Impact of Increased Nutrient Input on Coral Reefs on Bonaire and Curacao

By
Mark W. Wieggers, BSc

DEPARTMENT OF ENVIRONMENT
Ministry of Public Health & Social Development

Universiteit Utrecht

Impact of Increased Nutrient Input on Coral Reefs on Bonaire and Curacao

Cover pictures:	Outlet of Cargill Salt Company (left) Brain Lapointe during the excursion of the workshop (middle) Volunteers during monitoring week (right) (All pictures by Wieggers, 2007)

October 2007

Student:	**Mark W. Wieggers, BSc** **9907424** (Utrecht University, Natural Resources Management, MSc-Student)
Supervisors:	**Drs. Paul C. Hoetjes** (Gov. of the Netherlands Antilles, Senior Advisor) **Dr. Aat Barendrecht** (Utrecht University, Environmental Sciences, Associate Professor)

DEPARTMENT OF ENVIRONMENT
Ministry of Public Health & Social Development

Universiteit Utrecht

HARBOR BRANCH
OCEANOGRAPHIC

STINAPA
BONAIRE

SOMMA

REEF CARE CURAÇAO
KUIDA REF KORSOU

Table of Contents

Acknowledgements

This was project carried out as internship in my second year of my master Natural Resources Management. Many people were of great support to me, without their help and support I wouldn't be able to manage all this work. First I want to thank my two supervisors, Paul Hoetjes (MINA) and Aat Barendregt (UU) for their guidance and support. Also I would like to thank Brian Lapointe (HBOI) for supporting, guiding and sharing his wisdom with us.

On Curacao I would like to thank the staff of the Ministry of Public Health and Social Development of the Netherlands Antilles, and especially of the department of Environment and Nature (MINA), Letitia Buth, Eric Newton and Bart Geleuken. I am thankful to the volunteers and Reef Care Curacao for helping within this monitoring program. On Bonaire I would like to thank the staff of the Marine Park of Bonaire (STINAPA), especially Ramon de Leon, Frank van Slobbe from DROB Bonaire and the volunteers from Bonaire. On Saint Lucia I would like to thank the staff of Soufriere Marine Management Association (SMMA), especially Kai Wulf and Hazelann Prospere. For analyzing all our samples I would like to thank the University of Miami (USA), the University of Maryland (USA) and the McMaster University in Ontario (Canada).

Financial support came from NOAA International Coral Reef Program by the National Fish and Wildlife Foundation (NFWF) and from White Water to Blue Water (WW2BW) by the National Marine Sanctuary Foundation (NMSF). The monitoring program is also a part of the NACRI monitoring node financial supported by UNEP-CEP and the SPAW Program.

A number of people I do have to name for the love and support; Wil and Betsy Wieggers, Rob Wieggers, the Constancia family, the Trotters and last but not least my lovely girlfriend Juliette Libier. It would be much harder to continue having the drive to make this research to a beautiful end and feel at home on Curacao.

Picture. *Halimeda opuntia*
Algae are taking over reefs which are highly polluted. Here an example of Halimeda at Mokumanamana (Hawaii) (by Basch, unknown).

"It is now clear that coral reefs are the most nutrient-sensitive of all ecosystems."

- Thomas J. Goreau, Ph.D.
  President, Global Coral Reef Alliance

Summary

Coral reefs are one of the most sensitive ecosystems and are under enormous human pressure. Since a relative short period of time the impact of nutrient pollution is understood. On the Caribbean islands human, local population and tourists, pressure is getting worse. Bonaire and Curacao, and in a later stadium Saint Lucia, are monitoring the nutrient pollution on their reefs.

This monitoring program includes water sampling, reef cover analysis by video transects, chlorophyll α analysis, nitrogen isotope analysis from algae and fish stock counts. The preliminary results are showing reasons for concern. The reefs of Bonaire are at the thresholds of polluted values found by Lapointe. The situation on Curacao is even more concerning; the sites at the Mega Pier and Piscadera Bay are polluted higher than the thresholds.

Well waste water management is needed on both islands and for Curacao a reduction of the impact of pollution for the two polluted sites is necessary. These measures are needed to guarantee a healthy coastline, beautiful coral reefs and a sustainable tourist industry.

Summary (Dutch)

Koraalriffen zijn één van de meest gevoelige ecosystemen en staan onder enorme druk door mensheid. Sinds relatief korte tijd zijn de gevaren van nutriëntenvervuiling onderkend. Op Caribische eilanden groeit de druk, zowel door de lokale bevolking als de toeristen. Bonaire en Curaçao en in een later stadium ook Saint Lucia, zijn een nutriënten monitoringsprogramma voor hun koraalriffen begonnen.

Dit monitoringsprogramma bevat watermonsters nemen, rifbedekking analyseren door middel van videotransecten, chlorofyl α analyse, stikstofisotopen analyse van algen en vistellingen. De voorlopige resultaten tonen redenen tot zorgen. The riffen van Bonaire zijn vervuild tot aan de drempelwaarden gevonden door Lapointe. De situatie op Curaçao is zelfs reden tot meer zorgen; de Mega Pier en Piscadera Baai zijn vervuild tot boven deze drempelwaarden.

Goed afvalwaterbeheer is noodzakelijk op beide eilanden en voor Curaçao is een vermindering van vervuiling noodzakelijk voor de vervuilde plekken. Deze maatregelen zijn noodzakelijk om een gezonde kust, prachtige koraalriffen en een duurzame toeristische sector te garanderen.

Summary (Papiamento)

Will be followed later.

Summary (Spanish)

Will be followed later.

Ch. 1. Introduction

Oceans are covering 70 percent of the Earth's surface and are up to 10 kilometers deep. Mankind was living from the sea for ages and even now over 25 percent of the proteins we use origins from the oceans. Unless the importance of oceans they are polluted by mankind for ages as well. The effects are damage stating (Smith and Smith, 1998; Waldman and Shevah, 2000; Pearce, 2003; Stewart, 2006).

The most diverse and complex ecosystem in the oceans are coral reefs. It survives in shallow tropical waters without a high concentration of nutrients. An ecosystem as a coral reef is fragile and not able to adapt quickly to a changing environment (Dornelas *et al.*, 2006). The importance of coral reefs is enormous. They protect shores from wave damage and coastal erosion, a breeding place for fishes and so a support to fisheries, supply for all kinds of natural products and a high biomedical value and biodiversity. The importance of coral reefs for future climate change is incredible. During the Ice Ages coral reefs formed the only place for marine life to survive. When all coral reefs are destroyed future climate changes will have an irreversible destructive effect on marine life (Lapointe, 1997; GCRA, 2006; NOAA, 2006).

The runoff from the land is bringing lots of nutrients with it to the coral reefs. Several land-based sources like sewage and fertilizers are adding nutrients to the runoff. The effects of these added nutrients are poorly studied. A monitoring program on several coral reefs was needed to estimate the effects of the nutrient pollution. The Netherlands Antilles took this challenge and did set up a nutrient monitoring program for the coral reefs of Bonaire and Curacao. The results after one year are hereby reported. Soon the marine park of Saint Lucia joined the program to expand the amount of gained knowledge. Saint Lucia is described in less detail compared to Bonaire and Curacao.

Historical Coral Reef Description

Different than Aruba, Curacao and Bonaire were formed from volcano rocks 120 million years ago. As result for this event the reefs of the two islands are very close to the shoreline. Van Duyl (1985) made an atlas of the coral reefs of Curacao and Bonaire. Compared to the worldwide rate of coral cover decrease the present situation is not so much worse. Several species did disappear in the whole Caribbean but overall, including the damage of the hurricanes, diseases and bleaching events, the two islands are doing quite good compared to the reefs in the Caribbean region (Bries *et al.*, 2004). Nevertheless, over a long period from the seventies up till the nineties, de coral cover did significantly decrease (Bak and Nieuwland, 1995).

Hurricanes do affect the reefs of Curacao and Bonaire almost on a yearly base. Although the influence is small, two hurricanes, Ivan and Lenny, did cause some serious damage. Smaller hurricanes or hurricanes on a distance, do affect the reefs in disturbance in temperature (4°C lower) and higher wave energy. The damage is especially located in the shallow reefs (Van Veghel and Hoetjes, 1995; Bries *et al.*, 2004).

Another result caused by mankind is the decrease in fish stock over the last decennia. This is a result of many different causes but mankind is responsible for most causes. Decennia ago "you could walk on the fish", the sea was filled up by three feet long fishes, but nowadays they are large if they reach one foot (Stewart, 2004).

Also the algae growth is concerning. A significant decrease in hard coral cover (50.1 to 44.4%) and increase in algae cover (28.6 to 41.7%) in four years is resulting in 2001 a change of dominant cover on Curacao (Wiebe *et al.*, 1975; ReefKeeper International, 2001). This indicates within a healthy ecosystem, the availability of nutrients or the shortage of grazing fishes is a problem.

Since 1975 it became clear that diving tourism could be a long lasting industry. Don Stewart understood the importance to get the diving industry organized and established Caribbean Underwater Resort Operators (CURO). Nowadays Captain Don Habitat Resort is the most famous diving resort on Bonaire and the diving industry is the number one economy of Bonaire and Captain Don Stewart is worldwide seen as the founder of the diving tourism as we know it (De Meyer, 2004; Stewart, 2004).

Threats of Coral Reefs

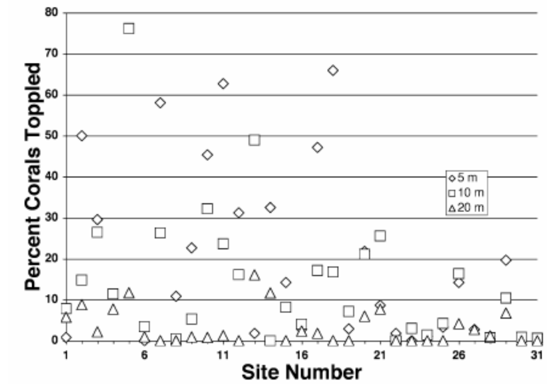
Threats for coral reefs can be separated in different classes in different ways. Macro disturbances and micro disturbances is an example. Macro disturbances do have a large impact on the reefs caused by volcanos, hurricanes, epidemic diseases, heavy pollution and *Acanthaster* outbreaks. The results can be mass mortality or differential mortality, respectively mortality of all species or species specific mortality. Micro disturbances have a smaller continuous impact what can cause a change over time. These disturbances are caused by erosion, predators, sediment pollution and human uses. The results are possible change in population composition (Van Duyl, 1985). In this writing is chosen for classification in triggers of the causes of the threats, natural, indirect human and direct human threats.

Natural Threats

Natural threats for coral reefs have always existed. These threats only form a small part of all the threats of the coral reefs. Intense storms, earthquakes and volcano's can damage the coral reefs.

Hurricanes

Hurricanes are causing major damage especially for the shallow reefs. The wave activities are high at the shallow parts and have a destructive effect on the corals. The damaged corals will role to the deeper parts of the reef and will do indirect damage caused by the wave activities (Woodley *et al.*, 1981; Ostrander *et al.*, 2000). The hurricane Lenny from November 1999 did cross Saint Lucia and had a major impact on Bonaire and Curacao. Over thirty sites on Curacao was the damage brought in the following graph (1.1).

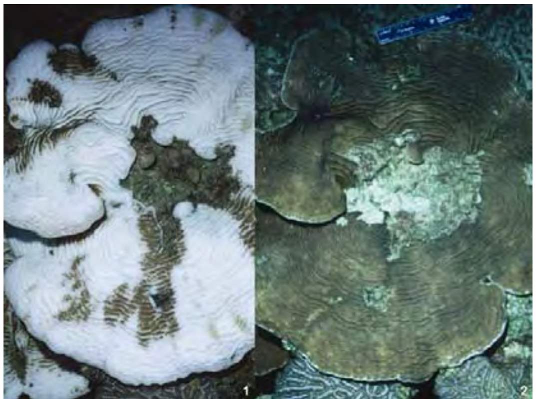


Graph 1.1. Damage by Lenny on Curacao. *The damage by hurricane Lenny on Curacao is for 31 sites monitored. Both squares are representing the shallow parts and the triangles the deeper parts of the reefs (Bries* et al.*, 2004).*

Diseases

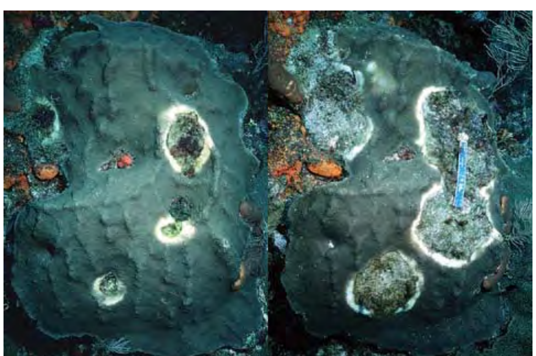
Another natural threat for coral reefs is diseases. Reefs in the Caribbean are far more sensitive for diseases than elsewhere in the world. This might be caused by the shape of the continent enclosing the Caribbean Sea for a large part. Coral reefs are in closer contact for that reason which makes the area more vulnerable for diseases (Goldberg and Wilkinson, 2004). Another possible explanation is described in the second next subchapter.

Bleaching (picture 1.1[A+B]) is effected by stress on the corals for several possible reasons. By losing the symbiotic algae, the corals are losing their color. This can be occurring for several weeks or even months, than the corals will die or recover. Sometimes bleaching occurs locally on a reef or even several corals. This can be caused by some local pollution or microclimatic changes. The last decades more and more huge and even worldwide bleaching events are recorded. These are caused by temperature rise, long exposure of UV radiation or bacteria infections. These huge bleaching events especially occur in El niño years (Baker *et al.*, 2004; Burke *et al.*, 2004).



Picture 1.1 A+B. Bleaching
An Agaricia *coral colony shown. Left bleached and right almost recovered from a bleaching event (by Bruckner, unknown).*

Yellow-Blotch Disease (pictures 1.2 A+B) is recognizable at the white-yellowish band of recently exposed skeleton of the coral. The disease is starting like a small a small yellow spot which is slowly expanding and leaving dead coral behind. The deadly process is moving only seven to ten centimeters per year. Because this process is so slow, the dead coral is never white skeleton but always overgrown by algae (Wiebe *et al.*, 1975; Cervino *et al.*, 2001).



Pictures 1.2 A + B. Yellow-Blotch Disease
Montastraea faveolata *colony affected by Yellow-Blotch Disease. The second picture is from the same colony eight months later (by Bruckner, unknown).*

Tsunamis

Since the 26th of December 2004 the world is familiar with the so-called tsunamis, a natural phenomenon consisting of series of waves generated when water is rapidly displaced on a massive scale. Besides the more than 250.000 deaths in December 2004, tsunamis do have three destructive effects, the wave actions, smashed and moved coral and sediment covering, on the coral reefs (Madin and Connolly, 2006; Wilkinson *et al*., 2006). Unless many positive stories, it is not proven that coral reefs protect the land against tsunamis (Baird *et al*., 2005; Liu *et al*., 2005).

