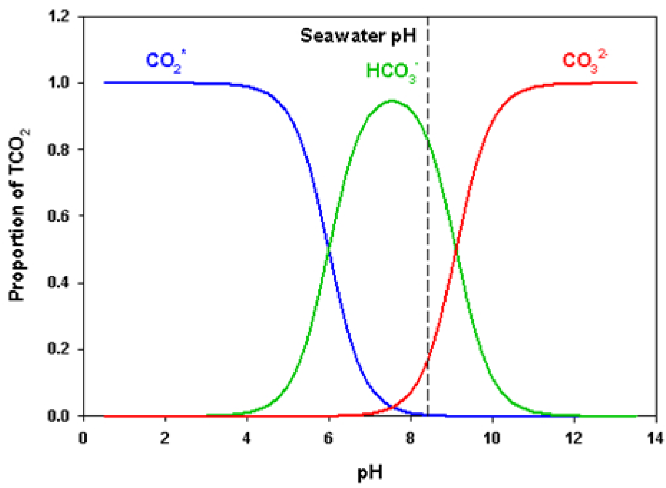


Figure 2.1. Relative proportions of the three inorganic forms of CO_2 dissolved in seawater as a function of pH.

2.2 Ocean carbonate chemistry

In seawater Ca^{2+} is one of the most abundant ions (0,04%mass of all salts). Carbonate CO_3^{2-} is one of the four forms in which inorganic carbon exists in sea water, its concentration is determined by both pH and the global carbon cycle. The amount of inorganic carbon in the ocean is influenced on one side by the rate of deposition of carbon containing ions, for instance precipitation of $CaCO_3$ by reef building organisms. In this way coral reefs act as a global sink for carbon (Raven *et al.* 2005). On the other side, atmospheric carbon dioxide (CO_2) acts as a source of carbon. The amount of CO_2 in the ocean is related to the concentration. of CO_2 in the atmosphere according to Henry's law (Eq 2.1).

$$[CO_2]_{atm} \propto [CO_2]_{ocean} \qquad (2.1)$$

When CO_2 enters the ocean, it will react with seawater to produce H^+ and various negative forms of dissolved carbon (Fig.2.1). A small amount of gaseous CO_2 will stay in the seawater and the rest of the CO_2 will react with water to form carbonic acid, H_2CO_3. Carbonic acid splits up to a hydrogen and bicarbonate ion, HCO_3^- (about 91% in this form). Bicarbonate splits up to a hydrogen and carbonate ion, CO_3^{2-}.

All forms of dissolved carbon are present in seawater, with their relative proportions being determined by pH (Fig. 2.1). Equation 2.2 shows the interdependency of the inorganic carbon species. Figure 2.1 point's out how the relative abundance of carbon species changes with pH. pH is a term that describes acidity of a solution, a measure for the H^+ concentration (Eq.2.3).

$$H_2O + CO_2 \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^- \leftrightarrow 2H^+ + CO_3^{2-} \qquad (2.2)$$

$$pH = -\log_{10}[H^+] \qquad (2.3)$$

2.3 Influences of Climate Change

Since the start of the industrial period, large quantities of CO_2 have entered the atmosphere due to human activity. This anthropogenic CO_2 is mainly the result of fossil fuel burning, but also deforestation, agriculture and cement production play a role (Sabine *et al.* 2004). The concentration of CO_2 in Earth's atmosphere now exceeds 380ppm, which is 80ppm above the maximum values in 740.000 years (Petit *et al.* 1999). Due to increased CO_2 levels, oceans global average temperature is increased by 0.74°C, the sea level has risen 17cm, carbonate concentrations are depleted by 30mmol/kg and oceans pH is decreased by 0.1pH unit (IPCC 2007).

Ocean acidification

Over the last two decades about 30% of the anthropogenic CO_2 was taken up by the oceans (Sabine *et al.* 2004). Ocean acidification is the decrease in the oceans pH, cause by the uptake of anthropogenic CO_2 from the atmosphere (Kleypas *et al.* 2006; Hoegh-Guldberg *et al.* 1999, 2007).

Equation 2.2 shows that CO_2 acts as a weak acid in water. Carbonic acid dissociates to form bicarbonate ions and protons. These protons in turn react with carbonate ions to produce more bicarbonate ions, reducing the availability of carbonate (Hoegh-Guldberg *et al.* 2007). The net effect of dissolution of CO_2 seawater is to increase concentrations of H^+, H_2CO_3 and HCO_3^-, while decreasing concentrations of CO_3^{2-} (Fig.2.1). From equation 2.2, this might seem counterintuitive; adding CO_2 should shift the equilibrium of the first reaction to the right. This is not the case because the excess of H_2O makes the CO_2 on the left side of the reaction negligible for the equilibrium of the reaction: $[H_2O] >> [CO_2] \approx [H_2O]$. Since CO_2 is a weak acid in water, additional CO_2 will increase H^+ concentrations and thus decrease CO_3^{2-}.

Decreasing carbonate concentrations have important consequences for calcifying organisms like corals and clams that form their skeleton out of calcium carbonate (Raven *et al.* 2005). Calcification involves precipitation of Ca^{2+} and CO_3^{-2} ions as shown in equation 2.4. This is an equilibrium process and $CaCO_3$ is vulnerable to dissolution (equation 2.4 reaction to the left) unless Ca^{2+} and CO_3^{2-} ion concentrations are high enough, meaning the seawater is saturated with respect to Ca^{2+} and CO_3^{-2} ions. The saturation state of seawater for a mineral (known as Ω) is a measure of the thermodynamic potential for the mineral to form or to dissolve, and is described by equation 2.5. Ω is the product of the ion concentrations divided by the product of the ion concentrations when precipitation and dissolution are in equilibrium. A value of one for Ω means the calcium carbonate will not precipitate nor dissolve.

← Mineral precipitation

$$CaCO_3\ (s) \leftrightarrow [Ca^{2+}] + [CO_3^{2-}] \tag{2.4}$$

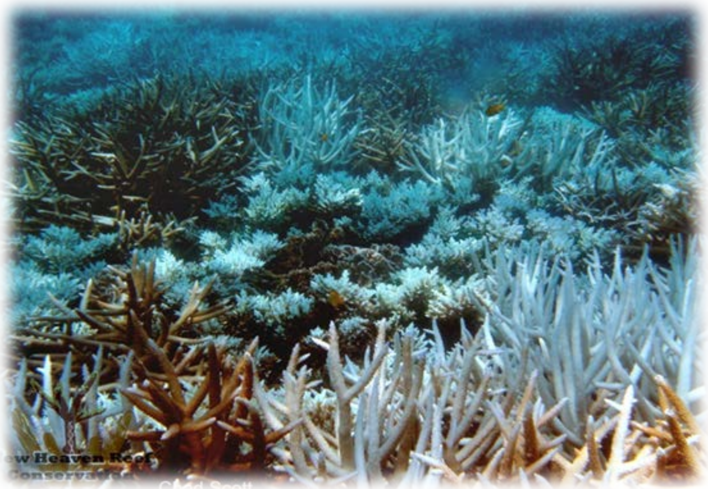
→ Mineral dissolution

$$\Omega = \frac{[Ca^{2+}]\left[CO_3^{2-}\right]}{K_{sp}} \tag{2.5}$$

In seawater, a natural horizontal boundary is formed as a result of temperature, pressure, and depth, and is known as the saturation horizon. Increasing CO_2 levels and the resulting lower pH of seawater decreases the saturation state of $CaCO_3$ and raises the saturation horizons of both forms closer to the surface.

The lowering of sea water pH does not mean corals will instantly start to dissolve, but at lower pH and CO_3^{2-} concentrations, $CaCO_3$ precipitation is energetically less favorable. Consequently the process requires more of the corals energy budget and calcification rates are reduced, leaving less energy for growth and reproduction (Raven *et al.* 2005).

Coral bleaching



Picture 2.1 Chalok Ban Kao reef, Koh Tao, where branching corals appear bleached after expelling their zooxanthallae. May 2010, Photo by Chad Scott.

Since the 1980's coral reef "bleaching", caused by unusually high sea temperatures, has had devastation and widespread effects. Small but prolonged rises in ocean surface temperatures stresses corals and causes them to expel their symbiotoic zooxanthallae (Coles *et al.* 1977). Corals lose their color, become white and appear bleached (Pic. 2.1). The zooxanthallae usually contribute to the corals energy budget and accelerate calcification, but high temperatures damage their photosynthetic machinery, resulting in an overproduction of oxygen radicals (Baker *et al.* 2008). This causes cellular damage to both zooxanthallae and the coral and leads to breakdown of the symbiosis, which if persists for a long time will lead to mortality of the coral colony (Coles *et al.* 1977). However, if temperatures drop back to normal, and corals have not been stressed to severely, they can retrieve new zooxanthallae and regain their health.

Bleaching can occur at a local scale, with parts of a reef area being affected, or at a geographic scale where entire reef systems are bleached. The latter is referred to as mass bleaching and was first described in the Great Barrier Reef in 1979 (Hoegh-Guldberg 1999; Baker *et al.* 2008). Strong bleaching episodes often follow after disturbances to the El Niño Southern Oscillation (ENSO). There have been six mass bleaching events since 1979, with the event of 1998 being the most severe one, when 16% of the world's hard coral died (NOAA 1998).

