Coral competition for space

Research project

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01-07-2018, Saba, Dutch Caribbean

SABA CONSERVATION FOUNDATION
has university of applied sciences
WAGENINGEN UNIVERSITY & RESEARCH
RESCQ

Coral competition for space

Research project

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Content

Abstract

Coral reefs fulfil many ecological functions such as maintaining the diversity, providing habitats and shoreline protection. One of the most important reef building corals is the *Aropora cervicornis* known as Staghorn. Over the past decades many corals have disappeared due to human and natural disturbances. *Acropora* species populations are also heavily damaged in the Caribbean since the 1980s by the white band disease (WBD). Also predation and competition between organisms can influence the growth and survival of corals. The *Acropora* species *A. cervicornis* is an important reef building coral which can be a dominant species because of their relative fast growing abilities. This gives them the ability to overgrow other soft and stony corals. However algal growth is faster than the growth of *A. cervicornis*, making the coral species susceptible to be overgrown by other organisms besides corals. Reefs can get overgrown by algae like seen around Saba, a small island in the Dutch Caribbean. Together with St. Maarten, St. Eustatius and the Turks and Caicos Islands Saba is part of the RESCQ (Restauration of Ecosystem Services and Coral reef Quality) project. This project aims to restore *Acropora* populations included the *A.cervicornis* by establishing a coral nursery. In this research the influence of predation and competition of other species on the growth and fitness of *A.cervicornis* will be studied. In this experiment *A.cervicornis* fragments were planted on the reef where different cleaning treatments were tested. Depending on the treatment the area around the planted fragments was cleaned from algae. Eventually 14 out of 15 fragments were healthy with a positive growth rate, there was no significant difference between the cleaning treatments. Some fragments showed predation signs such as spot-biting, but after polyp-recovery the fragments gained a positive growth.

Introduction

255,000 km^2 of the marine waters is coral reef (Spalding & Grenfell 1997). Coral reefs mainly consist of two different groups of corals, the scleractinian corals, known as the stony corals or reef building species, and the non-reef builders, known as the soft corals (Castro & Huber 2005). The small polyps on reef building corals create three-dimensional calcium carbonate structures and form important marine habitats for many different invertebrates, algae and fish species (Castro & Huber 2005; Boulon et al. 2005; Ferse 2008). Many reef building corals have symbiotic zooxanthellae that provide them food in the form of organic matter through photosynthesis (Castro & Huber 2005). Coral reefs fulfil many ecological functions such as maintaining the diversity, providing habitats, shoreline protection and they contribute on different nutrient cycles (Ferse 2008). One of the most important reef building corals is the *A. cervicornis* known as Staghorn. It provides the physical and biological foundation for many reef communities (figure 1). From the main branch *A. cervicornis* grows in cylindrical secondary branches to tertiary and so on, which makes it a relative fast growing coral species (Boulon et al. 2005). In the Caribbean *A. cervicornis* used to be wide spread around coastal zones (Aronson & Precht 2001), dominating the depths of 5-25 meters with some occasional record of a depth to 60 meters (Goreau & Wells 1967).

Over the past decades many corals have disappeared, due to human and natural disturbances. For example, most corals have been destroyed by human impacts such as overfishing combined with hurricanes and diseases (Hughes 1994; Aronson & Precht 2001). Due to global warming, acidification has a big impact on the conservation of coral reefs (Langdon et al. 2000). In the Caribbean around the 1980s, almost 95% of the *Acropora spp*. was badly destroyed (Aronson & Precht 2001; Gignoux-Wolfsohn et al 2012). The white band disease (WBD) caused this epic decline in abundance of this species in the region. The WBD is a bacterial infection specific for *Acropora spp*, infecting the coral tissue (Aronson & Precht 2001). The corallivorous snail species *Coralliophila abbreviata* is a vector that transmits the WBD, by causing 'rapid tissue loss'. Presumably *C. abbreviata* is able to retain the disease pathogen for at least two weeks and act as a reservoir for WBD. Both healthy corals and diseased corals can get infected by *C. abbreviata (*Gignoux-Wolfsohn et al 2012). Moreover, predation by *Hermodice carunculata*, *Stegastes* and other herbivorous fish can damage and decrease the growth of corals. Herbivorous fish predate over the surface of the coral and kills the polyps which can lead to algal tufts growing on the coralittes (dead polyps) (Humann & Deloach 2002). Because of the huge decline of the *Acropora spp.* the coral species have been listed as "Critically endangered" on the International Union for Conservation Nature (IUCN) Red list of Threatened species in 2008 (IUCN 2008).

Figure 1.Staghorn coral (A. cervicornis) crowded with French grunts (Haemulon flavolineatum) (photo by Erik Meesters).

Not only predation but also competition between organisms can influence the growth of corals. In high diverse ecosystems such as coral reefs, which are considered as space limited systems (Boulon et al. 2005), competition between organisms is a determinant factor for a reef community (Horwitz et al. 2017). Overgrowing and encrusting competition for space between sponges, tunicates, algae and corals can eventually cause the death of corals (Humann & Deloach 2002). Sponges tend to overgrow dead coral tissue, however some sponges can secrete an acid which damages coral tissue (Humann & Deloach 2002; García-Hernández 2017). However, *A. cervicornis* can be a dominant species because of their relative fast growing abilities. This gives them the ability to overgrow other soft and stony corals. Some coral species can be dominant by using their ability of extracoelenteric digestion (Goreau et al. 1971). However, for *A. cervicornis* the ability of extending mesenterial digestive filaments onto neighbouring species is very low, this does not give them the ability to "eat" other species. Algal growth is faster than the growth of *A. cervicornis*, making the coral species susceptible to be overgrown by other organisms besides corals (Boulon et al. 2005). Due to overfishing and disease of the D*iadema antillarum*, algal grazing has been reduced which resulted in an increased algae growth (Hughes, 1994; Edwards & Fisk 2010). Healthy corals with no predation signs, such as spot biting, damaged polyps and spire extendings, has the best chance of surviving due to less algal growth (Humann & Deloach 2002). Coral growth rate depends on the growth of algae and predation, with corals growing slower with high algae growth and tissue injuries due to predation.