Predation

Predation on corals is done by none corals as well as by corals. Dr. Judith Lang (1970) is one of the first scientists who did describe predation on corals by corals. In her research center Lang filmed the nightly activities of the so called aggressive corals. With small tentacles the coral reach out to the soft coral tissue of the prey and bit by bit it digests the prey.

Predation on corals by none corals occurs mainly by plantivorous fishes. When the corals are in the last larval phase and try to settle somewhere on the reef the concentration of predators is much higher than before in the open ocean (Fabricius and Metzner, 2004). Corallivorous gastropods *Drupella spp.* caused in Southeast Asia and Australia for enormous decrease in coral populations. They feed on the live tissue of corals leaving white scars behind which are overgrown by algae within days. The outbreaks of *Drupella spp.* are known as one of the worst disturbances of coral reef ecosystems (Cumming, 1999).

Indirect Human Threats

Climate Change

Climate change is a threat for many, if not all ecosystems in the world. Climate change is a very broad term. To describe the threats of climate change more specific the causes are split up. The sea surface temperature is rising. Because corals are living close to their upper boundaries considering temperature this can lead to mass bleaching. When the temperature is one or two degrees Celsius above average for over a month the disruption between the symbiotic relationship between polyps and zooxanthellae will occur. This process is leading to bleaching of the corals (Hoegh-Guldberg, 1999; Pockley, 1999; Pockley, 2000; Aronson and Precht, 2006; Grimsditch and Salm 2006).

The reduction of the ozone layer is causing a reduction of protection against UV-radiation. This is not only causing warming up of the sea surface, but also indirect the El Niño Southern Oscillation events. The expectations are with an increase of temperature a more frequent El Niño Southern Oscillation event. These events are causing mass bleaching worldwide (West and Salm, 2003; Baker *et al.*, 2004; Obura, 2005).

Box 1.1. Carbon dioxide absorption reactions:

$H_2O + CO_2$	=	H_2CO_3	(1)
H_2CO_3	=	$H^+ + HCO_3^-$	(2)
HCO_3^-	=	$H^+ + CO_3^{2-}$	(3)
$Ca^{2+} + CO_3^{2-}$	=	$CaCO_3$	(4)

The increase in atmospheric carbon dioxide (CO_2) is causing a shift in balance of dissolved carbon dioxide in the sea surface. More carbon dioxide in the sea water will have the following chemical reactions. First carbon dioxide will dissolve to carbonic acid (H_2CO_3) as shown in box 1.1 reaction 1. A hydrogen (H^+) molecule is spit off from the carbonic acid and is forming bicarbonate (HCO_3^-) (see box 1.1 reaction 2). As shown more carbon dioxide is causing an increase in the concentration of carbonic acid and bicarbonate ions. This is causing a decrease in the concentration of carbonate ions (CO_3^{2-}) (see box 1.1 reaction 3). Carbonate ions are needed to form calcium carbonate ($CaCO_3$) (see box 1.1 reaction 4) which is the main substrate of coral reefs. If the production of calcium carbonate is lower than the removal and dissolving of calcium carbonate from the coral reef, the coral reef will shrink in size (Buddemeier *et al.*, 2004).

Caused by climate change the sea levels are rising. Unless the rate of rising seems very low, one to nine millimeter per year, the threats for corals are present. One threat occurs when the sea level is rising and the corals may not receive enough sunlight anymore. In that case the symbiotic relationship between polyps and zooxanthellae ends and bleaching will occur. The second threat is the sedimentation from the coastal erosion caused by the rising sea level. The second threat the most concerning threat of the two (Pockley, 2000; IPCC, 2001).

Direct Human Threats

Over-fishing

Traditionally fishing is a source of food for as long as mankind can remember. Fishing is in the present day becoming a threat. Worldwide a decline of fish stock is occurring especially at high populated areas. The world wide demand for fish is increasing. In the Caribbean fish is one of the most important ingredients for local dishes. These are very popular also by the tourists which results, next to the increasing local population, an extra increase of demand. Over-fishing is also caused by the demand for aquarium trade.

The effects on coral reefs by over-fishing are damage stating. Clear relations are found between over-fishing and shark populations. If the average length of the fish stock is only ten centimeters due to over-fishing sharks can not feed on them anymore. Another clear relation is found between over-fishing and macroalgae overgrowth. When over-fishing occurs, the algae grazing fish stock is declining and macroalgae can overgrow the corals. A third relation due to over-fishing is the decline of predators of coral predators. The coral predator populations will grow and they will feed on the corals more intensively. All these stress and pressure on the corals make them probably even more vulnerable to diseases. The physical damage by fishing is not even mentioned so far (Hughes, 1994; Roberts, 1997; Aronson and Precht, 2006).

Sediment pollution

A report from the last century is mentioning a runoff of sediment from the Princess Beach, Avila Beach, Bulado Beach and the Sonesta Beach (all on Curacao) of at least 3 350 m^3 sediment per year (Bhairo-Marthé and Van Dijk, 1996). This runoff is mostly from the artificial beaches created to attract tourists. These beaches need to be restored every now and then. Sediment pollution is causing a reduction in photosynthetic activity and light availability and an increase of risk for diseases and bio-erosion. In extreme cases there is a risk that the reefs partly or completely get covered by sediment (Grigg and Dollar, 2004; Ramos-Scharron and MacDonald, 2007).

Nutrient and chemical pollution

Nutrient pollution is causing several threats for coral reefs. One of them is the possible increase of risk on diseases. This could be a possible explanation for the high sensitivity for diseases in the Caribbean (Goldberg and Wilkinson, 2004; Hallock, 2005). The added nutrients are on the short time causing growth from turf algae to macroalgae (see figure 1.2). Nutrient pollution is also causing shifts in colonization competition between algae and corals (Lapointe, 1997).

Figure 1.1 is showing how large the problem can get in crowded areas. Willemstad, the capital city of the Netherlands Antilles, is formed around the natural harbor the Schottegat. All the red dots are presenting discharges of polluted water. The Mega Pier is located at the Oceanside on the Westside of the mouth of the Schottegat. The Mega Pier is the monitoring site in this research where the highest pollution is expected (Bhairo-Marthé and Van Dijk, 1996).

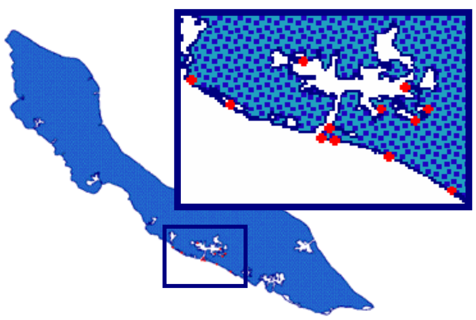


Figure 1.1. Sewage around the Schottegat. *The red dots are representing the locations of sewage around the Schottegat (Curaçao). Based on: Bhairo-Marthé and Van Dijk (1996).*

Diving tourism

Intensive diving industry can be a threat for the reefs as well (Hawkins *et al.*, 1999). Unless the Bonaire National Marine Park (BNMP) is a worldwide example of a successful marine park, divers do harm the reefs. Divers are touching, breaking, disturbing and polluting the reefs. BNMP is not warning for nothing; "Coral reefs take millenniums to grow, seconds to destroy". Dodge and Lang (1983) even measured not even a centimeter growth in one year.

Project Aware is trying to inform divers about ways to protect the underwater environment. They presenting the following ten ways;

1. Dive carefully in fragile aquatic ecosystems, such as coral reefs.
2. Be aware of your body and equipment placement when diving.
3. Keep your dive skills sharp with continuing education.
4. Consider how your interactions affect aquatic life.
5. Understand and respect underwater life.
6. Resist the urge to collect souvenirs.
7. If you hunt and/or collect game, obey all fish and game regulations.
8. Report environmental disturbances or destruction of dive sites.
9. Be a role model for other divers in diving and non-diving interaction with the environment.
10. Get involved in local environmental activities and issues.

These ten ways of stimulating awareness were provided by Project AWARE Foundation (2004). In this way divers might be more aware of diving in a sustainable way so the reefs can preserved for generations.

Development of coastal areas

Development of the coastline is putting extremely pressure on nature. Not only coral reefs are threatened by these activities but also for example sea turtles. Hotel accommodations, restaurants, bars and clubs are rising along the coastline. All development is necessary for the tourist industry. Also the pollution and disturbances of these activities are harmful (Debrot and Pors, 1995). Nevertheless it will be always a trade-off between preserving nature and economical development. Well over thought decisions need to be made.

Aim of the Monitoring Program

This monitoring program is developed as a baseline study to gain a greater knowledge and sight about the coral reefs of Bonaire and Curacao (see map 1.1). By monitoring the reefs the department of Environment and Nature of the Netherlands Antilles expects to be able to develop the required policy for the marine life of their territory. The marine researcher Dr. Brain Lapointe, who is closely involved to this monitoring program, is aiming to get a more detailed understanding in the development and the processes of the Caribbean reefs. Since October 2006 Saint Lucia joint the program.

Considered is that the growth of macroalgae an indication is for unhealthy reefs. This consideration is supported by Lapointe (1997) as shown as in the next figure (1.2). Decline of grazing activities and an increasing nutrient availability is causing macroalgae growth.

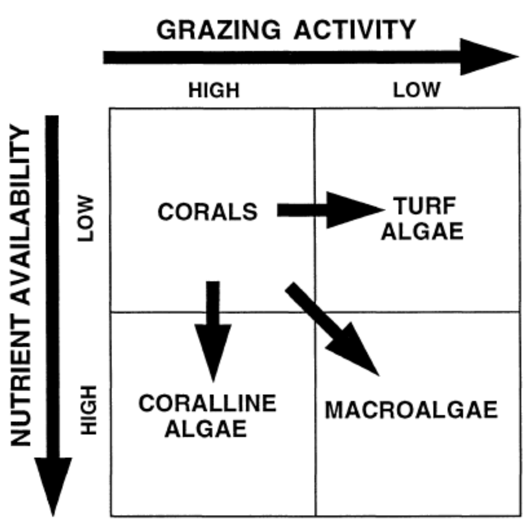


Figure 1.2. Human influence on algae growth. *More fishing is causing lower grazing activity and more pollution is causing more nutrient availability. Together both human influences are pushing the ecological balance from corals to macroalgae (Lapointe, 1997).*

On the x-axis the grazing activity is shown. That was supposed to be measured by the fish counts. Due to different used methods and not enough counts that part is deleted for now in this report. Nevertheless is the planned method described in the next chapter. The y-axis is showing the nutrient availability. The nutrient which is limiting for coral ecosystems is nitrogen. The available nitrogen and phosphor in the water are measured as well as the amount of phytoplankton as an indicator for the nutrient availability.

The monitoring program is focused on nutrient pollution on coral reefs. In what way does nutrient pollution effects the health of a coral reef? What is the actual pollution at the moment on the islands? Is any dramatic change required in policies or management to preserve the coral reefs? These questions are only a few of the reasons why a government as the Netherlands Antilles does need a monitoring program.

Research Questions

The main research question is; does nutrient pollution have any relation to the health of the coral reefs of Bonaire and Curacao? This question will be answered by the following research questions;

- Is there a correlation between the nitrogen source and macroalgae growth?
- Is there a correlation between nitrogen source and phytoplankton levels?

Hypotheses

The expectations are to find the two correlations, like elsewhere is found in the Caribbean (Lapointe, 1997; Barile and Lapointe, 2005). Expected is to find more macroalgae growth on Curacao and so to find more healthy reefs on Bonaire. Also is expected to find more sites with a high nutrient availability on Curacao than on Bonaire. The last expectation is to find on Saint Lucia more nutrient availability than on Bonaire and Curacao.

Map 1.1. Caribbean Sea
In red are Curacao, Bonaire and Saint Lucia shown on this Caribbean map.

Ch. 2. Research Methods

Site Descriptions

The monitoring has been carried out for one year on two islands, from March 2006 to December 2006 on Bonaire and Curacao, and is launched in October 2006 on the island St. Lucia. In the past many events had a great influence on the conditions of the reefs. Nevertheless the importance, are these events poorly documented. Bonaire and Curacao experienced an equal series of events. In 1982/1983 a massive extinction took place under *Echinoidea* shortly followed by the extinction of *Acropora cervicornis*. In 1995 Bonaire and Curacao were having a major bleaching event followed up the next year by yellow blotch disease. A minor bleaching event took place in 1998 as well. At the same time in the mid 90's, a second extinction, this time *Acropora palmate* took place. After these events two hurricanes, Lenny (1999) and Ivan (2004), damaged the coral reefs destructively.

The wave energy environment of Bonaire and Curacao is documented by Van Duyl (1985). Six categories are created to describe the waves. These are shown in the next table (2.1). Maps 2.1 and 2.2 are including these

Table 2.1. Wave Energy Environment

Wave energy environment		Height (m)
1	Very high wave energy environment	2.0-3.5
2	High wave energy environment	1.5-2.0
3	High-moderate wave energy environment	1.0-1.5
4	Moderate wave energy environment	0.5-1.0
5	Moderate-low wave energy environment	0.3-0.5
6	Low wave energy environment	0.0-0.3

Source: Van Duyl (1985).

Bonaire

On Bonaire are ten monitoring sites, eight on the island Bonaire and two on the island Klein Bonaire (see map 2.1). Also some measurements are taken around the Cargill Salt Company and in the Lagoon, but those can not described as monitoring sites because of the low frequency of visits. The sites are described following the current from south following the western shoreline to the north. The names are from the official dive sites.

Red Slave: This site is located in the very south of Bonaire at the west side of the Pekelmeer. The current can be very strong and is assumed to be unpolluted by the island. There is no coastal development or activity except the tourists visiting the Red Slave Houses (see picture 2.1).

Angel City: This site is located at the west side of the salt company. There is no coastal development present except the salt company. The processing of salt seems very clean but the bacterial residues are dumped into the sea every now and then. These residues will be possible influencing this monitoring site by adding an occasional nutrient input.

Eighteenth Palm (Plaza Resort): This site is located in front of Plaza Resort's artificial beach. Besides the effects of tourists swimming, snorkeling and diving in the sea, the added sand and expected nutrient pollution are influencing the reef conditions.

Playa Lechi (south from Something Special): This site is located next to the boulevard at the north side of Kralendijk. This site is surrounded by small yachts and sailing boats.

Front Porch: This site is just a small little bit more to the north than the last site. A little less yachts and buildings are present.

Habitat: This site is again just a little more to the north than the last two sites. Only a few yachts are present but more tourist activities, diving and a big tanker is lying close by.

Karpata: This site is located at the south of the country house Karpata and at the east side of the Marine Reserve. It is a popular and beautiful diving site. There is no coastal development nearby.

Playa Funchi: This site is located at the west coast of the Washington Slagbaai National Park. Not much of disturbance or pollution because this site is inside the National Park.