3. Koh Tao and threats to Koh Tao´s Coral Reefs

Koh Tao is a small island near the western shore of the Gulf of Thailand (Pic.3.1). It covers an area of about 19km^2 and has over 300.000 visitors annually (Weterings 2011). On the west side of the island there are three villages, the east side is relatively unpopulated. Koh Tao has the most diverse and abundant coral reefs in the area, and the islands economy is almost exclusively centered around scuba diving tourism and fishing. Despite its small size, Koh Tao has over 40 dive centers, and is responsible for 46% of all PADI scuba dive certifications issued in Thailand in 2009 (Scott *et al.* 2010).

Koh Tao's increasing popularity for diving is very beneficial to its economy, but the reefs have experienced many stresses caused by this rapid economic development. Examples of stresses are: Waste water and sewage disposal in sea causes eutrophication with the result that algae start overgrowing corals; inexperienced divers and snorkelers physically damage corals with their fins; Deforestation has caused soil erosion which has led to sedimentation on coral reefs (Weterings 2011); and overfishing disturbs the ecosystems balance. These localized but continuous stresses greatly reduce the ecosystems resilience.

Picture 3.1 Map of Koh Tao, a small island near the west coast of the Gulf of Thailand.

On Koh Tao, two major bleaching events have occurred in the last 15 years. The 1998 global mass bleaching event caused high mortality on Koh Tao. However, on most sites monitored, coral recovery after the bleaching event was high in most areas. It was found that in areas with low recovery the reef experienced additional stresses like wastewater dis charge or sedimentation. (Yeemin_2006, Scott *et al.* 2010). In 2010, reefs in the Gulf of Thailand suffered from the most severe bleaching event so far. The sea temperature increased from 29 degrees in the beginning of March to 31-33 degrees in April-June (DMCR 2011). At the most affected sites on Koh Tao 98% of the corals was bleached with 70% mortality after the bleaching (Scott *et al.* 2010)

The Save Koh Tao Marine Branch, a collaboration established in 2000 by local community members, has taken several active measures to restore and rehabilitate the damaged reef areas around the island (Marine Cons.KT, website). Coral nurseries provide small coral fragments a stable environment to grow, this can help to increase the reef area and provide a means of restoring damaged areas faster than would naturally occur (Epstein *et al.* 2003). Artificial reefs are concrete or metal structures that are built to serve as a habitat for marine biota and reduce the pressure of diving tourism on popular reef sites (Rinkevich *et al.* 2005).

4. Biorock Artificial Reef Structures

Biorock is a type of artificial reef structure that uses low voltage direct electrical current to improve growth of corals and calcite-secreting organisms. This process is called mineral accretion, and uses electrolysis of seawater to lower the surrounding water pH, which causes ions like Mg^{2+}, Ca^{2+} and CO_3^{2-} to precipitate and collect on the structure as either calcium carbonate (Calcite or Aragonite) or the less dense magnesium hydroxide (Bruchite). Corals, calms, and other calcium carbonate secreting organisms attached to the structure are able to grow on average 3 to 5 times faster, even under normally lethal high temperatures and pollution, restoring these ecosystems where natural regeneration is impossible (Goreau *et al.* 2003, 2005).

Picture 4.1 Divers attaching corals onto one of the Biorock domes at Hin Fai, Koh Tao. Photo by Chad Scott.

4.1 Process of mineral accretion

A Biorock, schematically represented in figure 4.2, consists of a small anode and a large cathode structure onto which the corals can grow. When a direct current is applied to the system, electrolysis of seawater will cause the following two reactions to take place:

$$\text{Anode}: 2\ H_2O(l) \rightarrow O_2(g) + 4\ H^+(aq) \qquad (4.1)$$

$$\text{Cathode}: 2\ H_2O(l) \rightarrow H_2(g) + 2\ OH^-(aq) \qquad (4.2)$$

At the anode, oxygen (O_2), chlorine (Cl_2) and H^+ ions are formed. The anode environment will be

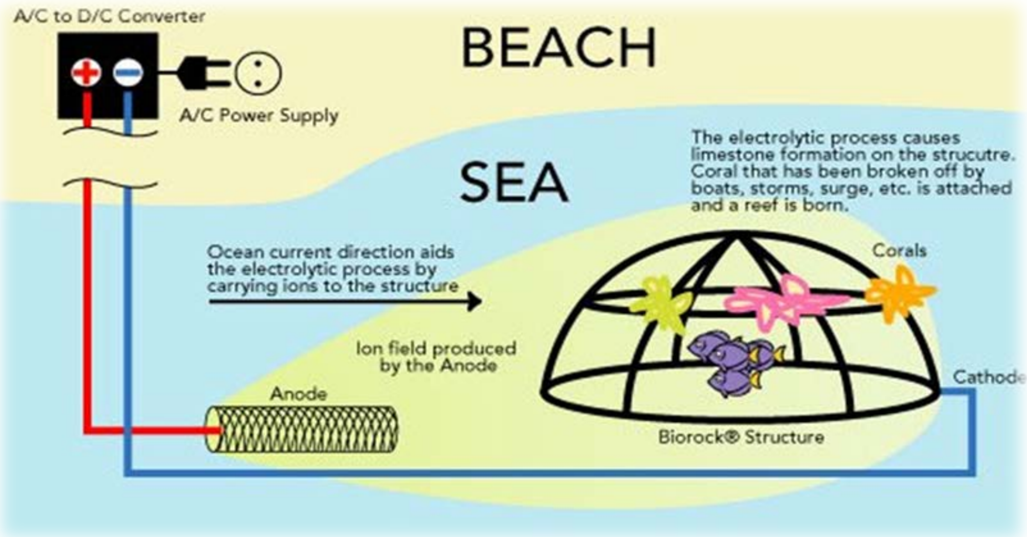


Figure 4.2 Schematic representation of a Biorock. Alternating electrical current is transported from a power supply on the shore, converted to direct current by a convertor. The small anode is placed below or on the sediment. The cathode is constructed of metal or other conducting material and can be built in any shape.

formed hereby lowering the pH. The low pH increases CO_3^{2-} concentrations enough for $CaCO_3$ to spontaneously precipitate onto the cathode.

The seawater pH is on average 8.07, at the Biorock structure it can go up to pH=11. This effect ranges not further than a few centimeters; changes in pH are local with a steep pH gradient. The net charge of the cathode and anode is zero, hereby not affecting overall seawater chemistry. Biorock is the only reef rehabilitation method which addresses climate change. It (although locally) lowers the seawater pH, hereby counteracting the effect of ocean acidification. Mineral accretion is favored at higher temperatures (van Treeck *et al.* 1997), e.g. during ENSO or high seawater temperatures due to global warming, the Biorock does well.

4.2 Biorock material

The cathode may consist of any conductive material in any shape desired. Non-galvanized steel mesh (chicken wire) is preferred (van Treeck *et al.* 1997). The anode is usually made of carbon, lead or titatium (van Treeck *et al* 1997), but also magnesium and aluminium are used (Zamani *et al.* 2010). A direct current ranging from 1-24V with a density of approximately $3Am^{-2}$ cathodic surface gave the best result. Voltage is not a critical factor, but higher current densities result in faster precipitation and the balance between Bruchite and Aragonite tends shifts towards Bruchite, which is weaker and more fragile. Some Bruchite dissolves in time and is replaced by Aragonite, therefore Biorock structures continually grow and get stronger with age, in contrast to all other marine construction materials. They have the property of self-repair, damaged areas or cracks expose the electric field and are first filled in as the material grows (Goreau 2003,2). High temperatures, high salinity and low water currents favor mineral deposition (Sadrzadeh *et al.* 2008), but strong water currents improve the hardness of the material by reducing the pH gradient around the cathode, hereby enlarging the proportion of Aragonite being deposited (van Treeck *et al* 1997).

Biorock mineral accretion is a patented technology (Duckworth *et al.* 1985). In 2015, the patent will expire making this technology more easily available and affordable for coral reef conservation around the world. The budget for reef rehabilitation projects is usually small. For example on Koh Tao, where all reef rehabilitation projects area initiated by the local community. The projects are funded through private donations and fund raising events and all construction and maintenance work is done by volunteers (Scott, personal communication).

4.3 Applications of Biorock

The principle of mineral accretion by seawater electrolysis was first studied by Architect Wolf H. Hilbertz with the idea to form material from elements in the ocean and transport them back on land for building purposes (Hilbertz 1976). Though formation of building material went quite well, clams, oysters and other marine organisms started growing on the structures. Then the opportunity of using this technique to grow reefs arises (Hilbertz 1979), and since the 1980's Hilbertz collaborated with marine biologist Dr. Thomas Goreau to further develop the Biorock artificial reef technology.

As of 2011, Biorock projects have been initiated over 20 countries including Indonesia, Thailand, Maldives and Panama. Although very little literature about these projects has been published so far, their progress is well discussed on websites. The largest artificial reef project is around the Gili Islands, Indonesia, where they state corals on the Biorock grow 2 to 6 times faster and their survival is 20 to 50 times higher than in the natural environment (Gili Eco Trust, website). Corals growing on the Biorock structures in the Maldives experienced very low mortality after the 1998 bleaching event and also survived a tsunami in 2005 (Abdul Azeez, website).