Some reefs can get overgrown by algae, as seen around Saba, a small island in the Dutch Caribbean (personal communication February, 2018). Saba is the top of an active volcano and has a land area from 13 km^2. Saba has a Marine park with a total area of almost 1300 hectares. The Marine park protects globally threatened coral reefs and is divided in four zones; a recreational zone, a multi-purpose zone, mooring zone and a no-take zone (DCNA 2014). Saba has many reef boulders and a few "true reefs" (coral encrusted reefs) with a high abundance of fish species. Saba is surrounded by a submarine platform with many granite reef boulders, pinnacles and lava formations. Due to this, coral colonies can diffuse all around the isle (Klomp & Kooistra 2003). Together with St. Maarten, St. Eustatius and the Turks and Caicos Islands Saba is part of the RESCQ (Restauration of Ecosystem Services and Coral reef Quality) project. This project aims to restore populations of *Acropora spp.* included the population of *A.cervicornis* by establishing a coral nursery. The nursery on Saba consists of a main nursery with five ladders and seven trees from a different project. Due to a big swell on the 6th of March two ladders and two trees broke down and coral fragments were loss. This resulted in a total of three ladders and five trees, in this research only the ladders has been used. In this research the influence of predation and competition of other species on the growth and fitness of *A.cervicornis* was studied, additionally the impact of algal growth on *A.cervicornis* was observed.

Different sizes of *A. cervicornis* fragments from the ladders were cut and planted on reef boulders on the South-East side of Saba. Sites with other healthy corals without predation signs were assumed to be the best site for planting the coral fragments. A fish survey was done to determine which corallivorous and herbivorous fish would live on and around the reef boulders. In this experiment different cleaning treatments were tested. Depending on the treatment the area around the planted fragment was cleaned from algae, because it was expected that planted corals will get overgrow more easily (Edwards & Fisk 2010). The planted fragments were measured and observed for a period of four months.

2. Methods

This research was conducted on Saba, a small island from the Windward Islands (figure 2).

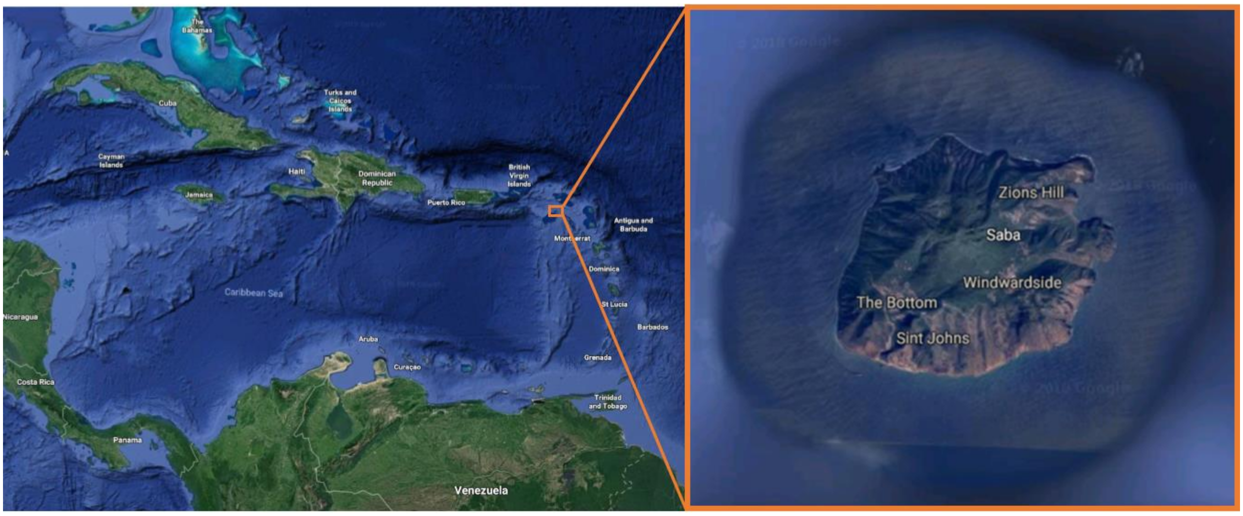


Figure 2. Saba one of the Windward islands (source Google maps).

2.1 The Nursery

The nursery is located between Ladder Bay and Wells Bay (17°38.235 N, 63°15.376 W)(figure 4), at a depth of 12 to 15,8 meters. The *ladders* are made from bamboo sticks with five rows, with a total capacity of 25 coral fragments (figure 3a). The *trees* are made out of ten rows of PVC pipes a total capacity of 60 coral fragments (figure 3b). The trees and ladders are attached to the bottom with two concrete blocks and are held-up by an air-filled buoy. In this research only fragments from the ladders have been used. The ladders I, J and G have *A.cervicornis* fragments and row 5 from ladder G contains *Acropora palmata* fragments. The other ladders (F and H) broke down during the swell on the 6th of March. The coral fragments in the ladders came from different mother colonies found around Saba.

Figure 3a. Ladder G with small A. cervicornis fragments.

Figure 3b. Tree A from Samford University with large A. cervicornis fragments.

2.2 Mother colony

The coral fragments were collected from three different mother colonies. The *A. cervicornis* was collected from Ladder Labyrinth on the West side of Saba (17°37.636 N, 63°15.591 W) and Hole in the Corner on the East side (17°37.002 N, 63°13.648 W) (figure 4). The *A. palmata* fragments were collected at Green Island on the North side of the Island (17°38.919 N, 63°13.842 W).