South Bay (Klein Bonaire): This site is located at the south of Klein Bonaire. This diving site is very popular and without pollution from Klein Bonaire.

Ebo's Special (Klein Bonaire): This site is located at the northeast side of Klein Bonaire and is named after Ebo Domacasse, one of the first Bonairian divers.

Salt Company: This site is one of the salt pans from the salt company in the south of Bonaire. Only during the first monitoring round is this site included.

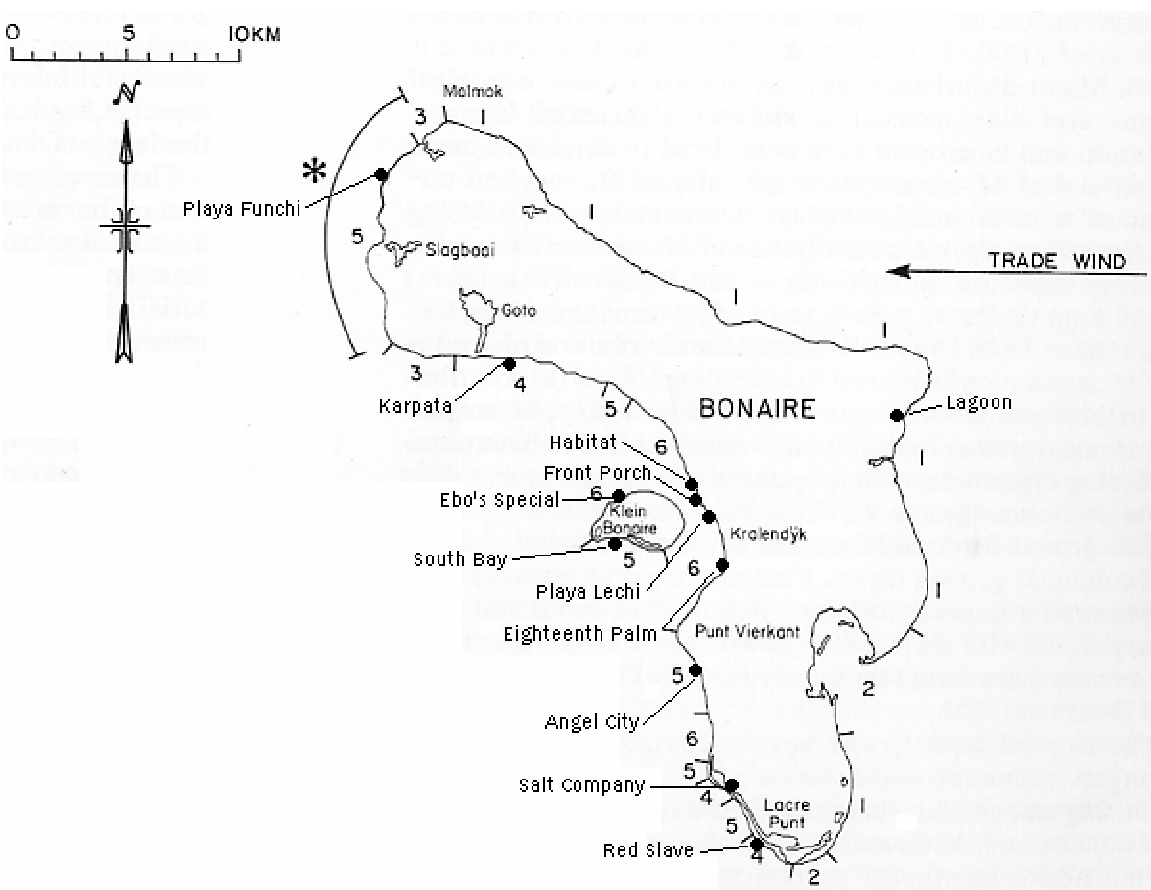
Cargill Channel: This site is a channel connected to the Cargill Pond. Once was sampled here within 24 hours of discharge from the salt pans. The location was a proximal 100 meters from the outlet.

Cargill Pond: This site is the outlet of the Cargill Salt Company. Here was once sampled together with the Cargill Channel.

Lagoon: Inland water on the eastside of Bonaire. The lagoon is located close to the landfill and far away from the urban area.

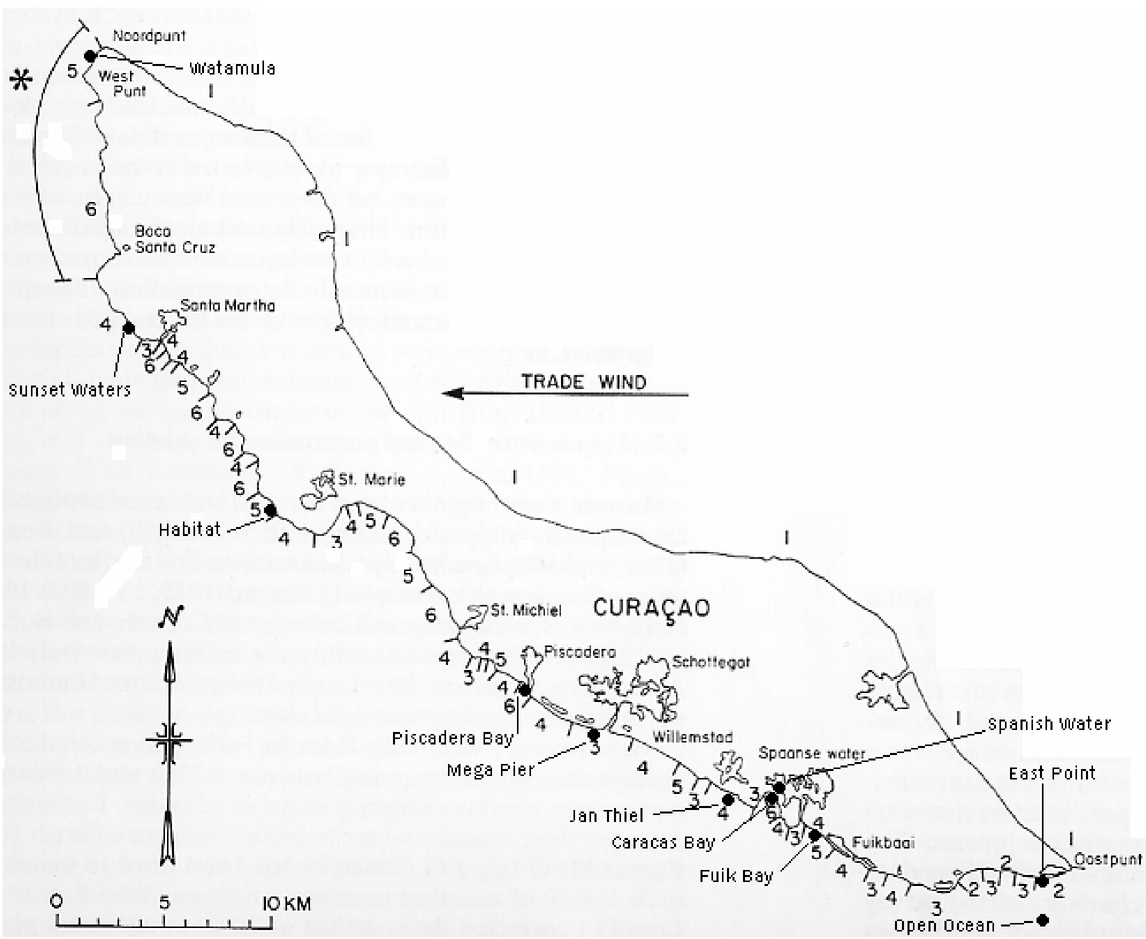
Picture 2.1. Red Slave Houses
(by Wieggers, 2007).

Map 2.1. Monitoring sites of Bonaire
This map is showing the islands Bonaire and Klein Bonaire. The numbers along the coastline are indicating the wave heights (1: 2.0-3.5 m, 2: 1.5-2.0 m, 3: 1.0-1.5 m, 4: 0.5-1.0 m, 5: 0.3-0.5 m, 6: 0.0-0.3 m). On Bonaire are ten (two none coral reefs) and on Klein Bonaire two monitoring sites shown with a black dot. All coral reefs are located at the calm west side of Bonaire (Van Duyl, 1985).



Map 2.2. Monitoring sites of Curacao

This map is showing the island Curacao. The numbers along the coastline are indicating the wave heights (1: 2.0-3.5 m, 2: 1.5-2.0 m, 3: 1.0-1.5 m, 4: 0.5-1.0 m, 5: 0.3-0.5 m, 6: 0.0-0.3 m). On Curacao are eleven monitoring sites, nine are coral reefs, one at the inland water of Spanish Water and one at the open ocean. All coral reefs are located at the calm southwest side of Curacao (Van Duyl, 1985).



Curacao

On Curacao are eleven monitoring sites, nine sites at the ocean of the southern side of the island, one site at the open ocean near East Point and one site at the inland water of Spanish Water close to Caracas Bay (see map 2.2). The sites are described following the current from southeast following the southern shoreline to the northwest.

East Point: At the very east part of Curacao a large area, almost a tenth of the island is private property. It is a conservation area where no development is allowed. The reefs around East Point like this monitoring site are undisturbed and rarely visit

Fuik Bay: This site was quite undisturbed but lately more and more activities and plans are influencing this area like a water company and a large hotel in the near future.

Caracas Bay: The beach of this bay is a popular swimming site. Also here are more and more developments. Also there is a huge pollution from Spanish Water released from Spanish Bay and possible sibling thru the small dike at Caracas Bay.

Jan Thiel: This site is influenced by three resorts and two more resorts are planned. Several divers and many swimmers are active and sewage might be a problem.

Mega Pier: This site is receiving an outflow from the Schottegat which is heavily polluted. Also many shipping activities and cruise ships are influencing this site.

Piscadera Bay: This site, close to the CARMABI office, is under influence of several resorts, hotels, sewage from the Piscadera Bay and possible the polluted water flow from the Schottegat.

Habitat Curaçao Resort: A nice calm area with some sailing, diving and swimming activities. Except for the resort there is no development.

Sunset Waters Beach Resort: More intense used is this site compared to the last one, the same disturbance but a little more intense.

Watamula: Close to Playa Kalki is located maybe the most beautiful site. For decades only disturbed by fishing activities from a little fishermen village.

Spanish Water: Very intense use by yachts, water sports and fisher boats plus a very high amount of sewage pollution from the urban surroundings.

Open Ocean: This site is chosen as a control site. From the surface is water sampled to compare to the water of the sites. This site is located nearby East Point.

Saint Lucia

Although the results from Saint Lucia are not yet worked out in this report, the importance of these sites is huge. The situation at forehand is that Bonaire is expected to be a relative clean island. Curacao is expected to be a little more polluted and Saint Lucia is representing a polluted area. In that case it is possible to do research over a gradient of pollution and draw conclusions and expectations for Bonaire and Curacao if pollution continues or even increases.

In cooperation with the Soufriere Marine Management Association (SMMA) ten monitoring sites are chosen. Since October 2006 the nutrient monitoring program started on Saint Lucia. The same methods are used as on Bonaire and Curacao. By the time of analyzing the preliminary results of Bonaire and Curacao only the first monitoring round was analyzed.

Analysis of Reef Cover

During the series of measurements, per site four videos are made from transects of 25 m. Two videos are made from the deeper parts (60 ft.) and two from the shallow parts (20 ft.) of the reef. The video was captured in such a way to capture approximately one square meter of reef cover. The tapes were digitalized for analysis.

These videos were analyzed using Coral Point Count with Excel extensions (CPCe). This Windows-based software is developed by the National Coral Reef Institute (NCRI) and the Nova Southeastern University Oceanographic Center (NSUOC). Out of a single video transect are 15 frames taken. From each of these frames are 20 random points selected by CPCe. The present species at all these points are identified by using Humann[1] (2002), Humann[2] (2002), Littler and Littler (2000) and Allen (2005). CPCe calculates the coral and algae cover of the reefs from the whole transect (Kohler and Gill, 2006).

Analysis of Phytoplankton

For analyzing the amounts of phytoplankton the chlorophyll *α* in the seawater was analyzed. Four large bottles of seawater were collected from the two depths (20 and 60 ft.). The bottles were filled 5 centimeters above reef surface. After filtering 100 ml for the nutrient analysis, another 100 ml was filtered. The chlorophyll *α* in these 200 ml of seawater will stick in the filter. The filter is folded in aluminum folio and labeled before putting it on ice. In frozen condition it is send to Miami. At the University of Miami (USA) the samples were analyzed.

Analysis of Nutrients

For the nutrient analysis per site four bottles are taken from the two depths (20 and 60 ft.). These samples are directly put on ice and in the dark. Once at the provisional lab in the field or at home, 100 ml of the seawater was filtered and put on ice again. In froze conditions it was send to Miami and for analysis to the University of Maryland (USA). The detection limits are shown in table 2.1. During the analyses of the nutrients is a correction for the detection limits needed for the nutrient concentrations below this detection limit.

Table 2.1. Detection limits

Nutrient	Detection limit (mg/l)
NH_4	0.0030
NO_2 & NO_3	0.0007
PO_4	0.0007
TDP	0.0015

Analysis of Nitrogen Source

Several divers collected from the two depths samples of algae for the analysis of the isotope ratio. *Lobophora*, *Dictyota* and *Halimeda* were aimed for but when they were not present or other algae were dominating the seafloor others were collected as well. These algae were dried in the oven for at least 12 hours at 70°C. After they were dried the algae were grained to fine powder. The powder was send to Miami in small vials and for analysis to the McMaster University in Ontario (Canada).

The reason for collecting algae was to examine the source of the up taken nitrogen. For estimating the possible nitrogen source the ratio between ^{15}N and ^{14}N isotopes (also called $\delta^{15}N$) is needed. This stable nitrogen ratio is like a finger print of the source. Living organisms like algae do have a similar nitrogen isotope ratio as its source. After calculating the isotope ratio $^{15}N/^{14}N$ (see box 2.1) it is possible to estimate the source of the nitrogen. In short it is possible to make the following generalization;

0.0 – 0.5 : natural fixation
1.0 – 3.0 : fertilizer
3.0 – 12.0 : sewage

These figures are based on several researches (Constanzo *et al*., 2001; Lapointe and Thacker, 2002; Lapointe *et al*., 2005). For the calculation is the isotope ratio $^{15}N/^{14}N$ the global standard ratio (0.3663%), based on the atmospheric N_2 is used (Constanzo *et al*., 2001; Lapointe *et al.*, 2004).

Box 2.1. Caculation of $\delta^{15}N$

$\delta^{15}N$ (‰) = $(R_{sample}/R_{standard} - 1) \times 1000$

Analysis of Fish Stock

The fish stock was supposed to be measured according the Bohnsack method, also used in comparable research by Lapointe. Due to a shortage of divers in Curacao and the use of another method by the volunteers of STINAPA on Bonaire, there is not enough usable data colleted.