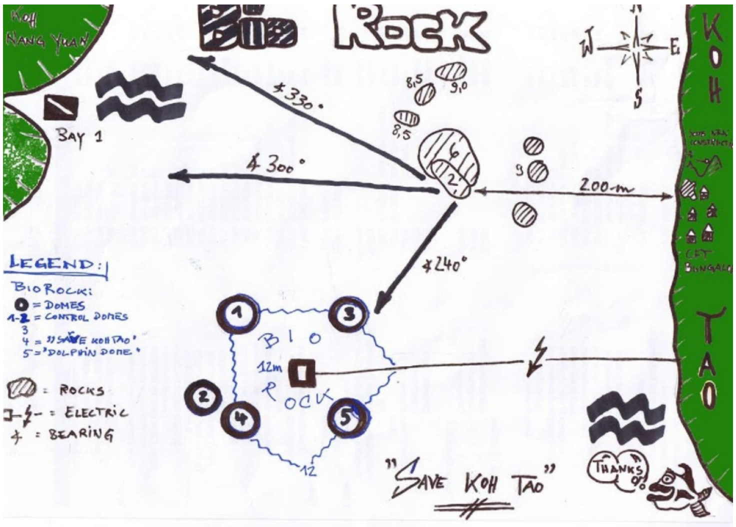
Around the Turks and Caisos Islands, four Biorock structures were built around 2007. After these structures were struck by hurricanes in 2008, only one structure had to be replaced, coral mortality was only 40% but after the damage the corals were more susceptible to coral diseases (Wells *et al.* 2010).

Several Biorock projects had problems with power supply. Electric cables can get damaged by anchors dragging through the sand (Wells *et al.* 2010). If the anode is not secured well it can shift and create strong electric fields causing algae to overgrow the corals (van Treeck *et al.* 1997). The Biorock on Koh Tao also suffers from a power deficit and no current is flowing through the structure since October 2011.

4.4 Koh Tao's Biorock

Picture 4.3 One of the four domes of the Biorock artificial reef, build by volunteers and ready into be moved to sea. Photo by Chad Scott

In the end of September 2008, more than 100 volunteers of local dive schools and the community gathered to build four large metal domes which form the cathode of the Biorock (Pic.4.3). Each dome is about 4 meters high and six meters in diameter. At the site named Hin Fai (Electric Rock in Thai), the domes are orientated in a square with about 12 meter space in-between, 250 meters from shore and with an average depth of 13 meters (Pic.4.4). They have arch on the side and a gap at the top so divers can swim through the domes. A power conver alternating current delivered by a cable frc smaller dome is placed close to the Biorock structure but is not connected to the power device and serves as a control dome. Throughout 2011 and 2012 volunteers have been working at the Biorock site to transplant coral fragments onto the structures, and great improvement in coral health and fish abundance have been observed at Hin Fai around the Biorock.



Picture 4.4 Map of the Hin Fai Birock dive site made by dive master trainers at New Heaven Dive School.

5. Project: Biorock growth rate analysis

In order to gain insight of the success of Biorock and other reef rehabilitation projects around Koh Tao, an ecological monitoring station has been taking transect photos for over four years. These photos can be used to assess growth and health of these corals. They have collected a large amount of data, but it has not been analyzed so far. The aim of this project is to compare growth rates of corals growing at the Biorock to that of corals at other (natural and artificial) reef areas around Ko Tao.

Growth rate is an important parameter in assessing the success of a reef rehabilitation project. Decisions for future rehabilitation projects are made based on how well corals "rehabilitate" and benefit from the project, i.e. how well do they grow. On the other hand, the costs of a project play a role. Costs include the initial costs of starting the project and building for instance the artificial reef structure, but also the amount of maintenance and the level of expertise required to keep the running.

5.1 Method

When coral fragments are transplanted to a coral nursery, artificial reef or natural reef, at random some of these fragments have been marked. These marked coral fragments were monitored in time to get an indication of the state of all fragments growing in that area. It is important to mark specific fragments because when the fragment grows, the size, shape, colour and also environment of the fragment will change, which all make it hard to remember which fragment was being monitored. Marking was carried out by numbering the nursery table the fragment is growing on or attaching a PVC tag next to the coral colony (pic 5.1). From all the data collected by the ecological monitoring station, one growth form which had a sufficient amount of photos was selected. Coral colonies of Coryombose growth form (Acroporidae and Pocciliporidae coral families) were analysed (Pic.5.1). Corymbose corals grow in a bush-like form and are generally found in areas where light

Picture 5.1 A Coryombose coral #8 growing on the Biorock. The blue tag is used for scaling.

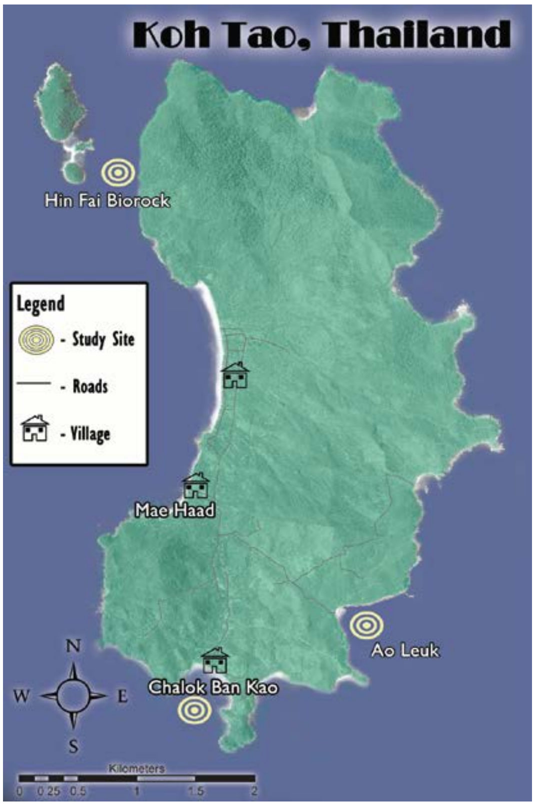
levels are high and currents are strong. Corymbose corals an average growth rate, this make them a good indicator for general coral growth in an area.

5.2 Study Sites

Coral colonies growing at three different dive sites around Koh Tao were compared (Pic.5.2). At each site, they were growing in a different type of reef rehabilitation project; The Biorock artificial reef structure at Hin Fai; Coral Nursery tables in Chalok Ban Kao; Natural reef area in Aow Leuk :

Site Name	Depth (m)	Substrate type
Hin Fai	10-16	Biorock
Aow Leuk	13	Natural reef
Chalok Ban Kao	8-10	Coral nursery

Picture 5.3 The metal of the Biorock is covered in calcium carbonate. A branching coral is growing on the structure.



Picture 5.2 A map of Koh Tao presenting the three study sites

Biorock, Hin Fai

Hin Fai is located at the North West side of Koh Tao, at a starting depth of 10 meters to a maximum of 16m. The Biorock artificial reef structure is described in chapter 4. Picture 5.3 shows a coral fragment growing on one of the Biorock domes.

Nursery tables, Chalok Ban Kao

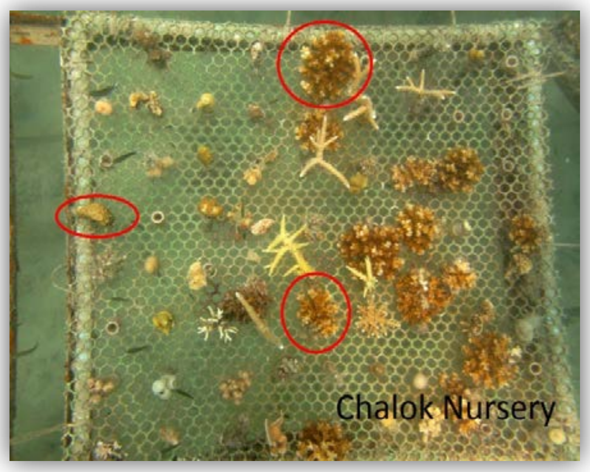
Chalok Ban Kao is a moderately populated bay with a lagoon zone extending from the beach to about 350 metres, making this a very shallow bay. Coral nursery tables are situated at 8m to a maximum depth of 10.6m. These tables provide a secure environment for small coral fragments until they are large enough to be placed back into the reef

(Pic. 5.5). Small coral fragments lying in the sand are moved constantly by wave action and will not be able to survive there. By collecting these fragments, removing death parts which are covered in algae and by securing them in plastic tubes placed in the nursery tables, these fragments can grow to a larger size to increase their change of survival.

Natural reef, Ao Leuk

Ao leuk is located in a quite bay with very little development on land. The reef is mostly a patch reef, with large submassive, massive an tabulate corals and rocks scattered in the sand. Most rocks contain small holes in which a coral fragment tube can be fitted. When the tube is completely inserted into the rock, the coral can grow over the tube onto the natural reef. The corals analyzed (pic 5.4) are at a depth of 13m.