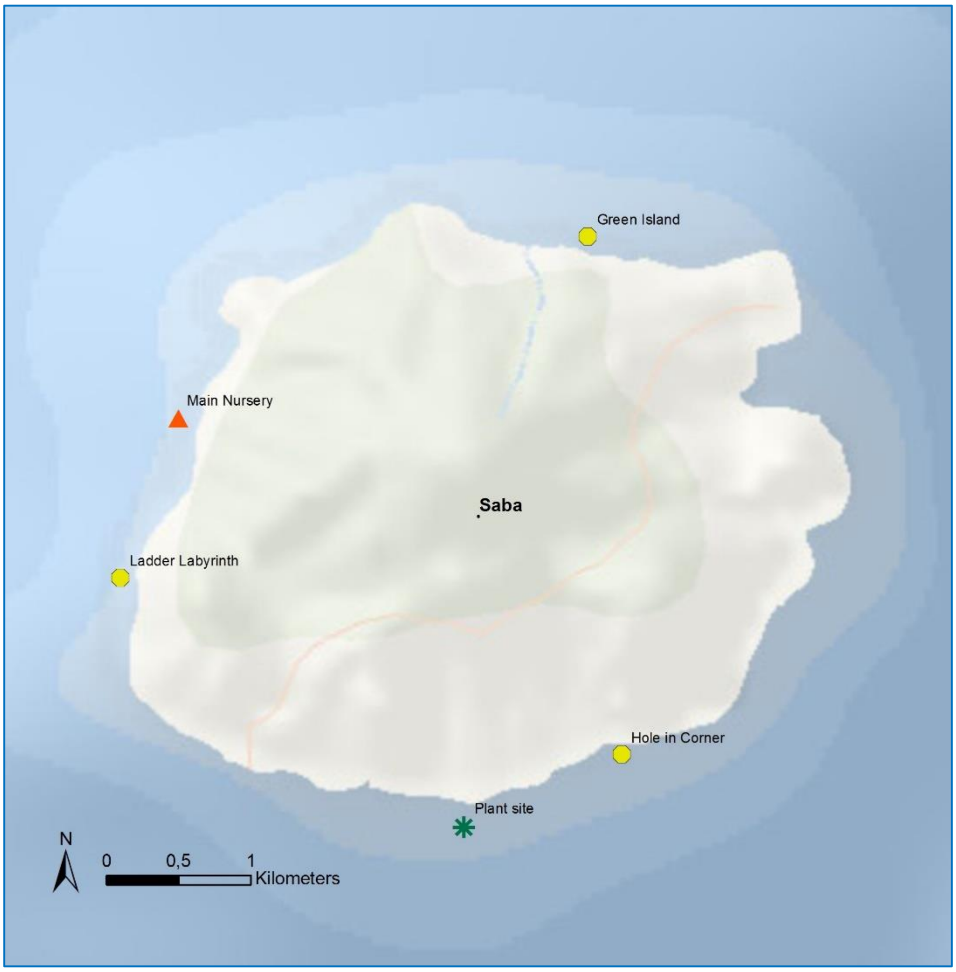


Figure 4. Map of Saba, Dutch Caribbean, with the nursery (orange), plant site(green) and mother colonies (yellow), ArcMap (made by Ginger Fairhurst).

2.3 Planting experiment

2.3.1 Planting sites

Three planting sites on the reef on the South-East side of Saba between Greer Gut and Big Rock Market (17°36.698 N, 63°14.307) were selected, this is in the Multi-purpose zone of Saba Marine park. The planting sites are reef boulders with low predation signs on other corals. The fragments were planted on a depth of 19.1 to 20.1 meters (measured with Cressi Giotto dive computer) because the naturally *A. cervicornis* of Saba was found on an average depth of 20 meters. On each boulder five holes of minimum 1 cm deep were pre-made with a hammer and chisel for the fragments, then a sketch (appendix 1) was made from each reef boulder with the location of each planted fragment.

2.3.2 The fragments

For this experiment one-year old *A. cervicornis* fragments from the main nursery were used. These fragments were attached to ladders F (planted before the swell on the 6th of March), I and G Ladder F containd *A. cervicornis* fragments from Ladder Labyrinth, ladder I and G contains *A. cervicornis* fragments from Hole in the Corner. Different primary branch sizes (180-306mm) of *A. cervicornis* fragments were measured, cut with steel pliers and planted. Half of the fragment piece was planted and the other half was returned to the ladder in the nursery. Sizes of the planted fragments ranged between 80 to 165 mm.

2.3.3 Planting *A.cervicornis* fragments

On the same day of collecting and cutting the fragments, the fragments were planted on the boulders. The first five fragments were planted on 22-02-2018, the next five fragments were planted on 27-02-2018, and the last five fragments were planted on 12-04-2018. Depending on the treatment for each fragment the area around the hole that was made on the boulders was cleaned with a steel brush (table 1).

Table 1. Different treatments for the A. cervicornis fragments

Treatment	Treatment code	Description
No treatment (control group)	0	No area cleaned
Treatment 1	1	Approximately 10cm radius cleaned
Treatment 2	2	Approximately 30cm radius cleaned
Treatment 3	3	Approximately 30cm radius cleaned and repeated

No treatment (0) means there is no area being cleaned. Treatment 1 is cleaning the area of approximately 10 cm around the fragment. Treatment 2 is an area cleaning of approximately 30 cm. And treatment 3 will be an area cleaning of 30 cm which will be repeated at every measurement of every three weeks. On each planting site (a reef boulder), five fragments of the same size were placed, three fragments with each a different treatment and two fragments with no treatment as a control group. The fragments were placed with a minimum distance of 50 cm from each other to prevent treatment interference. This was done in duplicate, and in a randomized block design. After cleaning the area the hole was filled with Aquascape construction epoxy, a semi-hard epoxy which gives the fragments enough stability. Immediately after, the coral fragment with the surface break down, was placed into the hole.