Aimed was for the Angelfishes, Surgeonfishes, Damselfishes and the Parrotfishes (see picture 2.2 – 2.5) because they are all algae grazers. To identify and learn more from these species De Boer *et al.* (1994) and Humann and Deloach (2003) were used.

Statistical Analyses

The descriptive analyses are carried out with SPSS 14.0.1 for each parameter. Because the low coefficient of determination of the trendlines in the graphs made in MS Excel 2003 (R^2 lower than 0.1), it is assumed there is no way of proving a correlation. Because of this problem the sites are tested per parameter for multiple comparisons. Used is the Tukey test with unequal sample sizes. The tests are carried out according the description of Zar (1999) and calculated step by step in MS Excel 2003 to accomplice completely understanding.

To compare the two islands a t-test is carried out in MS Excel 2003 as well. A significant difference is recognized by an outcome of less than 0.05.

Picture 2.2. French Angelfish (*Pomacanthus paru*)
This fish is photographed at the Bari Reef in Bonaire. The Papiamento name is "Sheu" (by Hazes, 2007).

Picture 2.3. Doctorfish (*Acanthurus chirurgus*)
This fish is photographed at the Snorkel Reef in Cuba. The Papiamento name is "Kleinfeshi blanku" (by Hazes, 2007).

Picture 2.4. Threespot Damselfish (*Stegastes planifrons*)
This ***Juvenile*** *fish is photographed at the Bari Reef in Bonaire. The Papiamento name is "Ladronchi" (by Hazes, 2007).*

Picture 2.5. Princess Parrotfish (*Scarus taeniopterus*)
This fish is photographed at the White Rock in Cuba. *The Papiamento name is "Gutu rab'i gai" (by Hazes, 2007).*

Ch. 3. Results

The results and the statistical outcome will be presented together per parameter for Bonaire and Curacao.

Cover of the Reefs

The cover of the reefs will be presented in coral cover and the ratio between the cover of macroalgae and turf algae. The cover of algae is not presented because it is almost equal to the area not covered by corals.

Coral Cover

The coral cover is presented for the shallow and the deeper parts of the reef for Bonaire and Curacao. On Bonaire are the sites Karpata and South Bay the only ones above a coral cover of 50%, the same limit is crossed by East Point and Watamula on Curacao (see Graph 3.1). On average the coral cover of Bonaire seems slightly higher than the coral cover of Curacao. The Tukey test showed ten different groups where only group 1 and 10 representing two completely different groups of sites (see Appendix 1). The lowest group number is presenting the lowest coral cover. Group 1 is presenting eight sites from Bonaire and thirteen from Curacao. Group 10 is presenting eleven groups from Bonaire and five from Curacao. The groups 2 to 8 are all overlapping the other nine groups.

The average coral cover of Bonaire is 29.6% and of Curacao it is 27.1%. According to the t-test (0.504) there is no significant difference between the two islands (see table 4.1).

Ratio of Algae Cover

In a similar way as the coral cover is the ratio of algae cover presented (see Graph 3.2). It is the ratio between the cover of macroalgae and turf algae. The higher the ratio, the more macroalgae present compared to turf algae. Only on Curacao are ratios above three measured, Caracas Bay, Piscadera Bay and the Habitat Resort. The values of the ratios of Curacao are clearly higher than the values on Bonaire. The Tukey test shows two different groups with a big overlap, only Caracas Bay from group 2 is not in group 1 (see Appendix 2). In the second group are five sites from Bonaire and nine from Curacao.

The macroalgae cover of Curacao (35.2%) is significant higher (0.000) than the macroalgae cover of Bonaire (14.3%). The turf algae cover of Curacao (37.1%) is significant (0.001) lower than the turf algae cover of Bonaire (55.3%). Logical the difference in the ratio between macroalgae and turf algae of the islands is also significant (0.000). The average of Bonaire and Curacao are respectively 0.5 and 1.7 (see table 4.1).

Phytoplankton

In graph 3.3 are the chlorophyll *α* levels of the phytoplankton shown, left from the red line Bonaire, on the right side Curacao. Besides the two sites with highly polluted inland water, Lagun and Spanish Water, is the chlorophyll *α* level at the Mega Pier very high. The chlorophyll *α* levels of the Mega Pier, Piscadera Bay and the deeper parts of Habitat Resort Curacao are according the Tukey test (see Appendix 3) significant higher than the other monitoring sites.

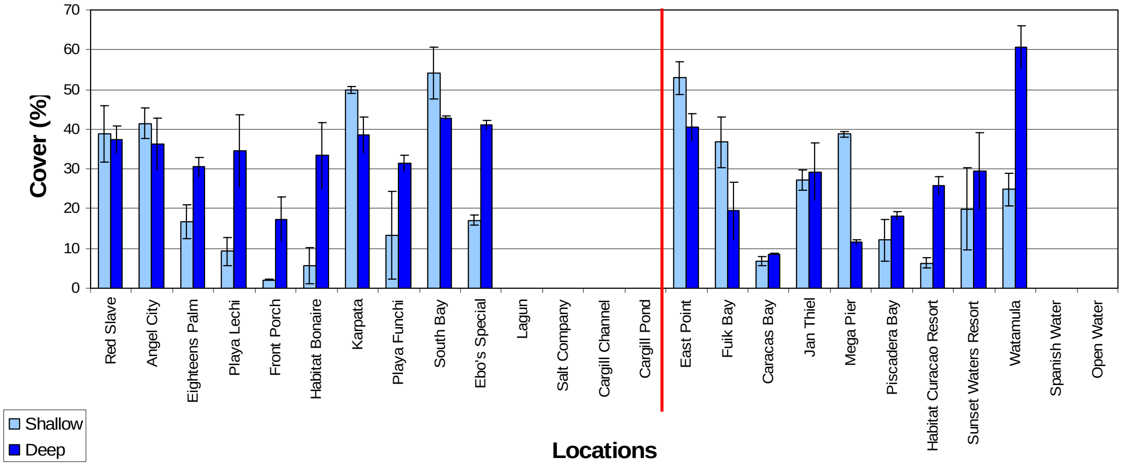
The average values on the reefs of Bonaire and Curacao are respectively 0.19 and 0.26 ug/l chlorophyll α which is significant different (0.000) (see table 4.1).

Nitrogen Source

The nitrogen isotope ratio of the algae presented in graph 3.4 is showing for the Mega Pier a ratio above 3‰. Most sites are limited to a maximum of 1.5‰, only Piscadera Bay and Mega Pier are above that limit. The Tukey test is showing four groups (see Appendix 4). Two of them are a small selective group with only the Mega Pier, shallow and deep, and Piscadera Bay, only shallow, and Spanish Water.

The average values on the reefs of Bonaire and Curacao are respectively 1.1 and 1.8‰ which is not significant different (0.054) (see table 4.1).

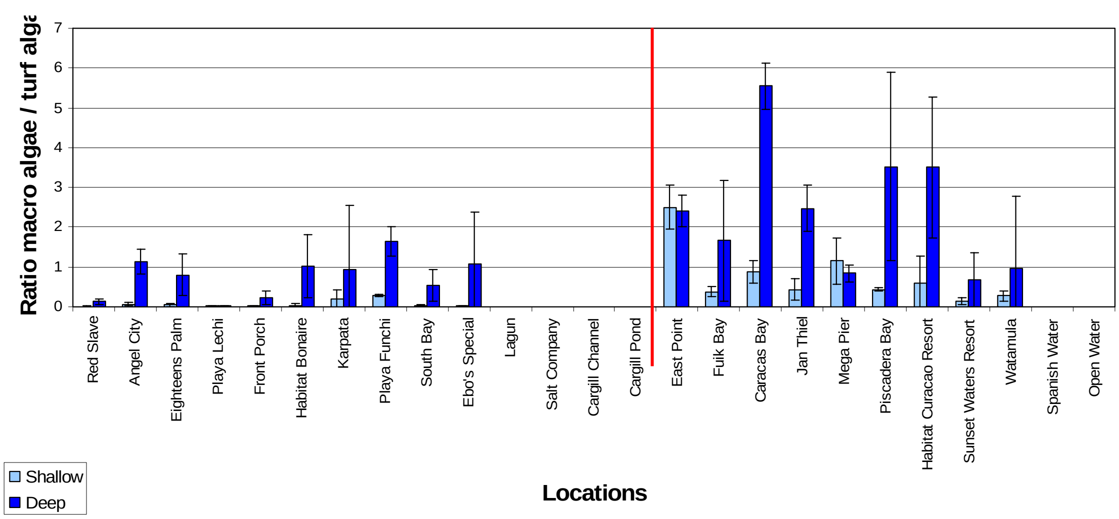
Graph 3.1. Coral Cover.



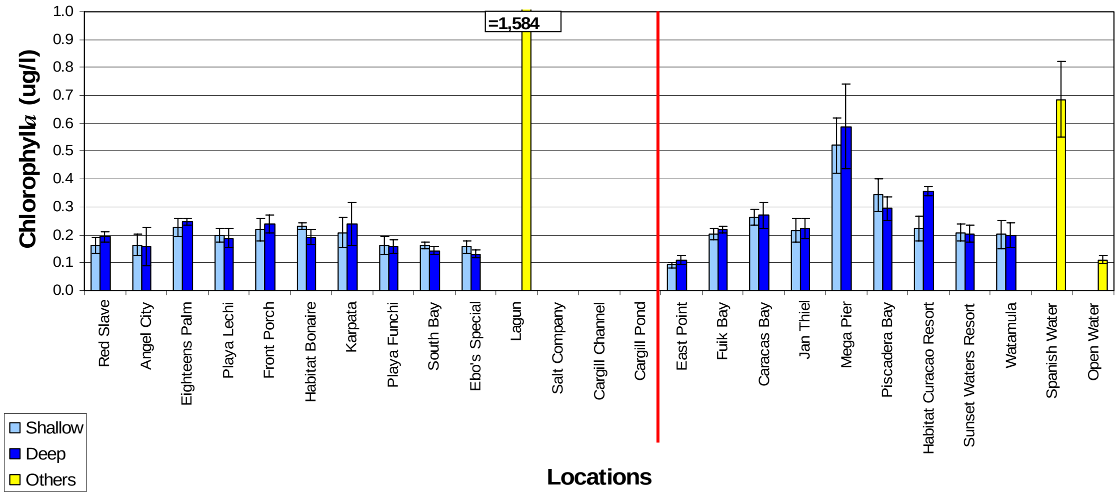
Graph 3.1. Coral Cover. *For all locations the average coral cover is shown. Light and dark blue representing respectively the shallow and deep of parts of the reef. On the left side of the red line are locations from Bonaire shown, on the right side Curacao.*

Graph 3.2. Ratio between the Cover of Macroalgae and Turf Algae. *For all locations the average of the ratio between the cover of macroalgae and turf algae is shown. Light and dark blue representing respectively the shallow and deep of parts of the reef. On the left side of the red line are locations from Bonaire shown, on the right side Curacao.*

Graph 3.2. Ratio between the Cover of Macroalgae and Turf Algae.



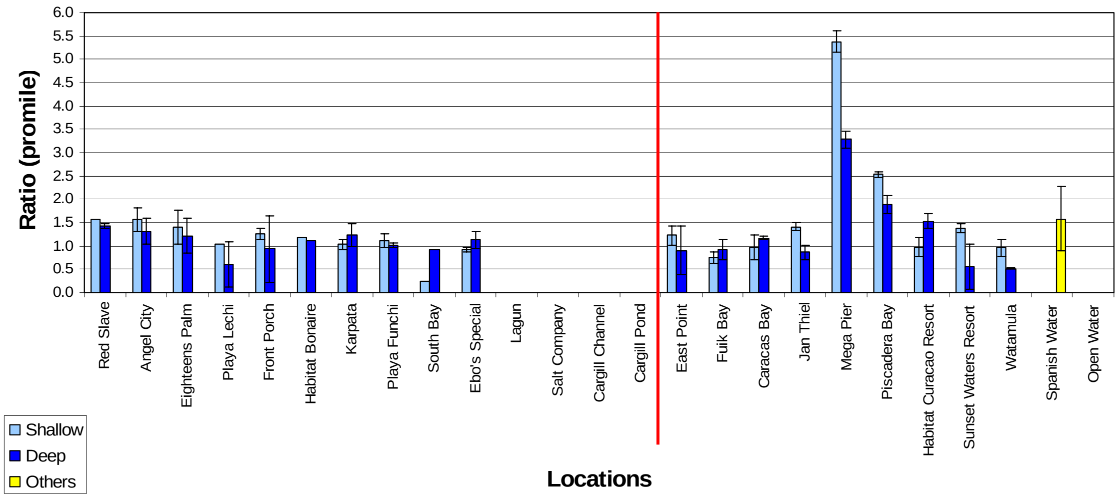
Graph 3.3. Chlorophyll *α*.



Graph 3.3. Chlorophyll *α*. *For all locations the average value for chlorophyll α is shown. Light and dark blue representing respectively the shallow and deep of parts of the reef. Yellow represents none coral reef sites. On the left side of the red line are locations from Bonaire shown, on the right side Curacao.*

Graph 3.4. Isotope Ratio $^{15}N/^{14}N$ of Algae. *For all locations the average of the ratio between ^{15}N and ^{14}N isotopes is shown. Light and dark blue representing respectively the shallow and deep of parts of the reef. Yellow represents none coral reef sites. On the left side of the red line are locations from Bonaire shown, on the right side Curacao.*

Graph 3.4. Isotope Ratio $^{15}N/^{14}N$ of Algae.



Nutrients

Two nutrients are measured during the sampling rounds. First phosphor and secondly nitrogen is presented. These are the two nutrients most limiting the growth of algae.

Phosphate

In graph 3.5 are the values for the phosphate (PO_4) levels shown. Most values are closely around 0.10 uM P/l. Only the levels of Angel City and Ebo's Special are above 0.15 uM P/l. The Tukey test can not show any significantly difference between the sites.

No significant difference (0.114) is found between the islands Bonaire (0.10 uM P/l) and Curacao (0.09 uM P/l) in the phosphate values on the reefs (see table 4.2).

Total Dissolved Phosphor

The total dissolved phosphor (TDP) levels shown in graph 3.6 are showing a very high value for the Salt Company. From the other sites are Angel City and Ebo's Special a little higher than the rest. The Tukey test is showing only a significant difference between the Salt Company and the rest.

No significant difference (0.661) is found between the islands Bonaire (0.26 uM P/l) and Curacao (0.27 uM P/l) in the TDP values on the reefs (see table 4.2).

Nitrite and Nitrate

In the graph 3.7 the nitrite (NO_2) and nitrate (NO_3) values for the Salt Company and the Cargill Channel are very high compared to the rest. From the rest is the Mega Pier relative high. The Tukey test is showing four significantly different groups, the Salt Company, the Cargill Channel and the rest.

A significant difference (0.006) is found between Bonaire (0.54 uM N/l) and Curacao (0.63 uM N/l) in the nitrite and nitrate values on the reefs (see table 4.2).