Picture 5.4 Three large coral fragments , transplanted and now growing on this rock in

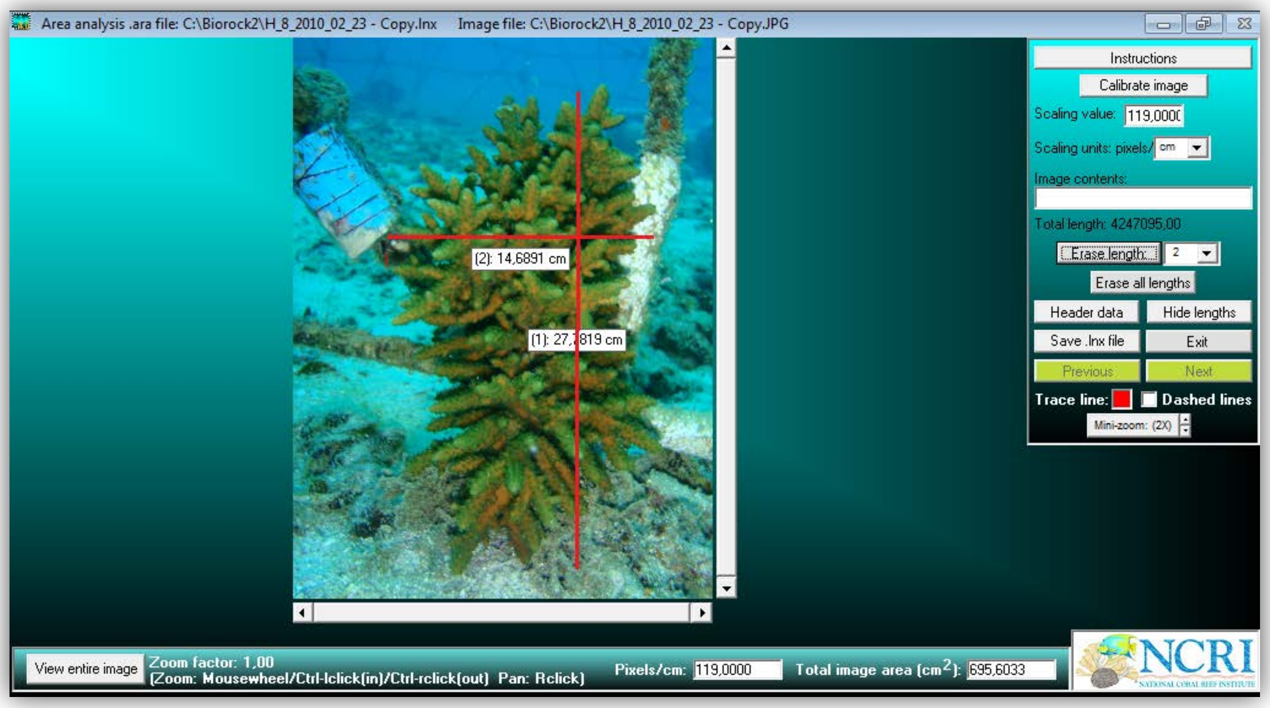


Picture 5.5 Coral fragments growing in tubes on a coral nursery table in Chalok Ban Kao.

5.3 Data analysis

The photo data of the selected coral colonies was analyzed using Coral Point Count program with Excel extensions (CPCe)(Kohler *et al*. 2006). Each photo was scaled by using a reference item of known size in the picture (pvc tag, grid). After scaling, the horizontal and vertical maximum length of the coral colony was determined using the Batch Linear extension Analysis option (pic. 5.6).

The horizontal and vertical lengths calculated with CPCe were exported to an Excel spread sheet. Coral size in this report is defined as the surface area in cm^2 units, from multiplication of the horizontal and vertical length in cm. Growth rate is defined as cm^2 per time unit. A more comprehensive description of the method is provided in Appendix A.



Picture 5.6. Printscreen of the CPCe program in batch linear analysis mode. At the top showing the file name, in the center the photo being analyzed. On the right side it shows the options to calibrate, calculate lengths, change header data and move to the next file.

5.4 Results and discussion

From the lengths of the corals calculated with CPCe, coral size expressed as horizontal x vertical length was determined. Sizes of corals at each site from 2010 until early 2012 are represented in figures 5.1 to 5.3. Figure 5.1 to 5.3 show that corals at each site have grown between 2009 and 2012. From figure 5.1, seasonal growth changes in Ao Leuk are evident, with strong

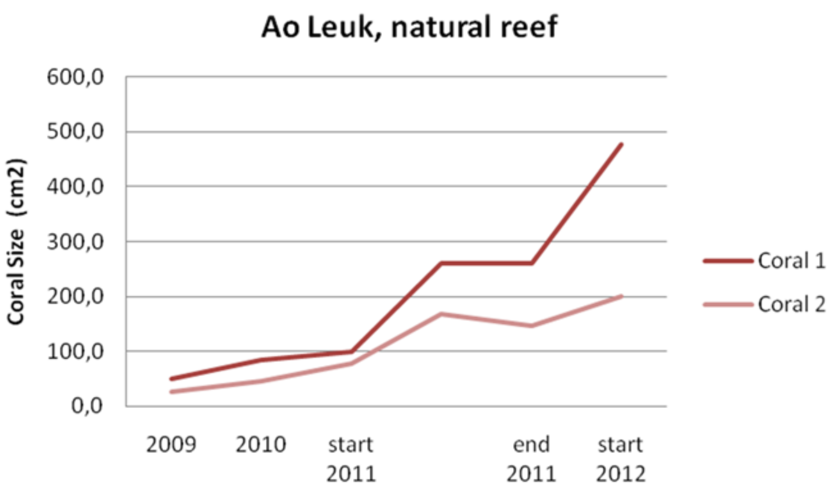


Figure 5.1 Change in coral size over time of corals in Ao Leuk. Coral size is defined as horizontal x vertical length.

growth at the start of 2011, and almost no growth in the end of 2011 during the monsoon season. Slow growth on the Chalok nursery (Fig. 5.2) in 2010 reflects the coral bleaching event, with one colony showing even a negative growth. Corals on Hin Fai Biorock show growth even in 2010 (Fig. 5.3) during the bleaching event.

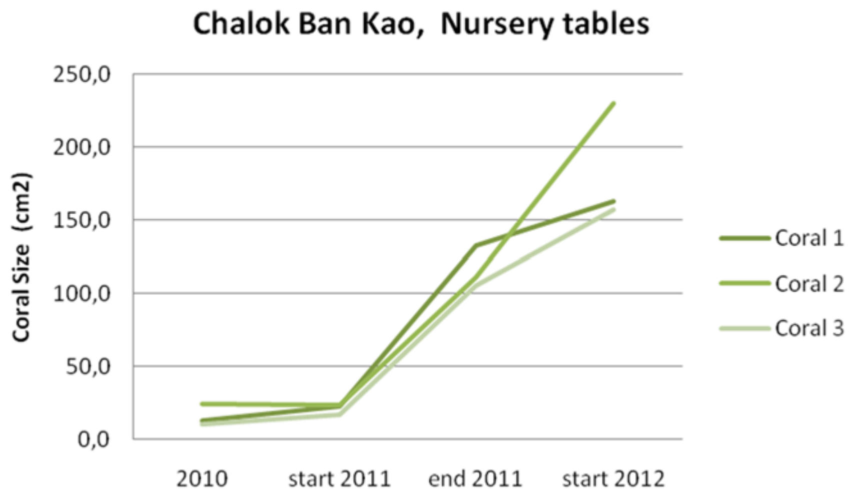


Figure 5.2 Change in coral size over time of corals in Chalok Ban Kao. Coral size is defined as horizontal x vertical length.

In 2011, after the bleaching event, corals grow much faster again. Due to a defect in the power convertor, the Biorock has been "off" since October 2011 (C. Scott, personal communication). At the end of 2011 and start of 2012 the graphs show that corals on the Biorock are still growing, but less fast then in 2011. Notice that the scaling is different for each graph; this has a large influence on their slopes.

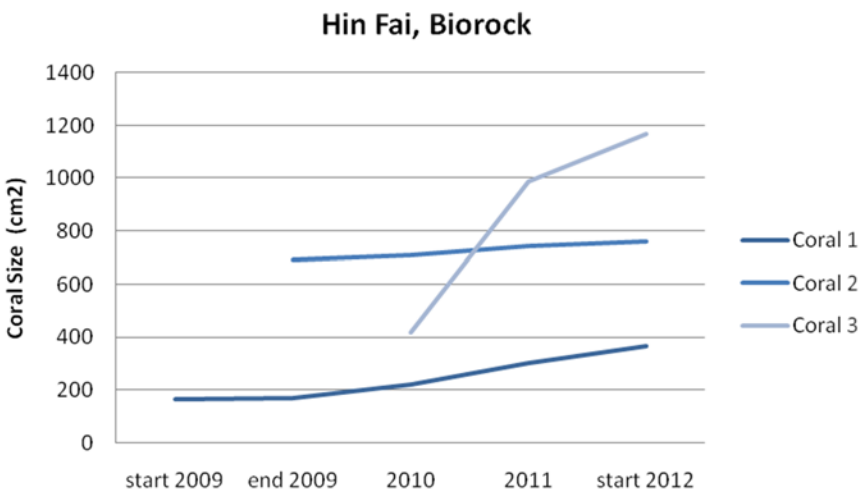


Figure 5.3 Change in coral size over time of corals at Biorock. Coral size is defined as horizontal x vertical length.

In figure 5.4, growth rates of the different sites are compared for each year. In 2010 all sites show poor growth, corresponding to the coral bleaching year. In 2011, corals on each site grow much faster, especially at Hin Fai Biorock. In 2012, Chalok nursery and Ao leuk grow slightly faster than in 2011 and the Biorock growth has slown down to 8m2/week. Which is much slower as it was in 2011 when the Biorock was on, but it still a good growth rate. This points out that when no current flows through the Biorock structure; it is just an artificial reef structure. Corals don't experience the benefits of the electrolysis, but are also not harmed by the lack of it. Corals grow at a normal rate and even slightly faster than corals in Ao Leuk and the Chalok nursery. Note that the higher growth rate in 2012 on the Biorock compared to Chalok Nursery and Ao Leuk might also be addressed to other factors.