2.4 Collecting data

Three days after planting the fragments were checked to make sure the epoxy was hardened. Then three weeks after planting the first measurement was done as a base-line measurement. The measurements were done every three weeks. Also a health status and algal abundancy was checked.

2.4.1 *A. cervicornis* measurements

First the primary branch was measured with a flexible measuring tape with millimetre divisions (Figure 5). Then the second (side)branches were counted and measured, the third were counted and measured, then the fourth and so on. The health status was checked, 1 being the coral fragment healthy without algae, white tips or predation signs; 2 is impaired/broken tips; 3 with predation signs; 4 is dead and 5 is missing. In case of impaired by algae an algae abundancy rate was estimated. Abundancy rate of 1 is low algae abundancy (1-10 %); 2 is medium abundancy (10-25%); 3 is medium to high abundancy (25-50%); 4 is high abundancy (50-99%) and 5 is fully covered by algae (100%).

Figure 5. Measuring A. cervicornis fragment with a flexible measuring tape.

2.4.2 Reliability-test

To increase the reliability of the measurements, a reliability-test was performed in the nursery. One row of fragments was double measured over a period of two days to assess measurement errors.

2.4.3 Fish inventory

The fish inventory was assessed by visual census the reef boulders with a one meter radius. While swimming to the reef boulders all fish from the families *Chaetodontidae* (Butterflyfish)*, Monacanthidae* (Filefish)*, Scaridae* (Parrotfish), *Tetraodontidae* (Pufferfish), *Balistidae* (Triggerfish), *Labridae* (Wrasses) and *Pomacentridae* (Damselfish) were counted. Then there was a three-minute wait and a new count to minimize the interaction between fish and observer. The counting was done with two observers each on a different side of the boulder.

2.5 Analysing data

2.5.1 Statistic analyses

All tests were executed with a 95% confidence interval. To test the differences between treatments the ANOVA-test was used. To determine the correlation between the algal growth rate (algal abundancy) and coral grow rate the Pearson correlation was used. The Pearson correlation test was also used to determine the correlation between treatment and predation. An independent T-test was used to find differences between the two measurement moments for the reliability-test. All statistical tests will be performed in Rstudio (version 3.4.1) and IBM SPSS (statistics 23).

3. Results

113 days after the first planted fragment all the fragments are alive and 1 out of 15 has 30% algae. After 87 days 14 of the 15 fragments have a positive growth rate. The reliability-test shows no difference (p=0.8615) between the two measurements in total length (mm).

3.1 Growth rate and health status

Over a period of 113 days there was a positive growth rate (figure 6), the mean growth rate per month is 0.417 cm after the fifth and last measurement. There was a decline of 2 cm in the first 33 days. After that there was a positive growth which stabilized after 53 days into a mean growth of 0.3 cm per month. In the four months of observation 9 fragments had broken tips, white spots or were predated, and one fragment had algae growth of 30% (abundancy rate 3) (Figure 7a)this fragment was one of the control group and had a negative growth of -0.2 cm. There was a visual growth of algae on the reef boulders, after 25 days reef boulder 3 was for 40% grown by cyanophyta algae. After 64 days boulder 3 was grown by the algae for 20%. All 15 fragments were in a healthy condition (100%) (Figure 8) when they were planted on the reef after 53 days this was 53.3% (8 fragments were completely healthy) and after 113 days 14 fragments were healthy (96.6%) (figure 7b).

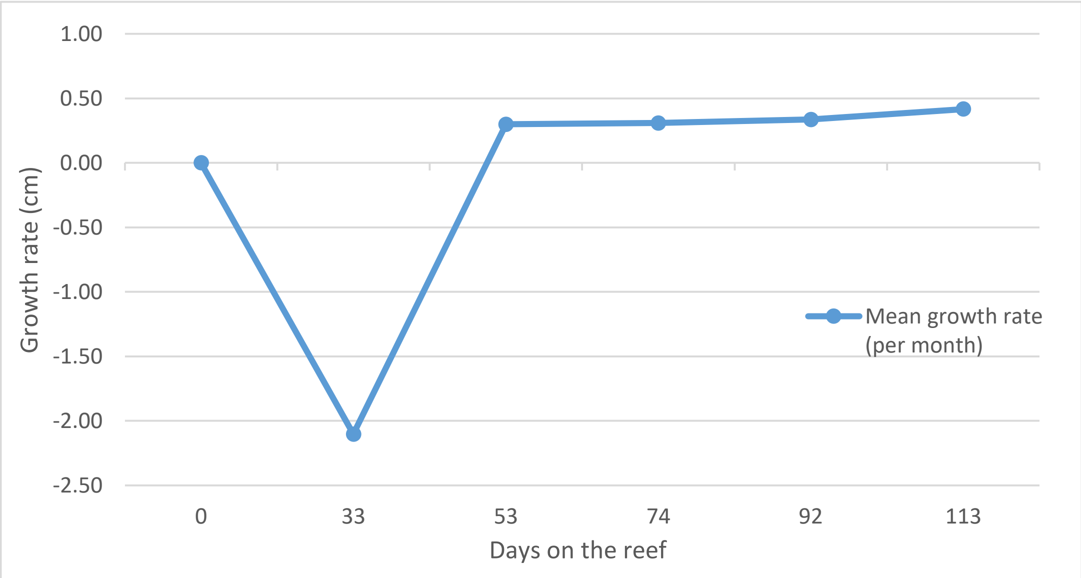


Figure 6. Average growth rate per month in centimetres over a period of 113 days.