Ammonium

The next graph, 3.8, is showing the values of the ammonium (NH_4) levels. Again the Salt Company is showing an extremely high value. Besides this value are the values for Red Slave, Angel City and Ebo's Special relatively high. The Tukey test only distinguishes the Salt Company as a significant different group from the rest.

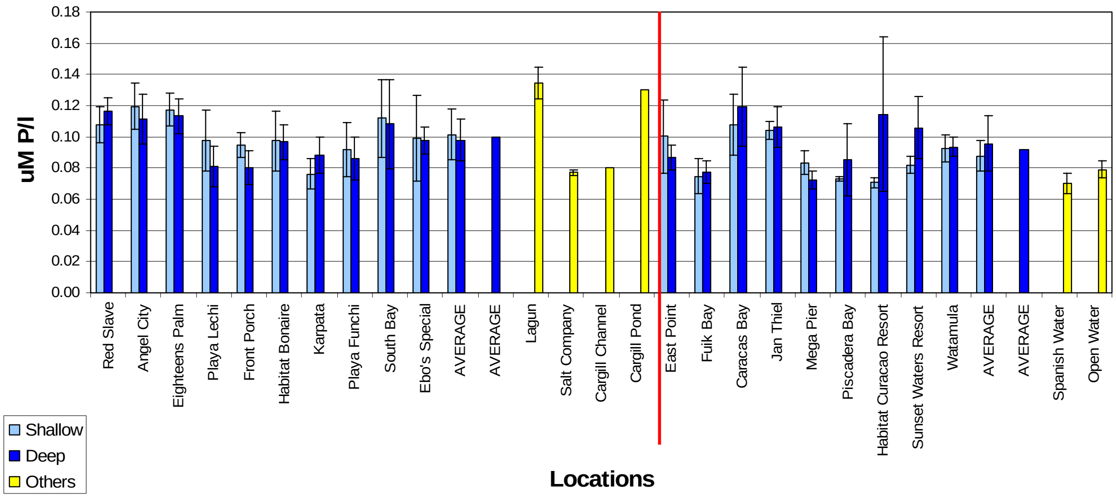
A significant difference (0.000) is found between Bonaire (0.77 uM N/l) and Curacao (0.50 uM N/l) in the ammonium values on the reefs (see table 4.2).

Dissolved Inorganic Nitrogen

Dissolved inorganic nitrogen (DIN) is the sum of ammonium, nitrite and nitrate. The graph of the DIN, 3.9, is showing an extremely high DIN value for the Salt Company too. The relative high values for the rest of the sites are occurring at Red Slave, Angel City, the Cargill Channel and the Mega Pier. The Tukey test only distinguishes the Salt Company as a significant different group.

Logically, after the nitrite, nitrate and ammonium values, significant difference (0.010) for DIN is found too. The average values on the reefs for Bonaire and Curacao are respectively 1.31 and 1.14 uM N/l (see table 4.2).

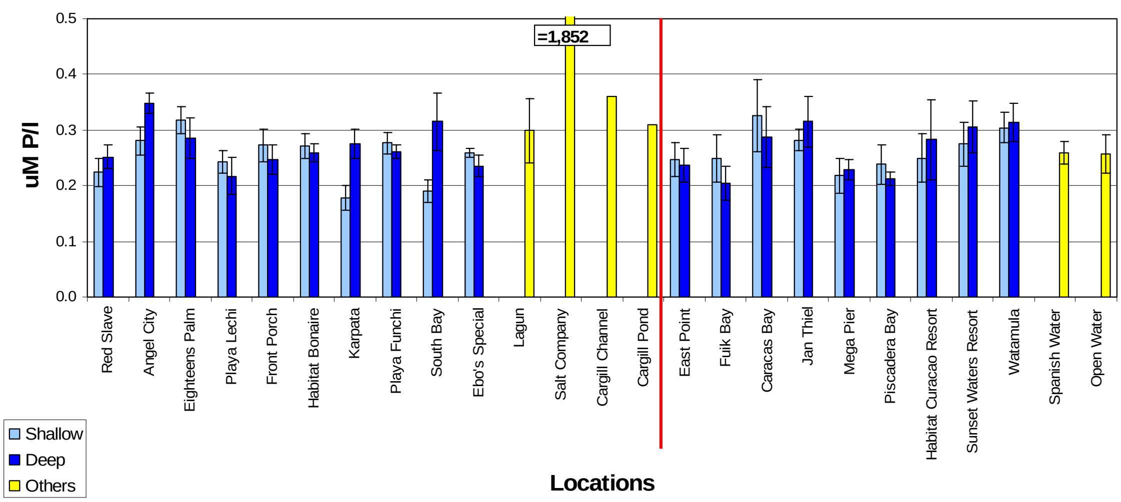
Graph 3.5. Phosphate.



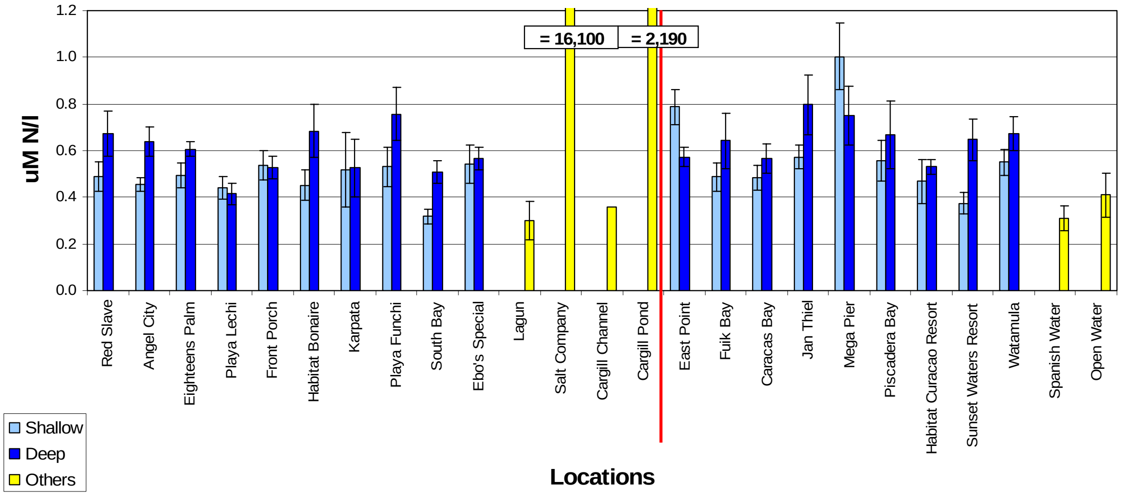
Graph 3.5. Phosphate. *For all locations the average value for phosphate (PO_4) is shown. Light and dark blue representing respectively the shallow and deep of parts of the reef. Yellow represents none coral reef sites. On the left side of the red line are locations from Bonaire shown, on the right side Curacao.*

Graph 3.6. Total Dissolved Phosphor. *For all locations the average of the total dissolved phosphor is shown. Light and dark blue representing respectively the shallow and deep of parts of the reef. Yellow represents none coral reef sites. On the left side of the red line are locations from Bonaire shown, on the right side Curacao.*

Graph 3.6. Total Dissolved Phosphor.



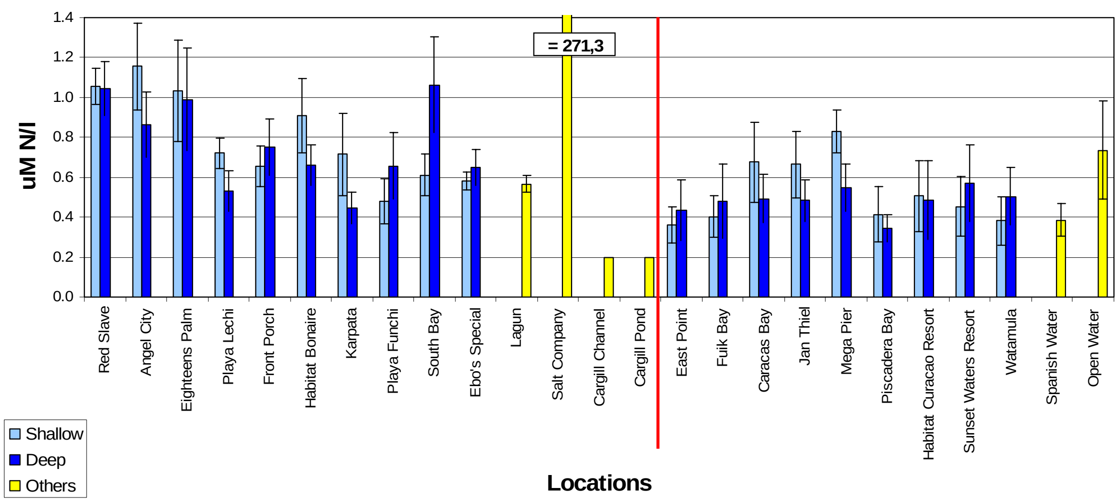
Graph 3.7. Nitrite & Nitrate.



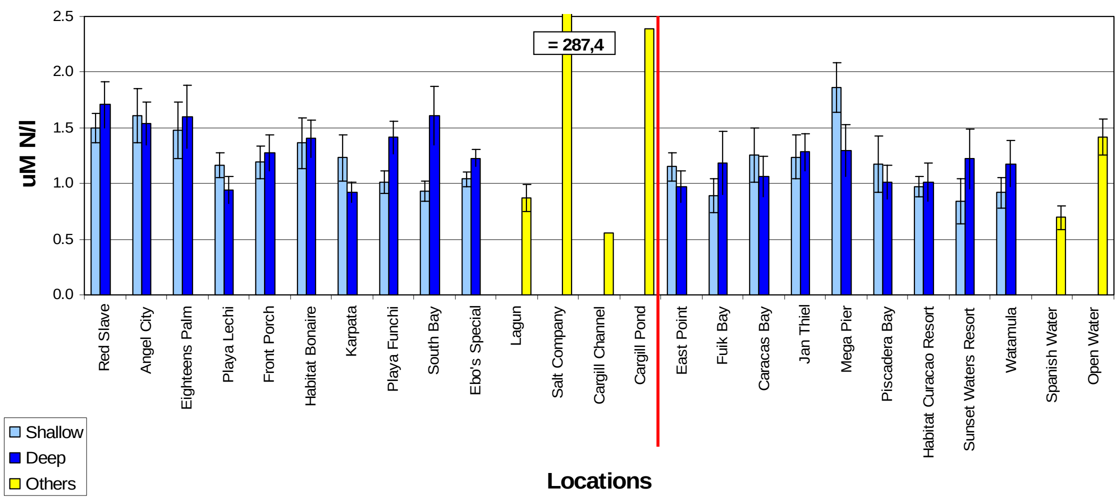
Graph 3.7. Nitrite & Nitrate. *For all locations the average value for nitrite (NO_2) plus nitrate (NO_3) is shown. Light and dark blue representing respectively the shallow and deep of parts of the reef. Yellow represents none coral reef sites. On the left side of the red line are locations from Bonaire shown, on the right side Curacao.*

Graph 3.8. Ammonium. *For all locations the average of ammonium (NH_4) is shown. Light and dark blue representing respectively the shallow and deep of parts of the reef. Yellow represents none coral reef sites. On the left side of the red line are locations from Bonaire shown, on the right side Curacao.*

Graph 3.8. Ammonium.



Graph 3.9. Dissolved Inorganic Nitrogen.



Graph 3.9. Dissolved Inorganic Nitrogen. *For all locations the average value for dissolved inorganic nitrogen is shown. Light and dark blue representing respectively the shallow and deep of parts of the reef. Yellow represents none coral reef sites. On the left side of the red line are locations from Bonaire shown, on the right side Curacao.*

Results of Saint Lucia

The averages values of the first monitoring round of Saint Lucia are shown in table 3.1. No video analyses are carried out for the reef cover and no statistical analyses are done on this data yet.

Table 3.1. Average data from Saint Lucia.

Content	Average concentration
Chlorophyll α	0.23 ug/l
Phosphate (PO_4)	0.09 uM P/l
Total Dissolved Phosphor (TDP)	0.24 uM P/l
Nitrite and nitrate (NO_2 & NO_3)	0.85 uM N/l
Ammonium (NH_4)	0.52 uM N/l
Dissolved Inorganic Nitrogen (DIN)	1.36 uM N/l

Open Water

A few kilometers from the coastline close to East Point of Curacao is located the reference monitoring point named Open Water. Nutrients and chlorophyll α are measured. In the graphs is the value shown as the first yellow bar on the right side. This site is never significant different from the less polluted reef sites.

Ch. 4. Discussion

Comparison between Islands

The average values of the three islands are compared in table 4.1. The average values of Bonaire and Curacao are tested statistically according to what is written in the methods. Only one round of monitoring is carried out by the time of this analysis for Saint Lucia. For that reason Saint Lucia is not statistically tested with Bonaire and Curacao.

Table 4.1. Average values of the three islands.

Para-meter	Bonaire	Curacao	Sign.	Saint Lucia
Coral c.	29.6	26.0	0.336	n.a.
R.algae c.	0.5	1.8	**0.000**	n.a.
Chlor. α	0.19	0.26	**0.000**	0.23
$^{15}N/^{14}N$	1.1	1.5	0.054	n.a.
PO_4	0.11	0.09	**0.031**	0.09
TDP	0.29	0.27	0.404	0.24
NO_2 & NO_3	0.58	0.65	0.083	0.85
NH_4	0.92	0.66	**0.010**	0.52
DIN	1.50	1.31	0.092	1.36

Curacao according to more polluted because the effects of nutrient pollution, more macroalgae growth and high chlorophyll α levels, are proven. The chlorophyll α level of Bonaire is at the threshold of Lapointe (2004) but the levels of Curacao are already passed that threshold which is alarming.

The nitrogen levels between Bonaire and Curacao are also significant different. The ammonium levels of Bonaire are higher than Curacao. Noteworthy are the nitrite and nitrate values. Where the dissolved inorganic nitrogen levels are comparable to the dissolved inorganic nitrogen levels, nitrite and nitrate levels of Curacao are higher than from Bonaire.

From Saint Lucia can be suggested that the chlorophyll α levels are as alarming as for Curacao. For the nutrients can be suggested that the phosphor levels are similar to the other two islands. For nitrite, nitrate and ammonium are Saint Lucias levels comparable to worse to Curacao and for the dissolved inorganic nitrogen level is Saint Lucia comparable to Bonaire.

Later in this chapter will all the parameters be discussed in further detail.

Exceptions of Curacao

Where there are no recurring significant differences between the monitoring sites of Bonaire, three monitoring sites of Curacao are striking. Like on forehand predicted the Mega Pier and Piscadera Bay are showing recurring significant differences and surprising in lesser extent Habitat Resort Curacao.

The Mega Pier is of course very much affected by the polluted water from the harbor, industrial and sewage activities in the Schottegat. The Piscadera Bay is affected by the broken pipeline which is leaking. Nevertheless the results are worse than expected on forehand. The monitored values at the Habitat Resort Curacao are still reasons to wonder. Known is the goodwill of the resort to limit the pollution of sewage as much as possible. The stable nitrogen isotope ratio is also indicating that sewage pollution is not occurring at that resort. What exactly can be the problem has to be said after further monitoring and research.