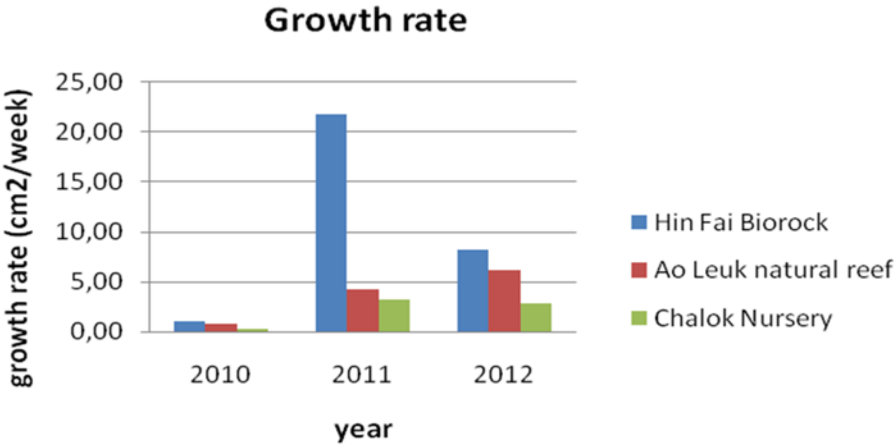


Figure 5.4 Growth rates in cm2/week of corymbose corals in Hin Fai, Ao Leuk and Chalok Ban Kao. The rates presented are average values calculated from several photos taken that year.

In this project we are comparing three sites at different bays around the island. There is a difference in depth and coral colony starting size. For a more accurate study coral colonies in the same area and depth, but on different artificial reef structures should be compared, which is beyond the scope of this project. This is an orientating project, to make an outline for future research and test the applicability of CPCe. Nevertheless figure 5.4 shows that when the Biorock is on, growth rates increase dramatically.

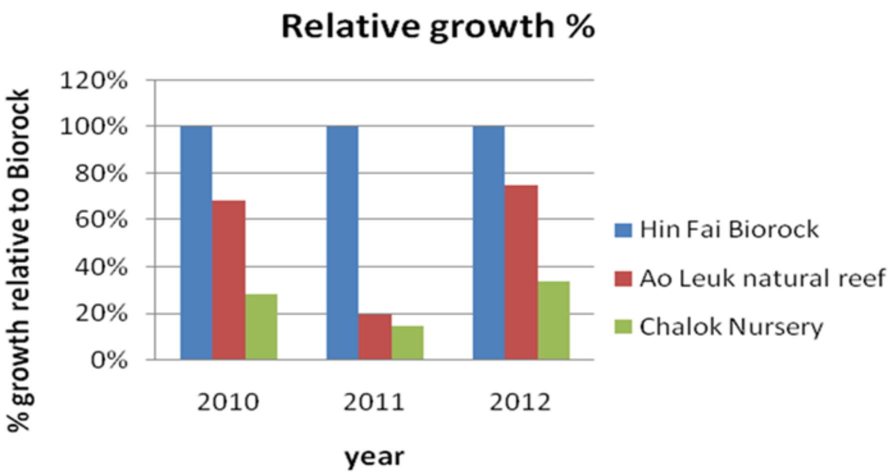


Figure 5.5 Relative growth percentages of corals in Ao Leuk and Chalok with respect to Biorock. Percentages are calculated from growth rates in figure 3

Figure 5.5 shows the relative growth at each site with Hin Fai Biorock as the baseline (100%). In 2010, corals at Hin Fai Biorock grow 30% and 70% faster than at Ao Leuk and Chalok respectively. In 2011 this goes up to 80% and 85%. When environmental conditions are good (2011) all the energy supplied by the Biorock can be invested in growth. When conditions are poor (2010 bleaching), the energy supplied by the Biorock structure is mainly invested in the corals immune system for survival. This explains less relative growth in 2010 compared to 2011, but also much less bleaching of corals on the Biorock compared to other sites.

Figure 5.6, created by SKT Marine Branch director Chad Scott to map the coral bleaching around Koh Tao, shows the health of corals half way through the 2010 bleaching event. Healthy (H) means corals are not stressed; they still have a good colour which indicates the symbiotic relationship with zooxanthellae algae is intact. Partially bleached (PBL) means coral colonies have lost some colour, the corals are stressed and have lost part of their zooxanthellae. Fully bleached (FBL) means corals are white, are highly stressed and lost their zooxanthellae. If these corals keep experiencing stressful events like elevated temperatures at this point, they have a high risk of dying. From figure 5.6 it is evident that growth rate is one factor addressing success of a certain reef rehabilitation project, health and consequently mortality is another important factor.

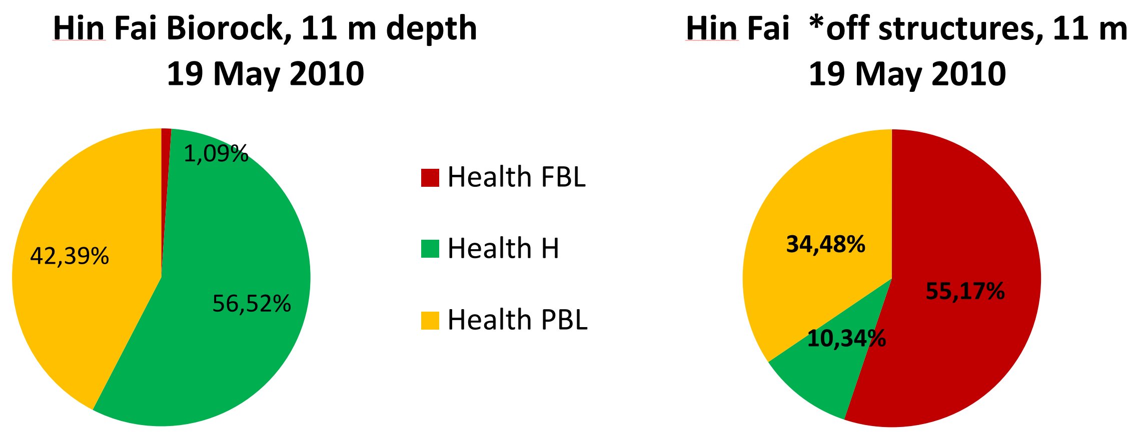


Figure 5.6 Health of corals growing on the Birock (left) compared to corals in the same area (right), half way through the 2010 bleaching event. H= healthy, PBL= partially bleached, FBL= fully bleached. By Chad Scott, Save Ko Tao 2010

5.5 Conclusion

The goal of this project was to assess the success of different rehabilitation projects and to compare coral growth rates on the Biorock to other sites around Koh Tao. The results of this project show that Biorock is a successful reef rehabilitation technique, coral can grow up to 80% faster than on a coral nursery or natural reef area when conditions are good. During stress events, like the 2010 mass coral bleaching, corals at the Biorock still grow slightly faster, but the main advantage of Biorock during and after stress events is the improvement of coral health and low mortality rates. When there is no current flowing through the Biorock, corals still grow well and it functions as an “ordinary” artificial reef.

Although Biorock is a rather expensive reef rehabilitation technique, it shows its value and is sustainable technique, as the structure grows stronger with age and keeps it strength even when no power is supplied.

During my internship, along with other marine conservation students, I have attached several coral fragments onto both the Biorock domes and the control dome. The Biorock at Hin Fai, Koh Tao is the only Biorock around the world which has a control dome, hereby making it an excellent site for a more controlled experiment, comparing coral growth with or without benefits of electrolysis, and controlling all other variables like depth, water quality, and wave action. Since we attached and tagged a more diverse range of coral fragments on the control dome and Biorock, future studies can be expanded, taking into account a wider range of growth forms and coral species.

Literature

Abdul Azeez (2005) Biorock Reefs in Maldives Survive Tsunami Unscratched. *www.globalcoral.org* January 3, 2005.

Baker, A.C., Glynn, P.W., Riegl, B. (2008) Climate change and coral reef bleaching: An ecological assessment of long-term impacts, recovery trends and future outlook. *Estuarine, Coastal and Shelf Science* **80,** pp 435-471.

Coles, S.L., Jokiel, P.L. (1977) Effects of Temperature on Photosynthesis and Respiration in Hermatypic Corals. *Marine Biology* **43**, pp 209-216.

Duckworth *et al.* (1985) Method of stabilization of particulate material. *United States Patent.* **4507177,** March 26.

Epstein, N., Bak, R.P.M., Rinkevich, B. (2003) Applying forest restoration principles to coral reef Rehabilitation. *Aquatic Conserv: Mar. Freshw. Ecosyst.* **13,** pp 387-395.

Gili Eco Trust (2011) What is Biorock? *www.giliecotrust.com/en/about-biorock.html*

Goreau, T.J., Hilbertz, W., Azeez, A., Dodge, R., Despaigne, G. (2003) Restoring Coral Reefs, Oyster Banks, and Fisheries by Seawater Electrolysis: Coastal Zone Management and Tourism Applications. *Oceans*. pp 755.

Goreau, T.J., Hilbertz, W., Azeez, A., Allen, J. (2003) Shore Protection, Beach Formation, and Production of Building Materials and Energy using Seawater Electrolysis Technology. *Oceans.* pp 2366

Goreau, T.J., Hilbertz, W. (2005) Marine Ecosystem Restauration: Costs and Benefits for Coral Reefs. *World Resource Review.* **17, 3**.

Hilbertz, W.H. (1976) Marine achitecture: an alternative. *Arch. Sci. Rev.*

Hoegh-Guldberg, O. (1999) Climate change, coral bleaching and the future of the world's coral reefs. *Mar. Freshwater Res.* **50**, pp 839-866.