Figure 7a. Boulder 3 fragment 3(B3F3) A. cervicornis fragment with cyanophyto algae.

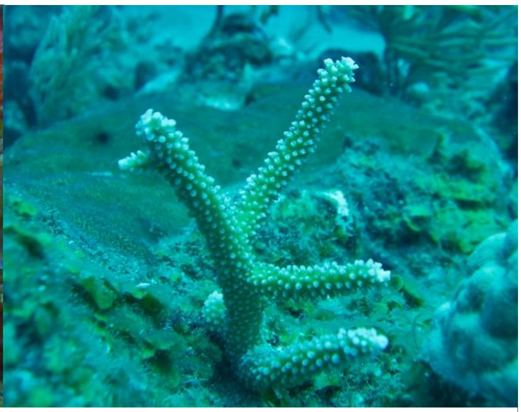


Figure 7b. Boulder 2 fragment 2 (B2F2) a healthy A. cervicornis fragment.

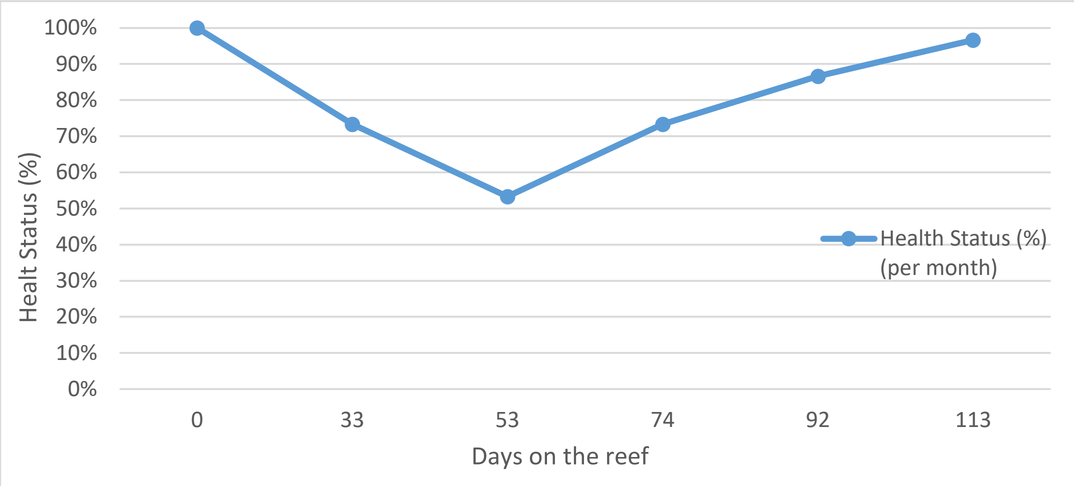


Figure 8. Health Status in percentage (100% is all fragments are in a healthy condition) trough the period of 113 days (5 observations), influenced by predation, loose fragments and white spots.

3.1.1 Predation

There is a negative growth rate when predation is observed on a fragment (p=0.008) (Figure 9). The LSD shows that there is a difference in growth rate between 1= healthy and 3= with predation signs (p=0.002)(Figure 10). And a difference between 2= impaired/broken tips, and 3 (p=0.017). The mean growth rate from healthy fragments is 0.6 cm, the growth rate of predated fragments is -2.6 cm.

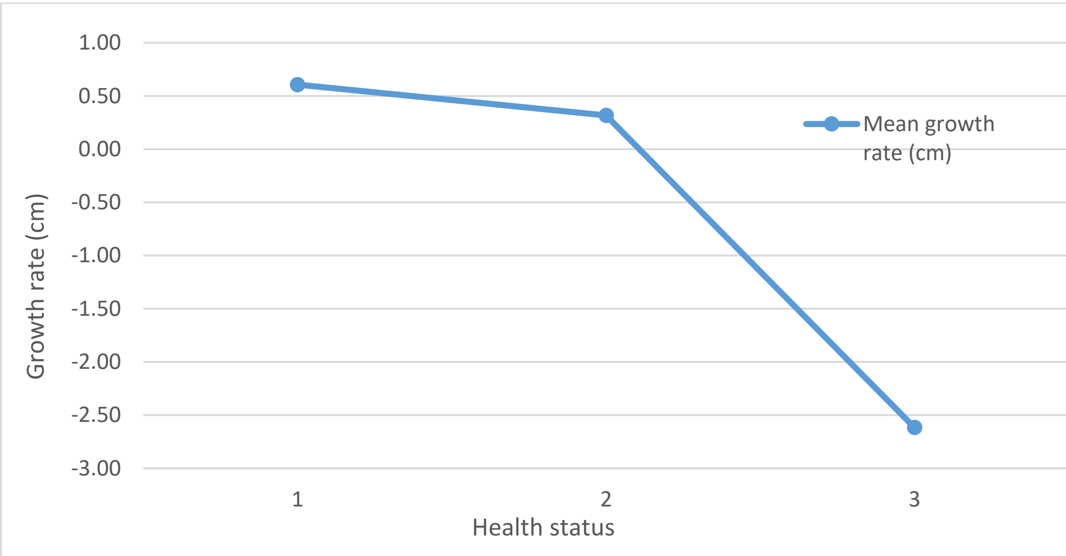


Figure 9. Mean growth rate of healthy (1) impaired (2) and predated (3) fragments.

There was no correlation between the treatment and predation pressure (correlation coefficient= 0.006).

Figure 10. Boulder 1 fragment 3 (B1F3) A. cervicornis fragment with predation signs.