When the two polluted monitoring sites, Mega Pier and Piscadera Bay, are removed from the calculations of the averages the following table (4.2) can be drawn.

Table 4.2. Average values of the three islands (without the two polluted sites).

Para-meter	Bonaire	Curacao	Sign.	Saint Lucia
Coral c.	29.6	27.7	0.644	n.a.
R.algae c.	0.5	1.8	**0.000**	n.a.
Chlor. α	0.19	0.21	0.154	0.23
$^{15}N/^{14}N$	1.1	1.0	0.455	n.a.
PO_4	0.11	0.10	0.117	0.09
TDP	0.29	0.28	0.656	0.24
NO_2 & NO_3	0.58	0.60	0.547	0.85
NH_4	0.92	0.65	**0.007**	0.52
DIN	1.50	1.25	0.031	1.36

According to table 4.2 does have Curacao still have significantly a higher ration macroalgae to turf algae than Bonaire. The second significant difference is between ammonium concentrations in the water. Bonaire still has a higher ammonium concentration.

None reef monitoring sites

But where the Cargill Salt Company has a high level of dissolved inorganic nitrogen as well as a high concentration of nitrite plus nitrate and ammonium, it doesn't have a high concentration of phosphate. That is surprising according the total dissolved phosphor value. Also the Cargill Pond shows results to worry. The dissolved inorganic nitrogen value is not significant higher than the rest but the concentration of nitrite plus nitrate is. The concentration of ammonium for the Cargill Pond is the lowest measured (see Appendix 5 to 9). It is unclear if the assumption that ammonium and phosphate pollution from the Salt Company is not affecting the reefs from Bonaire is correct.

Picture 4.1 Cargill Salt Company
The outflow is affecting the southern reefs of Bonaire. More research will be carried out to get more insight in the processes taking place. Cargill is well-willing to cooperate with the government to find a solution (by Wieggers, 2007).

Cover of the Reefs

The reef cover is already many times measured and analyzed (Bak, 1977; Van Duyl, 1985; ReefKeeper International, 2001; Bak *et al*., 2005; Nagelkerken *et al*., 2005). Many different researchers are using different methods. I am aware that some might be critical about my percentages and other researches were more positive (higher coral cover) than mine. Three people known for their work and experience supported me at different stages by analyzing the videotapes from the transects taken during the monitoring events. From my point a view I think the method and the exact depths are the reason why different researches do differ so much. In spite of my inexperience at the start of my internship these values are more than worth to analyze, secondly the algae cover is analyzed in the very similar way and those values I do compare.

Coral Cover

Unless between the islands no significant difference is found for coral cover, ten significant different groups are found (see appendix 1). Noticeable is that from the group of the highest coral cover only Watamula (deep), East Point (shallow), Fuik Bay (shallow) and Mega Pier (shallow) representing Curacao out of a group of sixteen monitoring sites. Besides that fact has to be said that the Mega Pier (shallow) was not looking very healthy, a short mono culture of corals.

From the group of the lowest coral cover were eight out of 21 monitoring sites from Bonaire, a little less than the half of the group.

Ratio of the Algae Cover

For the ratio between macroalgae and turf algae were two significant groups found (see appendix 2). From the group with the highest cover of macroalgae were nine out of fourteen monitoring sites from Curacao.

Again were no significant differences found between the islands, but it is noticeable more sites from Curacao are represented in the group with the most macroalgae.

Phytoplankton

The results clearly showing that the inland waters are polluted as well the Mega Pier and Piscadera Bay at both depths and the deeper parts of the reef in front of the Habitat Resort Curacao (see appendix 3). No analysis is done for the sites at the Cargill Salt Company because of the difficulties of filtering the water. Legally assumed is that the values at the salt company are far higher than the inland waters.

According to Lapointe (2004) the chlorophyll α concentrations of a healthy coral reef is 0.10 ug/l, the threshold of a nutrient polluted reef is 0.20 ug/l. Bonaire with a average of 0.19 ug/l chlorophyll α is at that threshold, where Saint Lucia and Curacao passed the limit already with respectively an average of 0.23 and 0.26 ug/l chlorophyll α.

Nitrogen Source

The polluted monitoring sites from Curacao are together with the inland waters of both islands significant different from the other sites (see appendix 4). The shallow site at the Mega Pier is even more polluted than all others. The stable nitrogen isotopes ratio indicates that only the two sites from Curacao, Mega Pier and Piscadera Bay, are polluted.

The islands stable nitrogen isotopes ratios on average are comparable to other coral reefs close to the coast of the Bahamas. Compared to reefs close to Florida (USA) and Australia, the reefs of Bonaire and Curacao are not so heavily polluted (see table 4.3).

Table 4.3. Stable Nitrogen Isotope Ratios over the World

Country	**Site**	**$^{15}N/^{14}N$**
Netherlands Antilles	Bonaire	± 1.1
	Curacao	± 1.5
Bahamas[1]	Green Turtle Cay	± 1.2
USA[2]	Lee County	± 4.9
Australia[3]	Moreton Bay	± 2.3

1. Lapointe *et al.*, 2005
2. Lapointe and Beford, 2007
3. Costanzo *et al.*, 2001

Nutrients

Within all the nutrient analyses were no significant differences found except for sites at the Cargill Salt Company. The Salt Company does have a much higher concentration of Total Dissolved Phosphor and Dissolved Inorganic Nitrogen.

The assumption that all available nutrients are taken up by the algae quickly is still standing, no significant differences are found in nutrient levels between the polluted and the unpolluted sites. Nevertheless a significant difference is found between the islands nitrogen levels. For phosphor all values are not significant different from each other and also the average values of Saint Lucia are very close.

With the assumption that phosphorous and nitrogenous pollution is related, it may be concluded that phosphor is limited at the reefs so that the phosphor concentrations stay constant.

Phosphate

For phosphate are no significant differences found (see appendix 5). From the ten reefs with the highest phosphate levels are only three located offshore Curacao. From the ten reefs with the lowest phosphate levels are only three sites located offshore Bonaire. This might indicate some difference but it cannot be proven significantly.

Total Dissolved Phosphor

Also for the total dissolved phosphor levels is no significant difference found (see appendix 6). Not even a trend can be shown.

Nitrite and Nitrate

Besides two sites at the Cargill Salt Company, two groups of reefs are significant different in nitrite and nitrate levels from other reefs (see appendix 7). The group with the highest nitrite and nitrate levels is including the polluted sites Mega Pier and Piscadera Bay and Curacao represents thirteen out of nineteen reef sites.

Ammonium

Besides the Cargill Salt Company there are no significant differences found in ammonium levels between the monitoring sites (see appendix 8). A trend can be showed when you look at the ten reefs with the highest and the ten reefs with the lowest ammonium levels. From the ten reefs with the highest ammonium levels is only one representing Curacao. From the ten reefs with the lowest ammonium levels are only two representing Bonaire.

Dissolved Inorganic Nitrogen

Besides the Cargill Salt Company there are no significant differences found in dissolved inorganic nitrogen levels between the monitoring sites (see appendix 9). Again a trend can be showed when you look at the ten reefs with the highest and the ten reefs with the lowest dissolved inorganic nitrogen levels. From the ten reefs with the highest dissolved inorganic nitrogen levels is only one representing Curacao. From the ten reefs with the lowest dissolved inorganic nitrogen levels are four representing Bonaire.

Methodological Constrains

There are two critical remarks I need to give at our research. The video transects are recorded with a camera. The camera is bought several years ago, back than the best available quality, but nowadays not the most advanced model. By extracting pictures from the video the resolution got even worse. I strongly recommend to swim very slowly while shooting the video or make fifteen pictures spread out over the transect. The possibility to use other software to extract the pictures is one I didn't tried, but would be considerable. Ideal would be a new, high resolution camera and to swim very slowly while shooting the video. Now I feel disappointed by losing extra possibilities to get this research at a more detailed level.

Another critical remark I have to make is a general problem in research carried out by several teams. Unless the teams got trained in March 2006 together, their ways of carrying out the research was different in January 2007 when I jointed both teams. Partly I guess these differences came to a short in volunteers on Curacao and the difference in interpretation, perception and priorities of different aspects of the research.

Communication of the Program

The monitoring program has to be translated and communicated to community of the islands. The policy makers and political parties have to be aware of the pollution of their island on the extremely vulnerable ecosystems like the coral reefs.

In June 2007 the department of Environment and Nature of the Netherlands Antilles (MINA) organized in cooperation with DROB-Bonaire and STINAPA a two-day workshop. At this workshop these preliminary results were presented.

Because of the diversity of the participators a general introduction towards the nutrient problems at coral reefs (by Lapointe, HBOI – USA) was needed. From a scientific but easily understandable point of view, the problems and the gained knowledge so far were explained. This presentation was followed by an introduction of the monitoring program itself (by Hoetjes, MINA – The Netherlands Antilles) and the explanation of the used methods during this monitoring program (by Wieggers, Utrecht University – The Netherlands).

After the lunch break the situation of the sites and the implementation of the program on Bonaire (by Van Slobbe, DROB - Bonaire) and Saint Lucia (by Prospere, Soufriere Marine Management Association – Saint Lucia) was explained in further detail. The final presentation was presenting the preliminary results of the monitoring program (by Wieggers, Utrecht University – The Netherlands).

The first day was closed off with a very interesting discussion. One of the subjects was the strange results found at the Cargill Salt Company of course a reason for discussion. It seems to be a fruitful discussion because of the well-willingness of Cargill Salt Company to solve the problem. Also the importance of the continuation of the monitoring program was an important subject. The preliminary results are showing that Bonaire and Curacao are at the thresholds of being polluted and measures as well as continuation of monitoring is of importance of the islands. All the presentations are available at the site www.nacri.org.

On the second day of the workshop an excursion was planned. This excursion led the group to the DROB office, to the Lagoon close to the landfill, to Playa Lechi at the boulevard and to the Cargill Salt Company. Lapointe was teaching the group about algae which are indicators for nutrient enriched environments (picture 4.2). Afterwards Gielen was explaining about the processes at the Cargill Salt Company where all could see the different colors of algae at the reefs close to Red Slave and Angel City.

Picture 4.2 Explanation about algae.
Dr. Brian Lapointe is explaning typical nutrient indicating algae at Playa Lechi Bonaire. In the back are Laudiana Laurence and Hazelann Prospere from the Soufriere Marine Management Association from Saint Lucia (by Wieggers, 2007).

The participation was above expectations. Besides the department of MINA, the Netherlands Antilles was also represented by the departments of DOW and LLV. Also many NGO's were represented like STINAPA, CIEE, Cargill Salt Company (Bonaire), Reef Care, Curacao Sea Aquarium (Curacao), Nature Foundation, Ocean Care (Sint Maarten), OMMM (Martinique) and last but not least SMMA (Saint Lucia). Also many volunteers from Bonaire and Curacao, interns and interested citizens of Bonaire were represented. From the media was only one reporter from The Bonaire Reporter represented.

Ch. 5. Conclusions and Recommendations

Conclusions

Overall the coral reefs of Bonaire and Curacao seem quite unpolluted and undisturbed compared to the other reefs but nutrient pollution is a problem. That is shown with the disturbing results of the phytoplankton levels and the ratio between macroalgae and turf algae cover.

The comparison between the reefs and the Open Water monitoring site, which is a reference, is not as reassuring as it seems. The reference site is not significant different from most of the reef sites. But two points have to be mentioned. The chlorophyll α concentration is around 0.1 ug/l. That concentration is according Lapointe (2004) the value for a healthy reef. Most sites do have chlorophyll α concentrations around the threshold for pollution, 0.2 ug/l. Secondly is the site sampled at surface level. At the surface level is more phytoplankton present and therefore is the chlorophyll α concentration an overestimation.

Bonaire is less polluted compared to Curacao. Nevertheless it is at its threshold of having nutrificated coral reefs. Curacao is already past those thresholds and measures should be taken place in the very short future. The first round of monitoring indicates that Saint Lucia is at a comparable level of pollution as Curacao is.

On Curacao are the, on forehand, expected problems proven, the Mega Pier and Piscadera Bay are polluted. A surprising result is the polluted Habitat Resort at Curacao where the source is still unknown.

On Bonaire is the Cargill Salt Company a nutrient source. The salt company and the government together are willing to perform more research about the pollution.

This report is focused on nutrient pollution and alarming results are shown. Measures have to be taken but other threats for coral reefs are also still present. The nutrient pollution is not yet in a stage that it is the main reason for the coral bleaching and diseases which occur. Over fishing, sediment pollution, global warming and all the other mentioned threats in chapter 1 are still threatening.

Recommendations

Recommendations for Bonaire are simple, support the waste water treatment system which is planned and do specific research to the effects of the salt company. Also be alert on the effects of sediment pollution what was visible at several sites.

For Curacao the problems are more diverse. The economical activities around the Schottegat do have a highly polluting effect on the Mega Pier. The known problem at the waste water pipeline at the Piscadera Bay does have a larger impact than expected. The signs of pollution at the Habitat Resort are surprising, but should be communicated with the resort. Habitat Resort Curacao can never have the intension not to be careful with the reefs. So except for the pollution from the Schottegat, with effective measures results can be expected on the short term if taken.

The trade off between economical development and the preservation of the coral reefs at the Mega Pier is a hard one. The economical development around the Schottegat is for a small island as Curacao, with its small economy, of great importance. Being aware of the pollution in the Schottegat and reduce it as much as possible would be a starting point. From that point it is possible to invest in the preservation of the other reefs of Curacao.

For Saint Lucia it is a little too early to give recommendations besides to be aware of the first signs. The chlorophyll α concentrations are as alarming as for Curacao.

Overall recommended is to continue the nutrient monitoring program within the cooperation between the three islands and if possible to expand to other islands as well. In that case all islands do get a clear view of trends in the Caribbean Sea and predict the possible future situation with continuous pollution. A very important note is to include fish counts according the same method, preferable the Bohnsack method, so the macroalgae growth can both be related to nutrient pollution and decline in grazing activities. Table 4.2 is showing the not highly polluted sites. The chlorophyll α concentrations are not significant different between Bonaire and Curacao, but the algae ratio is. That might indicate the importance for the fish count once again.

Picture 4.2. Enjoying the coral reefs
For a continuation of enjoying and learning from the coral reefs on Bonaire and Curacao well management and political support is needed. On this picture is Mark Wieggers together with a Dutch tourist exploring the reefs of Curacao (by De Boer, 2007).