Hoegh-Guldberg, O. *et al.* (2007) Coral Reefs Under Rapid Climate Change and Ocean Acidification. *Science* **318**, pp 1737.

IPCC, 2007. Climate change 2007: The physical science basis. Summery for policymakers. Contribution of working group I to the fourth assessment report of the Intergovernmental Panel on Climate Change. http://www.ipcc.ch Website. Jackson, J.B.C., Kirby, M.X., Berger, W.H., Bjorndal, K.A., Botsford, J.W., Bourgue, B.

Kleypas, J.A., Feely, R.A., Fabry, V.J., Langdon, C., Sabine, C.L., Robbins, L.L. (2006) Impacts of Ocean Acidification on Coral Reefs and Other Marine Calcifiers: A Guide for Future Research. Report of a workshop held 18-20 April 2005, St Petersburg, FL, sponsored by NSP, NOAA, and the U.S. Geological Survey, pp 88.

Marine Conservation Koh Tao. *http://www.marineconservationkohtao.com/*

Moberg, F., Folke, C. (1999) Ecological goods and services of coral reef ecosystems. *Ecological Economics.* **29**, pp 215-233.

Petit, J.R. *et al.* (1999) Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica.

Nature **399**, pp 429-436.

Raven, J. *et al*. (2005) Acidification due to increasing carbon dioxide. Policy Document 12/05 (The Royal Society, London, 2005.

Rinkevich, B. (2005) Conservation of Coral Reefs through Active Restoration Measures: Recent Approaches and Last Decade Progress. Environ. Sci. Technol. **39**, pp 4333-4342.

Sabine, C.L. *et al.* (2004) The Oceanic Sink for Anthropogenic CO_2. *Science* **305**, pp 367-371.

Sadrzadeh, M., Mohammadi T. (2008) Sea water desalination using electrodialysis. *www.sciencedirect.com* Desalination **221** (2008) 440–447.

Scott, C.M., True, J.D., Phillips, W. (2010) Spatial and Temporal Progression of Large Scale Coral Mortality During and Following a Mass Bleaching Event on Koh Tao, Thailand. Unpublished manuscript.

Scott, C.M. (2011) Coral Nursery Program Update. New Heaven Reef Conservation Program. Available at http://www.newheavendiveschool.com/th/marine-conservation/research-papers

Scott, C.M. (2012) Personal communication.

Spalding, M.D, Grenfell, A.M. (1997) New estimates of global and regional coral reef areas. *Coral reefs*, **16-4**, pp 225-230.

Spalding, M.D., Ravilious, C., Green, E. (2001). World Atlas of Coral Reefs. *Published by* UNEP-WCMC, print, Pp 205-245

Van Treeck, P., Schuhmacher, H. (1997) Initial Survival of Coral Nubbins Transplanted by a New Coral Transplantation Technology – Options for Reef Rehabilitation

Wells, L., Perez, F., Hibbert, M., Clerveaux, L., Johnson, J., Goreau, T.J. (2010) Effect of severe hurricanes on Biorock Coral Reef Restoration Projects in Grand Turk, Turks and Caicos Islands. *Rev. Biol. Trop*. **58**. pp 141-149.

Yeemin T, Sutthacheep M, Pettongma R (2006) Coral reef restoration projects in Thailand. *Ocean Coast Manage*, **49**, pp 562-575.

Zamani, P.N. *et al.* (2010) Study on Biorock® Technique using three different Anode Materials (Magnesium, Aluminum, and Titanium). *E-Jurnal Ilmu dan Teknologi Kelautan Tropis*, **2**, **1**, Hal. 1-8, Juni 2010

Appendix A. How to conduct a coral growth analysis with CPCe

Photographic and video methods are often used for coral reef monitoring. There are different ways of collecting and analyzing data that all provide different information. Individual coral colonies can be marked and followed in time to assess their health and growth. How to monitor coral growth is explained in section A.1. Another way is to conduct a point intercept photo transect analysis. This allows for estimation of the percentage of coral cover in a certain area. Coral Point Count with Excel extensions is a program which is designed to determine percentage coral cover on photos. Since I have not actually determined percentage coral cover on photos during my Internship, section A.2 does not contain a complete outline but merely an explanation on how to use CPCe for that purpose.

A.1 Monitoring coral growth

Selecting corals

When studying coral growth rates on for instance the Biorock, ideally you want to compare growth on the Biorock to a natural reef or other artificial reef structure. Most accuracy is obtained when sites compared vary only in one variable, the reef structure (e.g. Biorock, Nursery, Natural reef) and all other variables are constrained (e.g. coral species, coral colony starting size, water quality, depth). In this way you are sure that differences in growth can be addressed to the variable you want to measure, in this case reef structure.

Picture A.1 A coral with coryombose growth form growing on the Biorock

When starting a new project, select or transplant two or more similar coral colonies to your different study sites and mark them with a number or letter. Often PVC tags with a number incurved are tied on to the coral or reef structure. Make sure you use original tags that do not interfere with tags around the site used by different dive schools or researchers, so use a different colored, shaped or numbered tag. This tag will also serve as a scaling point in the photo´s, measure the length of the tag and secure it so it is visible, next to the coral in the photo (Pic.A.1).

Taking Photo´s

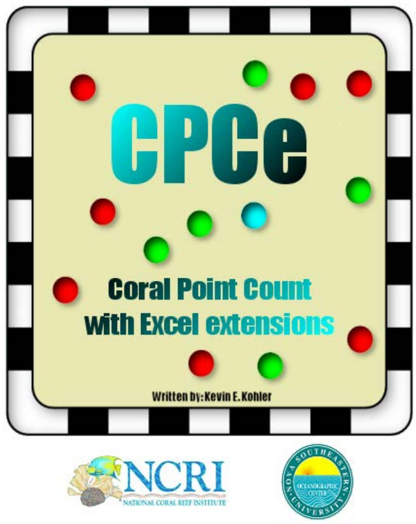
To compare coral growth or change in coral cover in time, the same photo should be taken with a specific time interval depending on the aim of the project. A three month time interval is sufficient for studying coral growth rates but when coral health during a bleaching event is monitored, one week intervals are more sufficient.

Always take the photo from the same angle, perpendicular to the surface where the coral is attached to, and on a distance of 1 m. Make sure the tag is visible and readable so it can be used for scaling, if there are other reference points in the photo like nursery grid of known size, this can also be used for calibration (Pic. A.2). For coral health studies, the color of the photo is important so make sure to use proper settings and to apply white balancing.

Picture A.2 A photo of a Acropora Coral, taken from 1m distance and with no angle. The grid in the photo can be used for scaling.

Organizing data

Picture A.3 CPCe program, developed by the National Coastal Reef Institute

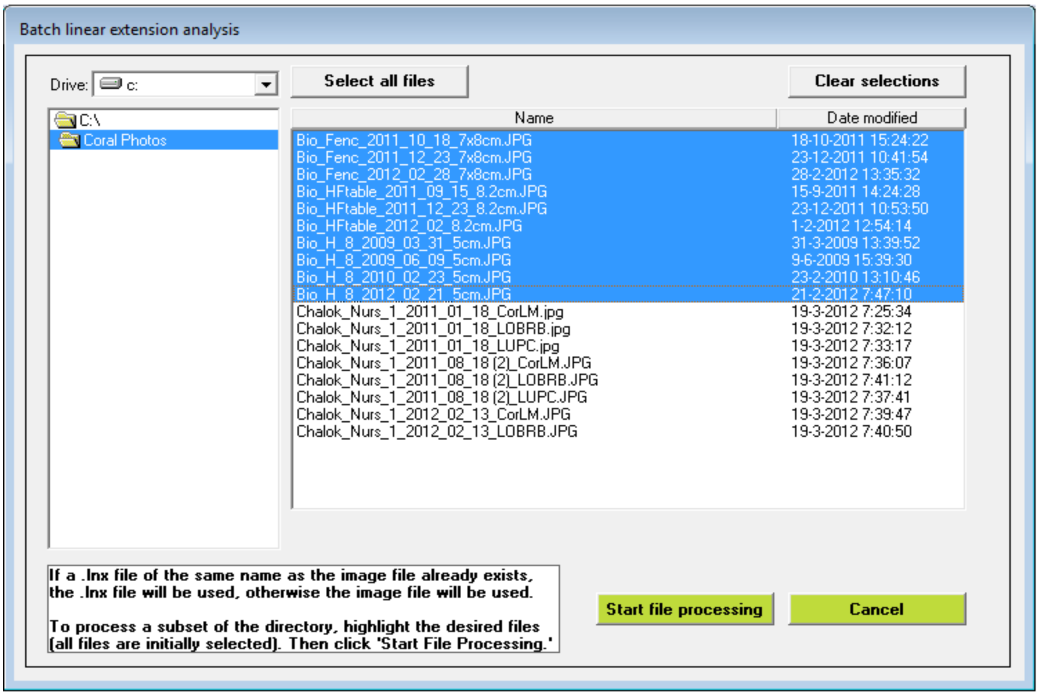


Data is usually collected over a long time period and often by different divers and cameras. To prevent loss of data and to save time on the analysis, agree on a way to organize and name the coral photos and make sure the title contains all the information needed. For example Biorock_S_8_2011_02_21_5cm; is a photo of coral number 8 on the Save Koh Tao dome of the Biorock, taken on 21st of February 2011 with a tag length of 5cm. In this way information cannot get lost when photos are edited and all photos will be organized in logical order in your folder.