3.2 Treatments

There is no significant differences between cleaning treatments and total sum (total length of the main branch and side branches together) (p=0.064). And no difference between cleaning treatments and growth rate(p=0.324). The fragments with no cleaning treatment (control group) had a mean total growth of 79 mm after 113 days (figure 11). The fragments with treatment 1 had a mean total growth of 54 mm, treatment 2 had a mean total growth of 51 mm and the fragments with treatment 3 had a mean total growth of 46 mm.

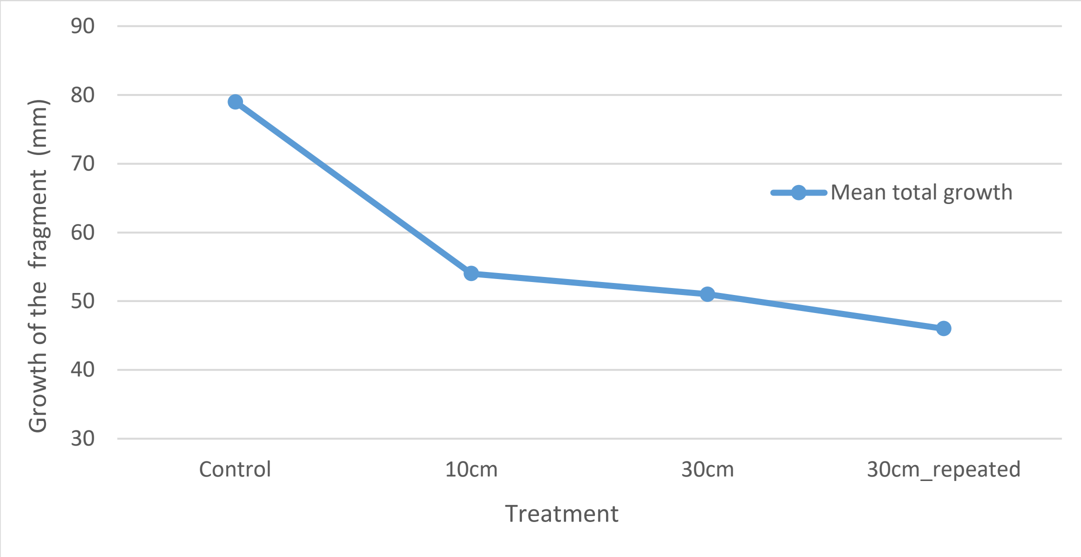


Figure 11. Mean total growth in centimetre of the fragment (sum of main branch and side branches) of each different treatment; control group, 10 cm radius, 30 cm radius an 30 cm radius repeated every measurement moment, over a period of 113 days.

3.3 Fish-survey

Eleven corallivorous fish species has been observed continuous on the reef boulders or within an one metre radius. Found species are: *Scarus taeniopterus, Halichoeres garnoti, Melichthys niger, Chaetodon capistratus, Thalassoma bifasciatum, Chromis cyanea, Chaetodon ocellatus, Stegastes partitus, Abudefduf saxatilis, Chrysiptera parasema* and *Sparisoma aurofrenatum.* All found species are facultative-eating corallivorous fish species.

4. Discussion

After 113 days, 14 out of 15 fragments had a positive growth rate of 0.3 cm per month. The first 20 days after planting the fragments, there was a decline in the growth rate of 2 cm. Possibly, the *A. cervicornis* fragments need time for tissue regeneration after being damaged by cutting. A research by Lirman (2000) describe small lesion injuries (<5 cm^2) on *Acropora* (focused on *A. palmata*) has tissue regeneration in 30 days. Beside that the damaged tissue was placed in the epoxy which probably protected the fragment. There was no mortality in the four months of this research; within the first 53 days there was a drop in the health status (53.3%) caused by broken tips, predation and loose fragments. The loose fragments were glued back on the boulder with epoxy. Eventually the health status was 96.6%, where 1 fragment was partly overgrown by cyanophyta algae. Different studies show that over time mortality rates decrease as fragments attach on the substrate and adjust to the new environment (Bowden-Kerby 2001; Herlman & Lirman 2008). Survival of the fragments is related to size and substrate; research shows that fragments with a size larger than 8 cm has a bigger survival rate (Bowden-Kerby 2001).

There is a negative growth rate of -2.6 cm on fragments with predation signs. Eleven facultative-eating corallivorous fish species were found. Most of the corallivorous fish can be classified as polyp-feeders which remove coral tissue without harming the underlying corallite (Cole et al. 2008). This has been observed on the fragments in this study, predation signs were spot-biting marks on the coral tissue. Presumably the fragment needs energy to regenerate the damaged tissue. According to Meesters et al. (1994) coral colonies response to polyp damage by regeneration and repair, so there will be less energy for growth. When the polyps were completely healed the fragments showed a positive growth rate again.

Notable is that the fragments without treatments tend to grow faster (total mean of 54 mm) than the fragment with a cleaning treatment. This was not significant; treatment 3 has a mean total growth of 46 mm. Expected was that the fragments with a cleaning treatment would grow faster. Macroalgae are capable of overgrowing scleractinian corals and the encounter between the two groups usually result in the algae winning (e.g. Chadwick, 1988; Hughes, 1989). One fragment was grown with algae, this fragment did not have a cleaning treatment. Algae can negatively affect corals by abrasion (Coyer et al., 1993) and arrogation of space (e.g. Hughes, 1989). *Acropora* species shows large reductions in growth when exposed to competition with algae (Tanner 1994). Algae places a drain on coral resources, even when they were not actively overgrowing the coral(Tanner 1994). Energy costs of the coral may arise from the need to repair damage caused by algae, such as tissue abrasion (Coyer et al., 1993) or from actively competing with the algae, trying to prevent overgrowth (De Ruyter van Steveninck et al., 1988). Probably is that why only this fragment shows a negative growth of -0.2 cm.