References

Literature

- **Allen**, C.J., 2005. Grizmek's Student Animal Life Resource. Corals, Jellyfishes, Sponges and Other Simple Animals. Tomson Gale, Farmington Hills, MI, United States of America.
- **Aronson**, R.B. and W.F. Precht, 2006. Conservation, precaution, and Caribbean reefs. Coral Reefs, 25: 441-450.
- **Baird**, A.H., S.J. Campbell, A.W. Anggoro, R.L. Ardiwijaya, N. Fadli, Y. Herdiana, T. Kartawijaya, D. Mahyiddin, A. Mukminin, S.T. Pardede, M.S. Pratchett, E. Rudi and A.M. Siregar, 2005. Acehnese Reefs in the Wake of the Asian Tsunami. Current Biology, Vol. 15, 1926–1930.
- **Bak**, R.P.M., 1977. Coral Reefs and Their Zonation in Hetherlands Antilles. American Association of Petroleum Geologists Studies in Geology. American Association of Petroleum Geologists, Tulsa, Oklahoma, pp. 3/16.
- **Bak**, R.P.M. and G. Nieuwland, 1995. Long-term Change in Coral Communities along Depth Gradients over Lewaard Reefs in the Netherlands Antilles. Bulletin of Marine Science, 56 (2): 609-619.
- **Bak**, R.P.M., G.Nieuwland, E.H. Meesters, 2005. Coral reef crisis in deep and shallow reefs: 30 years of constancy and change in reefs of Curacao and Bonaire. Coral Reefs, 24: 475-479.
- **Baker**, A.C., G.J. Strager, T.R. McClanahan and P.W. Glynn, 2004. Corals' adaptive response to climate change. Nature, Vol. 430, 12 August 2004.
- **Barile**, P.J. and B.E. Lapointe, 2005. Atmospheric nitrogen deposition from a remote source enriches macroalgae in coral reef ecosystems near Green Turtle Cay, Abacos, Bahamas. Marine Pollution Bulletin 50 (2005) 1262–1272.
- **Bhairo-Marthé**, S.K. and J. Van Dijk, 1996. The influence of the Schottegat at the southern coastal water qulity of Curacao (Draft). Caribbean Consulting Engineers & DHV Consultants, Project name: Kustwateronderzoek, Project no.: 245-461.
- **Bries**, J.M., A.O. Debrot and D.L. Meyer, 2004. Damage to the leeward reefs of Curaçao and Bonaire, Netherlands Antilles from a rare storm event: Hurricane Lenny, November 1999. Coral Reefs, 23: 297-307.
- **Buddemeier**, R.W., J.A. Kleypas and R.B. Aronson, 2004. Coral reefs and global climate change: Potential contributions of climate change to stresses on coral reef ecosystems. Pew Centre for Global Climate Change: Arlington, United States of America, 33 pp.
- **Burke**, C.D., T.M. McHenry, W.D. Bischoff, E.S. Huttig, W. Yang and L. Thorndyke, 2004. Coral mortality, recovery and reef degradation at Mexico Rocks Patch Reef Complex, Northern Belize, Central America: 1995-1997. Hydrobiologia 530/531: 481-487.
- **Cervino**, J., T.J. Goreau, I. Nagelkerken, G.W. Smith and R. Hayes, 2001. Yellow band and dark spot syndromes in Caribbean corals: distribution, rate of spread, cytology, and effects on abundance and division rate of zooxanthellae. Hydrobiologia 460: 53-63.
- **Constanzo**, S.D., M.J. O'Donohue, W.C. Dennison, N.R. Loneragan and M. Thomas, 2001. A New Approach for Detecting and Mapping Sewage Impacts. Marine Pollution Bulleting, volume 42, no. 2.
- **Cumming**, R.L., 1999. Predation on reef-building corals: multiscale variation in the density of three corallivorous gastropods, Drupella spp. Coral Reefs (1999) 18 : 147-157.
- **De Boer**, B., D. Hoogerwerf, I. Kristensen and J. Post, 1994. Antillean Fish Guide. Netherlands Antilles Parks Foundation. STINAPA no. 7.
- **De Meyer**, K., 2004. Island Adrift. Scuba Vision Films.
- **Debrot**, A.O. and L.P.J.J. Pors, 1995. Sea Turtle Nesting Activity on Northeast Coast Beaches of Curacao, 1993. Cartbbean Journal of Science, Vol. 31, No. 3-4, 333-338, 1995.
- **Dornelas**, M., S.R. Connolly and T.P. Hughes, 2006. Coral reef diversity refutes the neutral theory of biodiversity. Nature, Vol. 440, 2 March 2006.
- **Fabricius**, K.E. and J. Metzner, 2004. Scleractinian walls of mouths: predation on coral larvae by corals. Coral Reefs (2004) 23: 245–248.

- **GCRMN** (Global Coral Reef Monitoring Network), 2004. Status of Coral Reefs of the World: 2004 Volume 1. Australian Institute of Marine Science, 2004 ISSN 1447-6185.
- **Grimsditch**, G.D. and R.V. Salm, 2006. Coral Reef Resilience and Resistance to Bleaching. IUCN: Gland, Switzerland. 52 pp.
- **Goldberg**, J. and C. Wilkinson, 2004. Ch. 1. Global Threats to Coral Reefs: Coral Bleaching, Global Climate Change, Disease, Predator Plagues and Invasive Species. In: Status of Coral Reefs of the World: 2004 Volume 1. Australian Institute of Marine Science: Townsville, Queensland, Australia.
- **Grigg**, R.W.J. and S.J. Dollar, 2004. Anthropogenic and Natural Stresses on Selected Coral Reefs in Hawai'i: A Multidecade Synthesis of Impact and Recovery. Pacific Science, Vol. 58, Issue 2, pp. 281-304.
- **Hallock**, P., 2005. Global change and modern coral reefs: New opportunities to understand shallow-water carbonate depositional processes. Sedimentary Geology, Vol. 175, Issue 1-4, pp. 19-33.
- **Hawkins**, J.P., C.M. Roberts, T. Van 't Hof, K. De Meyer, J. Tratalos and C. Aldam, 1999. Effects of Recreational Scuba Diving on Caribbean Coral and Fish Communities. Conservation Biology, Vol. 13, Issue 4, pp. 888-897.
- **Hoegh-Guldberg**, O., 1999. Climate change, coral bleaching and the future of the world's coral reefs. Greenpeace: Sydney (Australia), 28 pp.
- **Hughes**, T.P., 1994. Catastrophes, Phase Shifts, and Large-Scale Degredation of a Caribbean Coral Reef. Science, New Series, Vol. 265, No. 5178, pp. 1547-1551.
- **Humann**[1], P., N. DeLoach, 2002. Reef Coral Identification – Florida Caribbean Bahamas. New World Publications, Inc. Jacksonville (Florida), United States of America.
- **Humann**[2], P., N. DeLoach, 2002. Reef Creature Identification – Florida Caribbean Bahamas. New World Publications, Inc. Jacksonville (Florida), United States of America.
- **Humann**, P, N. DeLoach, 2003. Reef Fish Identification – Florida Caribbean Bahamas. New World Publications, Inc. Jacksonville (Florida), United States of America.
- **IPCC** (Intergovernmental Panel on Climate Change), 2001. Climate Change 2001: The Scientific Basis: Contribution of Working Group I to the Third Assessment Report of the IPCC. Eds. Cambridge University Press: Cambridge, United Kingdom, 881 pp.
- **Kohler**, K.E. and S.M. Gill, 2006. Coral Point Count with Excel extensions (CPCe): A Visual Basic Program for the Determination of Coral and Substrate Coverage Using Random Point Count Methodology. Computers & Geosciences 32 (2006) 1259-1269.
- **Lang**, J., 1970. Jacques Cousteau – Mysteries of the Hidden Reefs. The Cousteau Society, Inc. and Amaya.
- **Lapointe**, B.E., 1997. Nutrient Threshold for Bottom-Up Control of Macroalgal Blooms on Coral Reefs in Jamaica and Southeast Florida. Limnology and Oceanography, Vol. 42, No. 5, Jul., 1997, 1119-1131.
- **Lapointe**, B.E. and K. Thacker, 2002. Chapter 35 Community-Based Water Quality and Coral Reef Monitoring in the Negril Marine Park, Jamaica: Land-Based Nutrient Inputs and Their Ecological Consequences. From; The Everglades Florida Bay and Coral Reefs of the Florida Keys – An Ecosystem Sourcebook. CRC Press, Washington D.C., United States of America.
- **Lapointe**, B.E., P.J. Barile and W.R. Matzie, 2004. Anthropogenic nutrient enrichment of seagrass and coral reef communities in the Lower Florida Keys: discrimination of local versus regional nitrogen sources. Journal of Experimental Marine Biology and Ecology: 308 (2004) 23-58.
- **Lapointe**, B.E., P.J. Barile, M.J. Wynne and C.S. Yentsch, 2005. Reciprocal Caulerpa Invasion: Mediterranean native Caulerpa ollivieri in the Bahamas supported by human nitrogen enrichment. Aquatic Invaders, volume 16, number 2.
- **Littler**, M.M. and D.S. Littler, 1984. Models of tropical reef biogenesis: the contribution of algae. In: F.E. Round and D.J. Chapman, Editors, Progress in Phycological Research vol. 3, Biopress, Bristol, pp. 323–364.
- **Littler**, D.S. and M.M. Littler, 2000. Caribbean Reef Plants. OffShore Graphics, Inc. Washington, D.C., United States of America.

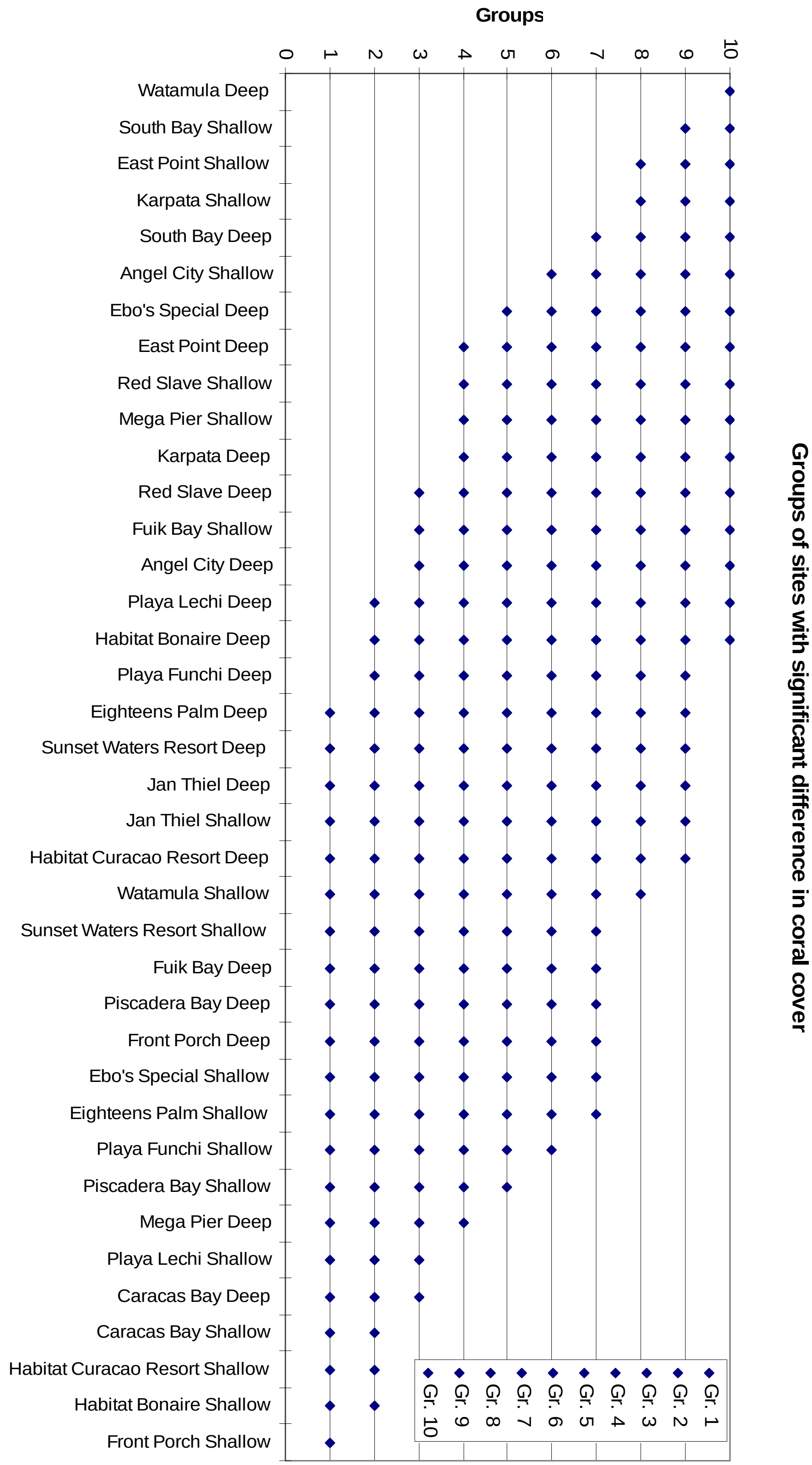
- **Liu**, P.L.-F., P. Lynett, H. Fernando, B.E. Jaffe, H. Fritz, B. Higman, R. Morton, J. Goff and C. Synolakis, 2005. Observations by the International Tsunami Survey Team in Sri Lanka. Science, Vol. 308 Issue 5728, p1595-1595, 1p.
- **Madin**, J.S. and S.R. Connolly, 2006. Ecological consequences of major hydrodynamic disturbances on coral reefs. Nature, Vol. 444, 23 November 2006.
- **Nagelkerken**, I., K. Vermonden, O.C.C. Moraes, A.O. Debrot and W.P. Nagelkerken, 2005. Changes in coral reef communities and an associated reef fish species *Cephalopholis cruentata* (Lacépède), after 30 years on Curacao (Netherlands Antilles). Hydrobiologia, 549: 145-154.
- **NOAA** (National Oceanic and Atmospheric Administration), 2006. http://www.cop.noaa.gov/ecosystems/coralreefs/current/cres-micro-factsheet-cr.html visited: September 2006.
- **Obura**, D., 2005. Resilience and climate change: Lessons from coral reefs and bleaching in the West Indian Ocean. Estuarine, Coastal and Shelf Science.
- **Ostrander**, G.K., K. Meyer Armstrong, E.T. Knobbe, D. Gerace and E.P. Scully, 2000. Rapid transition in the structure of a coral reef community: The effects of coral bleaching and physical disturbance. Proceedings of the National Academy of Science of the United States of America, Vol. 97, No. 10, pp. 5297-5302.
- **Pearce**, F., 2003. Extinction looms for Caribbean ‘rainforest of the oceans’. New Scientist, Vol. 179, Issue: 2405, pp. 9.
- **Pockley**, P., 1999. Global warming ‘could kill most coral reefs by 2100’. Nature, Vol. 400, 8 July 1999.
- **Pockley**, P., 2000. Global warming identified as main threat to coral reefs. Nature, Vol. 407, 26 October 2000.
- **Project AWARE Foundation**, 2004. Ten Ways a Diver Can Protect the Underwater Environment. Product No. 19200 (Rev. 9/04) Ver. 3.0.
- **Ramos-Scharron**, C.E. and L.H. MacDonald, 2007. Development and application of a GIS-based sediment budget model. Journal of Environmental Management, Vol. 84, Issue 2, pp. 157-172.
- **ReefBase**, 2006. http://reefgis.reefbase.org/mapper.asp Visited at 2006-12-20.
- **ReefKeeper International**, 2001. Curacao Reef Monitoring Update, November 2001.
- **Roberts**, C.M., 1997. Connectivity and Management of Caribbean Coral Reefs. Science, New Series, Vol. 278, No. 5342, pp. 1454-1457.
- **Smith**, R.L. and T.M. Smith, 1998. Elements of Ecology Fourth Edition. United States of America, New York: The Benjamin/Cummings Publishing Company, Inc.
- **Stewart**, D., 2004. Island Adrift. Scuba Vision Films.
- **Stewart**, B., 2006. Our Ocean Planet Oceanography in the 21st Century. Web-based textbook available on: http://oceanworld.tamu.edu/resources/oceanography-book/whystudytheoceans.htm visited: September 2006.
- **Van Duyl**, F.C., 1985. Atlas of the Living Reefs of Curaçao and Bonaire (Netherlands Antilles).
- **Van Veghel**, M.L.J. and P.C. Hoetjes, 1995. Effects of Tropical Storm Bret on Curacao Reefs. Bulletin of Marine Science, 56 (2): 692-694.
- **Waldman**, M. and Y. Shevah, 2000. Biological Diversity - An Overview. Water, Air, and Soil Pollution 123: 299–310, 2000.
- **West**, J.M. and R.V. Salm, 2003. Resistance and resilience to coral bleaching: Implications for coral reef conservation and management. Conservation Biology 17, 956-967.
- **Wiebe**, W.J., R.E. Johannes and K.L. Webb, 1975. Nitrogen Fixation in a Coral Reef Community. Science, Vol.188, No. 4185, pp. 257-259.
- **Wilkinson**, C., 2004. Status of Coral Reefs of the World: 2004 Volume 1. Australian Institute of Marine Science: Townsville, Queensland, Australia.
- **Wilkinson**, C., D. Souter and J. Goldberg, 2006. Status of Coral Reefs in Tsunami Affected Countries: 2005. Australian Institute of Marine Science: Townsville, Queensland, Australia.