Data Analysis

Coral Point Count with Excel extensions (CPCe) program is an easy and effective way to calculate lengths, surfaces and substrate cover of coral transect photos. The program is free downloadable from http://www.nova.edu/ocean/cpce/downloads/index.html.

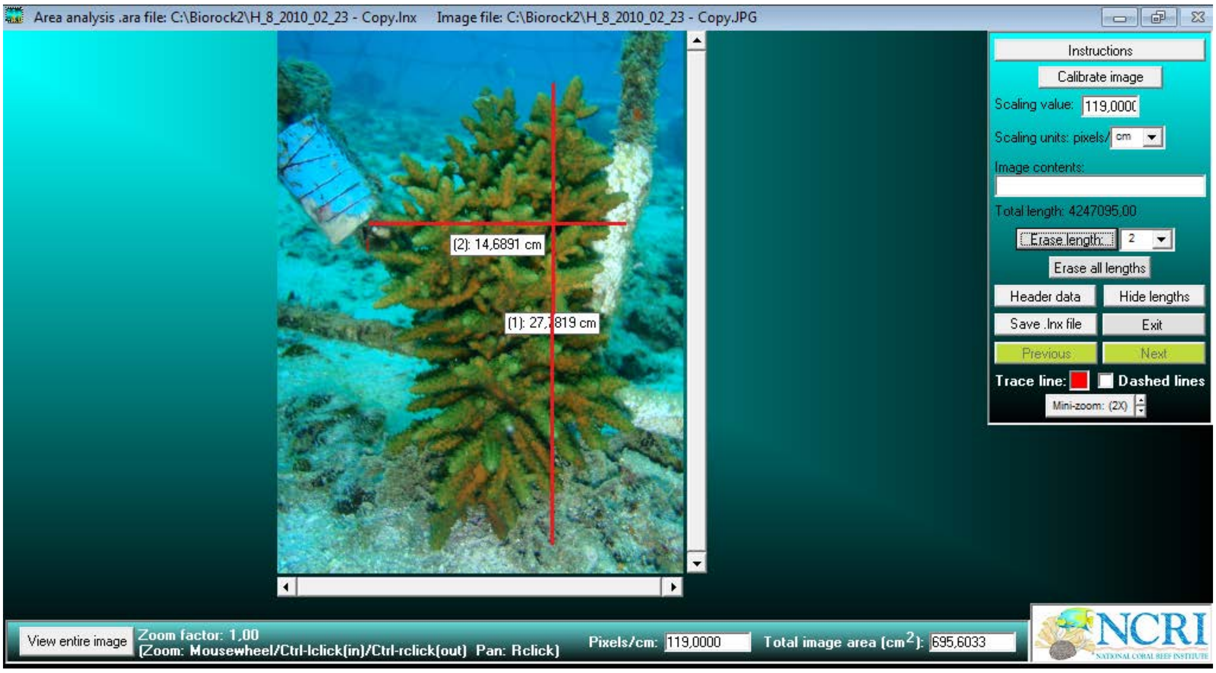
When CPCe 4.0 or CPCe 4.1 is installed on your computer, create a folder containing all photos on the C drive. Monitoring coral growth can be carried out by either measuring lengths or by calculating surface areas in CPCe. For this project horizontal and vertical lengths of corals were measured so this will be explained here in more detail. Open the program and select measurement followed by Batch Linear extension analysis, select the folder containing the coral photos, select the photos you want to analyze and click start file processing (Pic. A.4). The program will now show the first photo. In order to perform a length or area analysis, you must first determine the scaling of an image via image calibration. You need two points of known distance apart (tag), specify these points and provide the distance spanned between the two points as well as the units (cm). The program calculates the scaling and now you can determine a length by using the mouse, left clicking to start and right clicking to end a length.



Picture A.4 Print Screen of the CPCe window. Open a folder on the C-drive and select multiple photos for analysis.

In a single image, multiple lengths can be calculated, but when exporting the data to excel the lengths in one image file will be added to one sum of all lengths. I recommend that when analyzing multiple (horizontal and vertical) lengths, to create two separate folders for horizontal and vertical on the C-drive, and to do two separate analyses. In the final excel spreadsheet you can combine the data.

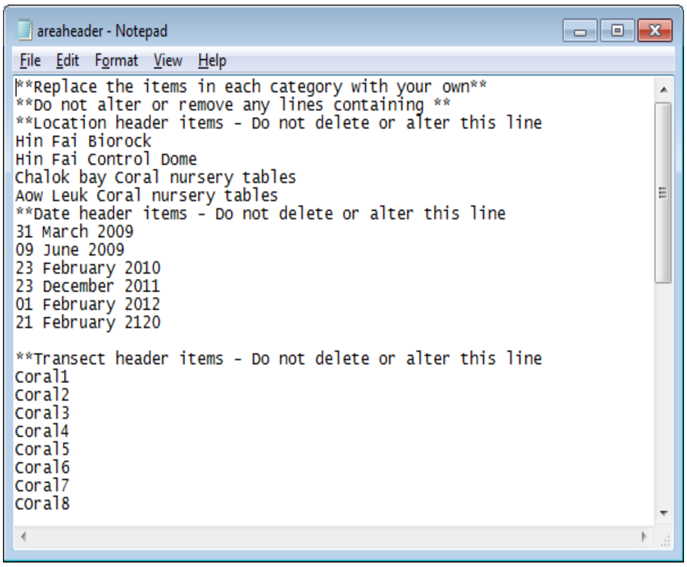
When the length in image one is calculated, click next and the scaling and length information of image one will be saved and image two can be analyzed. Header information like location, date and site depth can be added by clicking the header data button (Pic. A.5). Header information will be saved for all photos in this analysis. When all images are analyzed, click exit followed by save data to excel and exit. The program asks to provide a filename and location to save to excel spreadsheet.



Picture A.5 Print screen of the main CPCe window. The image is scaled with the calibrate image option. By dragging the mouse and right clicking, the length can be calculated.

Coral growth can be determined in different ways with the CPCe program. The surface area of a coral can be calculated by opening a photo in the program, selecting area/length analysis and encircling the shape of the coral with your mouse cursor. Every photo is analyzed separately. When using batch linear extension analysis mode to calculate horizontal and vertical lengths, multiple photos can be selected and analyzed together followed by exporting them to an excel spreadsheet.

In the excel spreadsheet you will find the filename, scaling factor, length calculated and header information. CPCe program contains header information. In order to customize the information for a specific area like Koh Tao, the header information file can be rewritten (Pic.A.6). The filename is areaheader.cfg and the location is the CPCe installation folder.


areaheader - Notepad
File Edit Format View Help
```
**Replace the items in each category with your own**
**Do not alter or remove any lines containing **
**Location header items - Do not delete or alter this line
Hin Fai Biorock
Hin Fai Control Dome
Chalok bay Coral nursery tables
Aow Leuk Coral nursery tables
**Date header items - Do not delete or alter this line
31 March 2009
09 June 2009
23 February 2010
23 December 2011
01 February 2012
21 February 2120

**Transect header items - Do not delete or alter this line
Coral1
Coral2
Coral3
Coral4
Coral5
Coral6
Coral7
Coral8
```

Picture A.6 Print screen of the areaheader.cpg file. It can be opened in wordpad to add information.

Data interpretation

When the photos are analyzed your excel spreadsheet contains the raw data information with horizontal and vertical lengths of the corals and header information. To give meaning to this information, several parameters can be calculated.

From the horizontal and vertical length a (rectangular) surface area can be calculated:

Horizontal length (cm) x Vertical Length (cm) = Area (cm^2)

Percentage change of surface can be calculated by comparing the surface area at time T_1 with the surface area of the previous picture taken at time T_0:

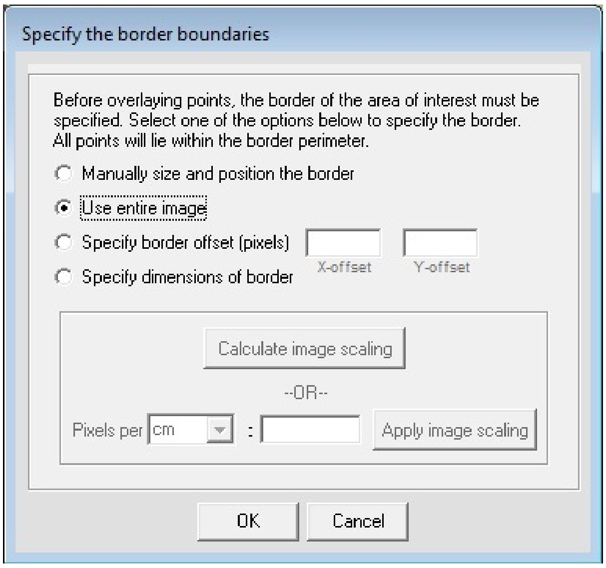
(Area T_1 / Area T_0) -1 *100% = % change

A.2 Monitoring coral cover percentages

CPCe was originally created for calculating bacterial colonies in petri dishes. The principle is very similar to determining substrate cover of a certain reef area on a photo. The National Coastal Research Institute has therefore rewritten the program for coral reefs. Since the program is designed for determining percentage substrate cover on a photo, most statistical features apply to this application and not to length and area calculations. I have not conducted a project with this application but I will briefly explain the application using CPCe 3.4