This project shows that the used planting method a good technique is to plant *A. cervicornis* fragments on the reef. Semi-hard epoxy works the best for planting the fragments. Small injuries do not form a problem for the survival of the fragments and eventually the fragments showed a positive growth. To find significant differences between the cleaning treatments and the long term survival the fragments should be observed for a longer period.

References

Aronson, R., & Precht, W. (2001). *White-band disease and the changing face of Caribbean coral reefs.* Hydrobiologia.

Boulon, R., Chiappone, M., Halley, R., Jaap, W., Keller, B., Kruczynski, B., Miller, M., & Rogers, C. (2005). *Atlantic Acropora Status Review*. NOAA .

Castro, P., & Huber, M. (2005). *Marine Biology, Chapter 14 Coral Reefs (Fifth edition).* McGraw-Hill.

Cole, A.J., Pratchett, M.S., & Jones, G.P., (2008) *Diversity and functional importance of coral-feeding fishes on tropical coral reefs.* Fish and Fisheries, 9, 286-307

Coyer, S.A., Ambrose, R.F., Engle J.M., & Carroll, J.C. (1993). *Interactions between corals and algae on a temperate zone rocky reef: Mediation by sea urchins.* Journal of Experimental Marine Biology and Ecology, 167, 21-37

DCNA. (2014). Saba National Marine Park. http://www.dcnanature.org/saba-national-marine-park/ Retrieved :2018

De Ruyter van Steveninck, E.D., Van Mulekom L.L., & Breeman, A.M. (1988). *Growth inhibition of Lobophora variegata (Lamouroux) Womersley by scleractinian corals.* Journal of Experimental Marine Biology and Ecology, 115, 169-178

Edwards, A., & Fisk, D. (2010) *Steps in planning a rehabilitation project.* In: Edwards, A. (Ed.) Reef Rehabilitation manual. The Coral Reef Targeted Research & Capacity Building for Management Program, 7-28

Ferse, S. (2008). *Artificial reef structures and coral transplantation: fish community responses and effects on coral recruitment in North Sulawesi/Indonesia.* Universität Bremen.

García-Hernández, J.E., Moorsel, G.W.N.M., & Hoeksema, B.W. (2017) *Lettuce corals overgrowing tube sponges at St. Eustatius, Dutch Caribbean.* Marine Biodiversity, 47, 55-56.

Gignoux-Wolfsohn, S. A., Marks, C. J., & Vollmer, S. V. (2012). *White Band Disease transmission in the threatened coral, Acropora cervicornis*. Scientific Reports, 2, 804.

Goreau, T.F., & Wells, J.F. (1967). *The shallow-water scleractinia of Jamica: Revised list of species and their vertical distribution range.* University of Miami.

Goreau, T.F., Goreau, N.I., & Yonge, C.M. (1971). *CORAL REEFS: AUTOTROPHS OR HETEROTROPHS?*. The Biological Bulletin, 141

Herlan, J., & Lirman, D. (2008) *Development of a coral nursery program for the threatened coral Acropora cervicornis in Florida*. University of Miami

Horwitz, R., Hoogenboom, M., & Fine, M. (2017). *Spatial competition dynamics between reef corals under ocean acidification.* Scientific Reports.

Hughes, T. (1994). *Catastrophes, Phase Shifts, and Large-Scale Degradation of a Caribbean Coral Reef*. American Association for the Advancement of Science .

Hughes, T.P. (1989). *Community structure and diversity of coral reefs: The role of history*. Ecology, 70, 275-279

Humann, P., & Deloach, N. (2002). *Reef Coral Identification, Florida, Caribbean, Bahamas (Second edition)*. New World Publications.

IUCN. (2008). Acropora cervicornis. http://www.iucnredlist.org/details/133381/0 Retrieved: 2018

Klomp, K., & Kooistra, D.J. (2003) *A post-hurricane, rapid assessment of reefs in the Windward Netherlands Antilles (stony corals, algae and fishes).* Atoll Research Bulletin

Langdon, C., Takahashi, T., Sweeney, C., Chipman, D., Goddard, J., Marubini, F., Aceves, H., Barnett, H., & Atkinson, M. (2000). *Effect of calcium carbonate saturation state on the calcification rate of an experimental coral reef.* PANGAEA.

Lirman, D., (2000) *Lesion regeneration in the branching coral Acropora palmata: effects of colonization, colony size, lesion size, and lesion shape.* Marine Ecology progress series, 197, 209-215