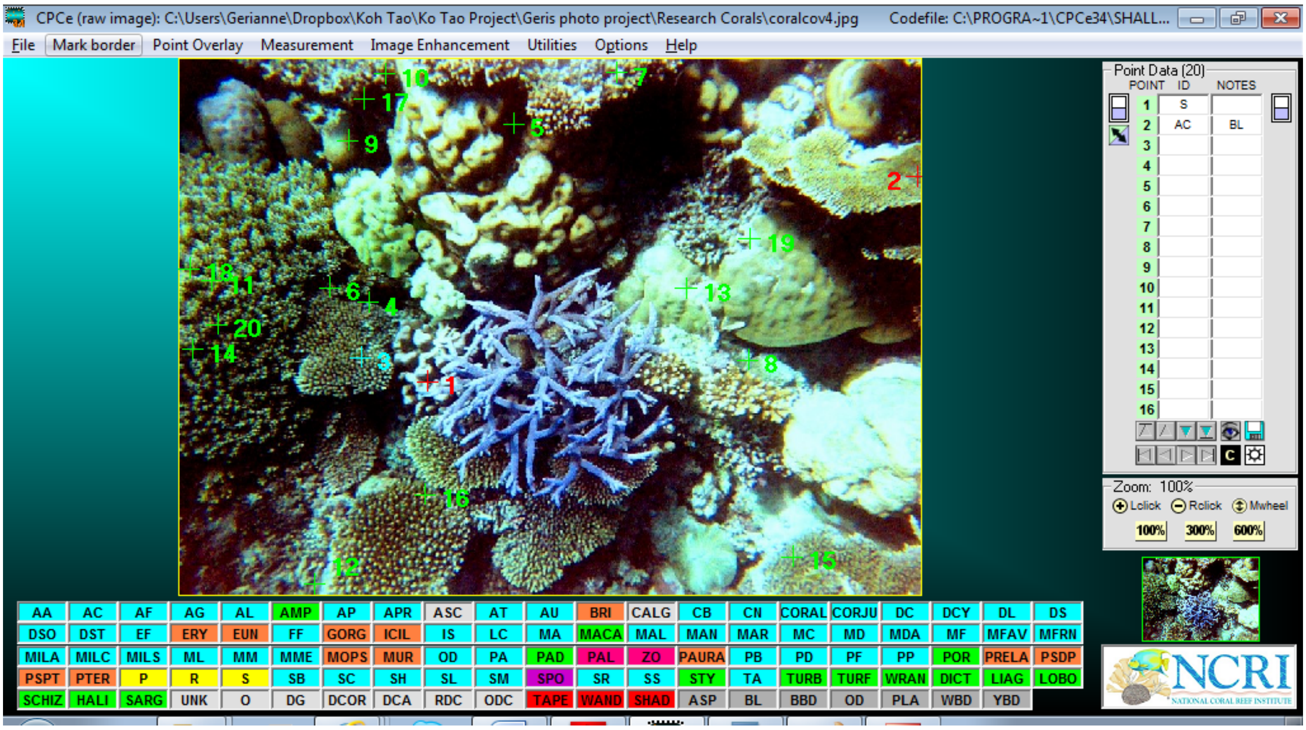
Data Analysis

When the program is opened click file, new raw image file and select the photo you would like to analyze. The program will now ask you to set borders to the picture. Select use entire image if you want to use the total photo (Pic.A.7). If you are using a transect frame which is visible on the photo, select manually size and position the border, and set the frame as border. Then click OK.



Picture A.7 Print screen of a CPCe window which allows for specification of the picture borders.

For data point distribution, select simple random with 10 or 20 data points, unless your project requires a different data point distribution. Click overlay points. The program now shows the photo with the 20 random points overlaying, denoted by letters or numbers (Pic.A.8). The next step is to determine the substrate cover at these points.



Picture A.8 Print Screen of CPCe in percentage substrate mode. It shows the picture with 20 random points overlayed. The colored boxes in the bottom represent the codes for different substrates and in the white columns on the right one can specify the code of the point.

Codes representing substrate cover are listed at the bottom of the screen in different colors (Pic.A.8). These codes include for example; Type of substrate like sand, rubble, hard coral or sponge; Hard coral growth forms like massive or foliose; Coral species like Acropora or Possilopora; Coral health state like partially bleached or recently killed. These codes are the options to choose from when assigning a certain "value" to the points.

On the right side of the screen each data point, here listed 1-16, can be specified by assigning a code in the ID column. Start for example at point 1: By clicking on the white cell next to 1, point 1 will be shown in red. Now select the code representing the cover at that point. Click S in yellow if point 1 overlays sand. The notes column can be left blank. Now move to point 2: If point 2 overlays a partially bleached branching Acropora coral, for ID click HC coding for hard coral, and for notes click PBL coding partially bleached. Now ID represents substrate type and notes represent health state. Depending on the aim of your project notes can represent growth form, species or health state. When a code is assigned to each data point, click on the save button below the notes column. The photo including data points and codes area now saved in a .cpc file.

When all photos are analyzed, multiple photos can be exported to an Excel spreadsheet by Exporting to an excel spreadsheet by clicking File, Save, Save .cpc files(s) to Excel (Pic A.9).

RESULTS SUMMARY CHART	# Points	%	SW Index
CORAL	0	0,00	0,00
SOFT CORAL	0	0,00	0,00
SPONGES	1	10,00	0,00
MACROALGAE	1	10,00	0,00
OTHER LIVE	2	20,00	0,69
DEAD CORAL WITH ALGAE	0	0,00	0,00
NON-LIVING SUBSTRATE	5	50,00	1,33
UNKNOWNS	1	10,00	0,00
TAPE, WAND, SHADOW	0	0,00	0,00
TOTALS	10	100,00	
NOTES (% of transect)			
Aspergillis	0	0,00	
Black Band Disease	0	0,00	

CATEGORIES	# Points	%	SW Index
Coral			
Branching Dead (BDC)	0	0,00	0,0
Branching Fully Bleached (BFBL)	0	0,00	0,0
Branching Healthy (BH)	0	0,00	0,0
Branching Partially Bleached (BPBL)	0	0,00	0,0
Branching Recently Killed (BRKC)	0	0,00	0,0
Coryombose Fully Bleached (CFBL)	0	0,00	0,0
Coryombose Healthy (CH)	0	0,00	0,0
Coryombose Partially Bleached (CPBL)	0	0,00	0,0
Coryombose Recently Killed (CRKC)	0	0,00	0,0
Diseased coral (DCOR)	0	0,00	0,0
Foliose Dead (FDC)	0	0,00	0,0
Soft Coral			
Soft Coral A (SCA)	0	0,00	0,0

Picture A.9 The Excel spread sheet created by CPCe contains total count, percentage, Shannon Weaver Index and standard deviation information of the different categories and notes.

Creating codes for a specific area

When CPCe is installed on your computer, the program will contain a list of codes applicable to general shallow coral reefs. For a specific project this list might not be satisfactory. To create personal codes one needs to rewrite the file which calls these codes.

In the CPCe installation folder on the C-drive the file shallow_coral_codes_41.cfg contains the coral code information and can be opened and edited in wordpad (Pic.A.10). Open de file and save it with another name in the same folder. This coral code file is separated into three sections: Major Categories, Species/Substrate, and Notes. Many of which can be changed, but the file has a few preconditions for the data to export to Excel and to create statistical information.

The first line contains a number which represents the number of major categories. Major Categories include for instance Coral, Sponges, Sand Rubble and Pavement. If you change the number of categories, also change the number in the first line. Major categories are displayed by the code ("C") followed by the description "Coral", separated by a comma. Major categories have the precondition it must include the

Picture A.10 The shallow_coral_codes_41.cfg file can be opened and edited in Wordpad.

shallow_coral_codes - Notepad

File Edit Format View Help

```
12
"C","Coral"
"G","Gorgonians"
"S","Sponges"
"Z","Zoanthids"
"MA","Macroalgae"
"OL","Other live"
"DCA","Dead coral with Algae"
"CA","Coralline Algae"
"DC","Diseased corals"
"SPR","Sand, pavement, rubble"
"U","Unknowns"
"TWS","Tape, wand, shadow"
"AA", "Agaricia agaricites","C"
"AC", "Acropora cervicornis","C"
"AMP", "Amphiroa","MA"
"ASC", "Ascidian","OL"
"BRI", "Briareum","G"
"CALG", "Coralline algae","CA"
"PAD", "Padina","MA"
"PAL", "Palythoa sp.","Z"
"ZO", "Zoanthid","Z"
"PAURA", "Plexaura","G"
"POR", "Porolithon","MA"
"P", "Pavement","SPR"
"STY", "Stypopodium","MA"
"TA", "Tubastraea aurea","C"
"TURB", "Turbinaria","MA"
"UNK", "Unknown","U"
"O", "Other","OL"
"DCOR", "Diseased coral","DC"
"DCA", "Dead coral with algae","DCA"
"TAPE", "Tape","TWS"
"WAND", "Wand","TWS"
"SHAD", "Shadow","TWS"
NOTES,NOTES,NOTES
"ASP", "Aspergillis","NA"
"BL", "Bleached coral point","NA"
```

codes "C", "Coral" and "TWS", "Tape, wand, shadow".

Species and substrate can contain everything which is a subcategory of one of the major categories. They are displayed by the code “AC” followed by the description “Acropora Cervicornis” followed by the Major category they belong to “C”, all separated by commas. A precondition is that each major category must have at least one sub-category.

Notes can include additional information which applies to multiple subcategories but to one major category.