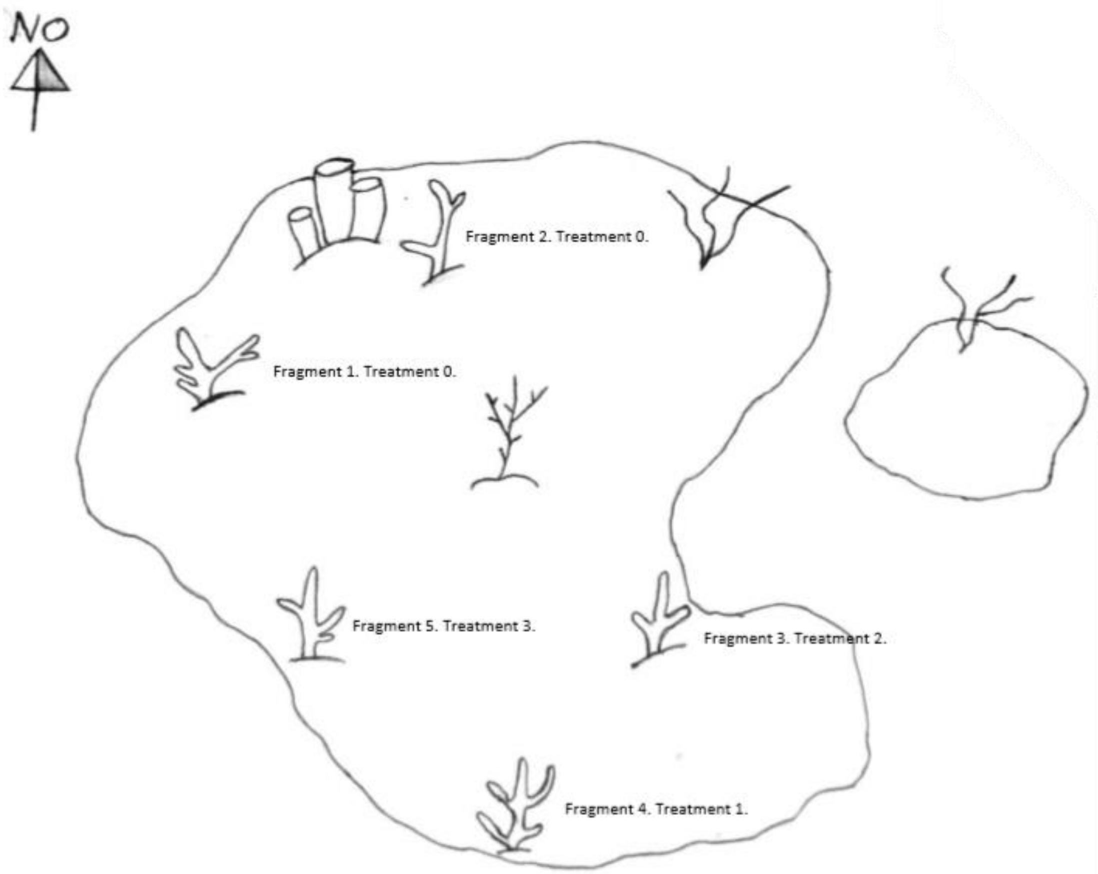
Meesters, E.H., Noordeloos, M., & Bak, R.P.M. (1994) *Damage and regeneration: links to growth in the reef-building coral Montastrea annularis*. Marine Ecology progress series, 112, 119-128

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

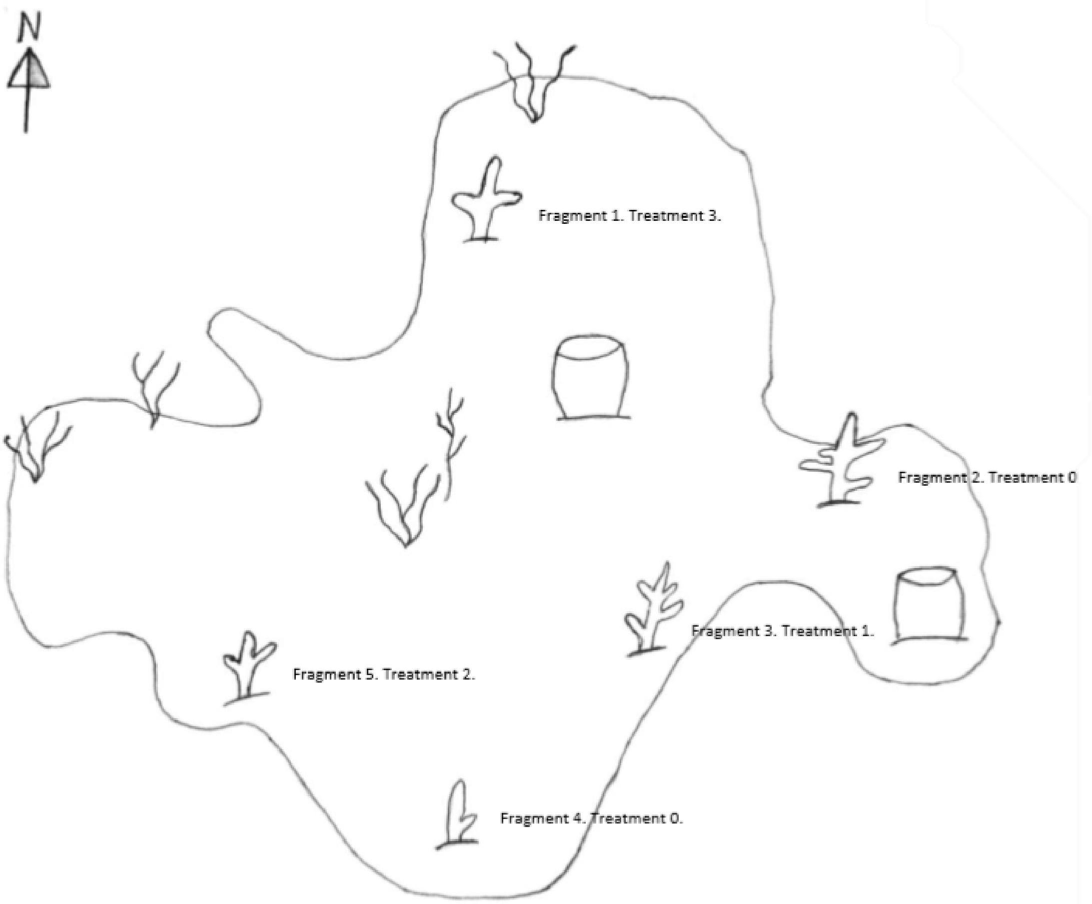
Tanner, J. (1994) *Competition between scleractinian corals and macroalgae: An experimental investigation of coral growth, survival and reproduction.* Journal of Experimental Marine Biology and Ecology, 190, 151-168

Appendix 1

Sketch and photo of reef boulder 1.



Sketch and photo of reef boulder 2.



Sketch and photo of reef boulder 3.