- **Woodley**, J.D., E.A. Chornesky, P.A. Clifford, J.B.C. Jackson, L.S. Kaufman, N. Knowlton, J.C. Lang, M.P. Pearson, J.W. Porter, M.C. Rooney, K.W. Rylaarsdam, V.J. Tunnicliffe, C.M. Wahle, J.L. Wulff, A.S.G. Curtis, M.D. Dallmeyer, B.P. Jupp, M.A.R. Koehl, J. Neigel and E.M. Sides, 1981. Hurricane Allen's Impact on Jamaican Coral Reefs. Science, Vol. 214, Issue: 4522, pp. 749-755.
- **Zar**, J.H., 1999. Biostatistical Analysis (Fourth Edition). Prentice-Hall, Inc., New Jersey, United States of America.

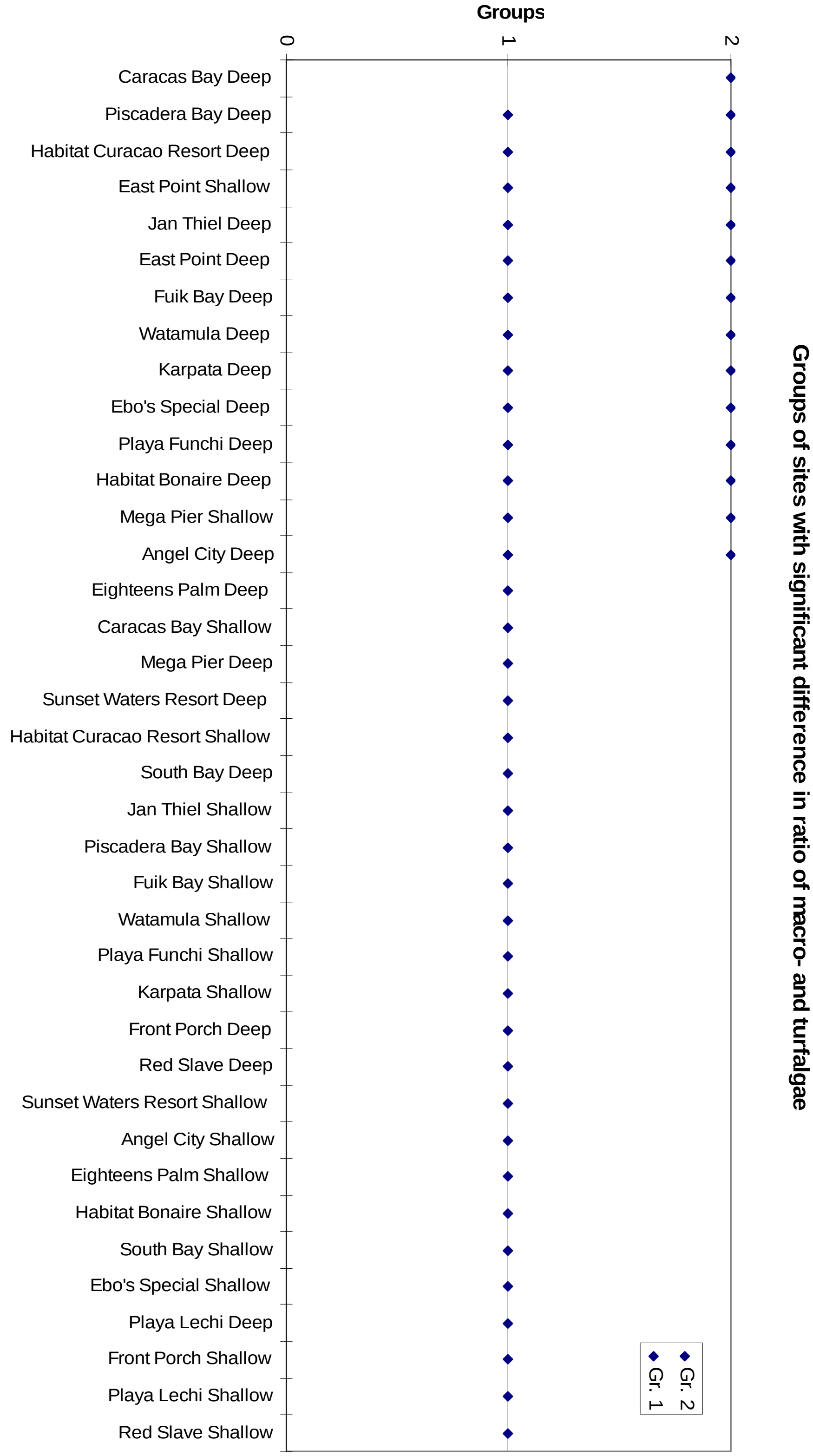
Pictures

Page

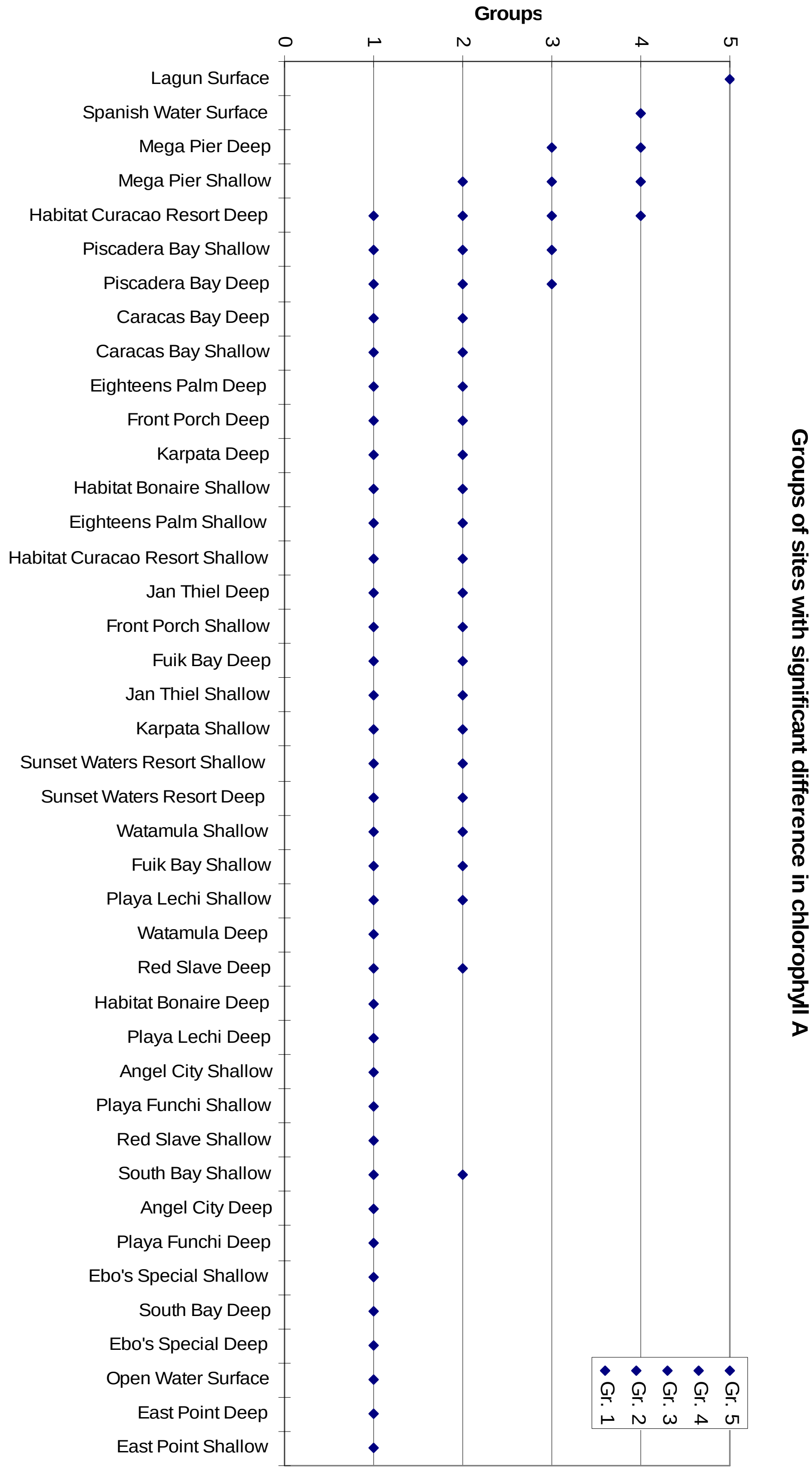
Graph. Groups of Sites with Significant Differences in Coral Cover
Ten different groups presenting the outcome of the Tukey test. The locations are in order of cover percentage from highest to lowest.



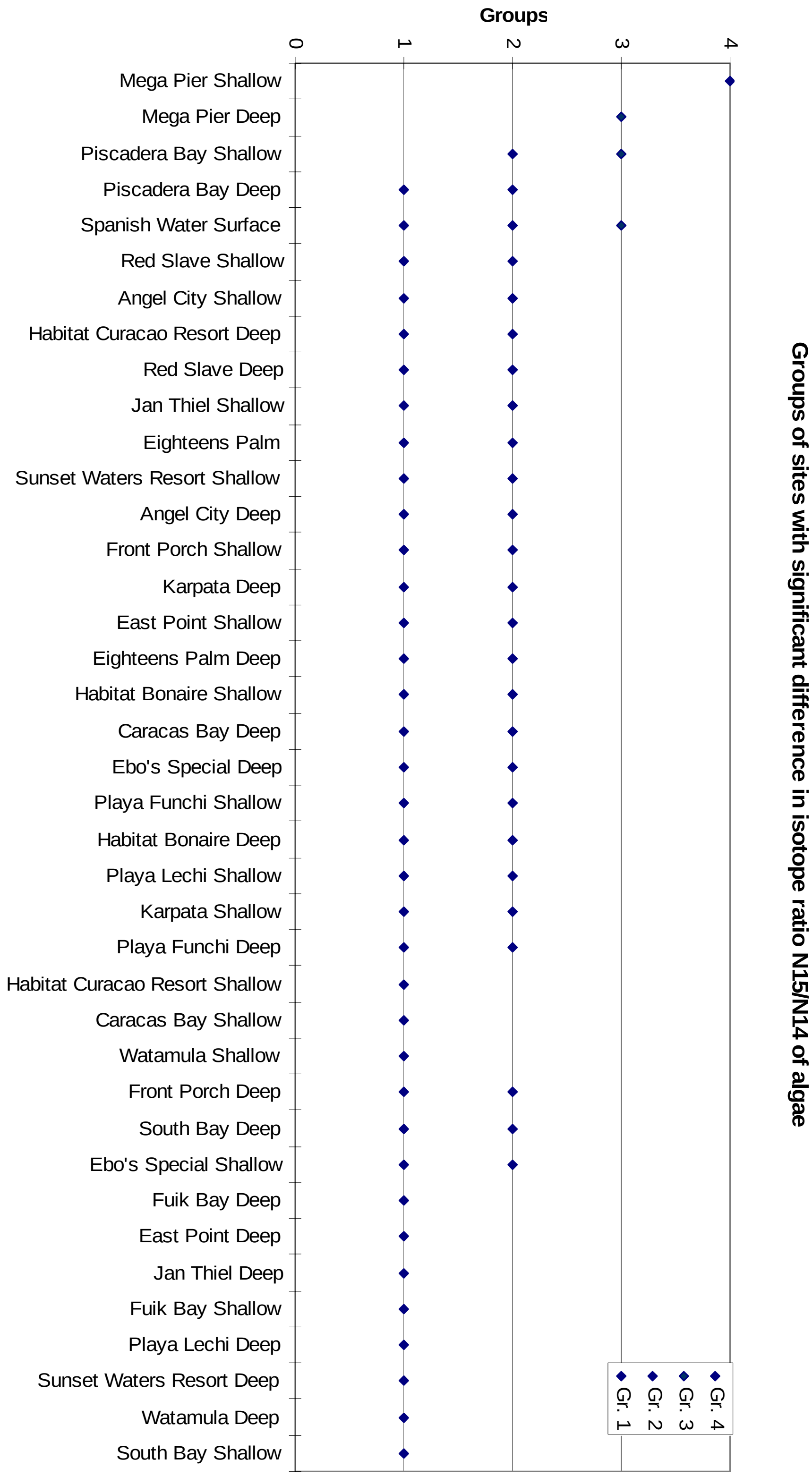
Graph. Groups of Sites with Significant Differences in Ratio of Macroalgae and Turf Algae
Two different groups presenting the outcome of the Tukey test. The locations are in order of cover percentage from highest to lowest.



Graph. Groups of Sites with Significant Differences in Chlorophyll *α*
Five different groups presenting the outcome of the Tukey test. The locations are in order of cover percentage from highest to lowest.

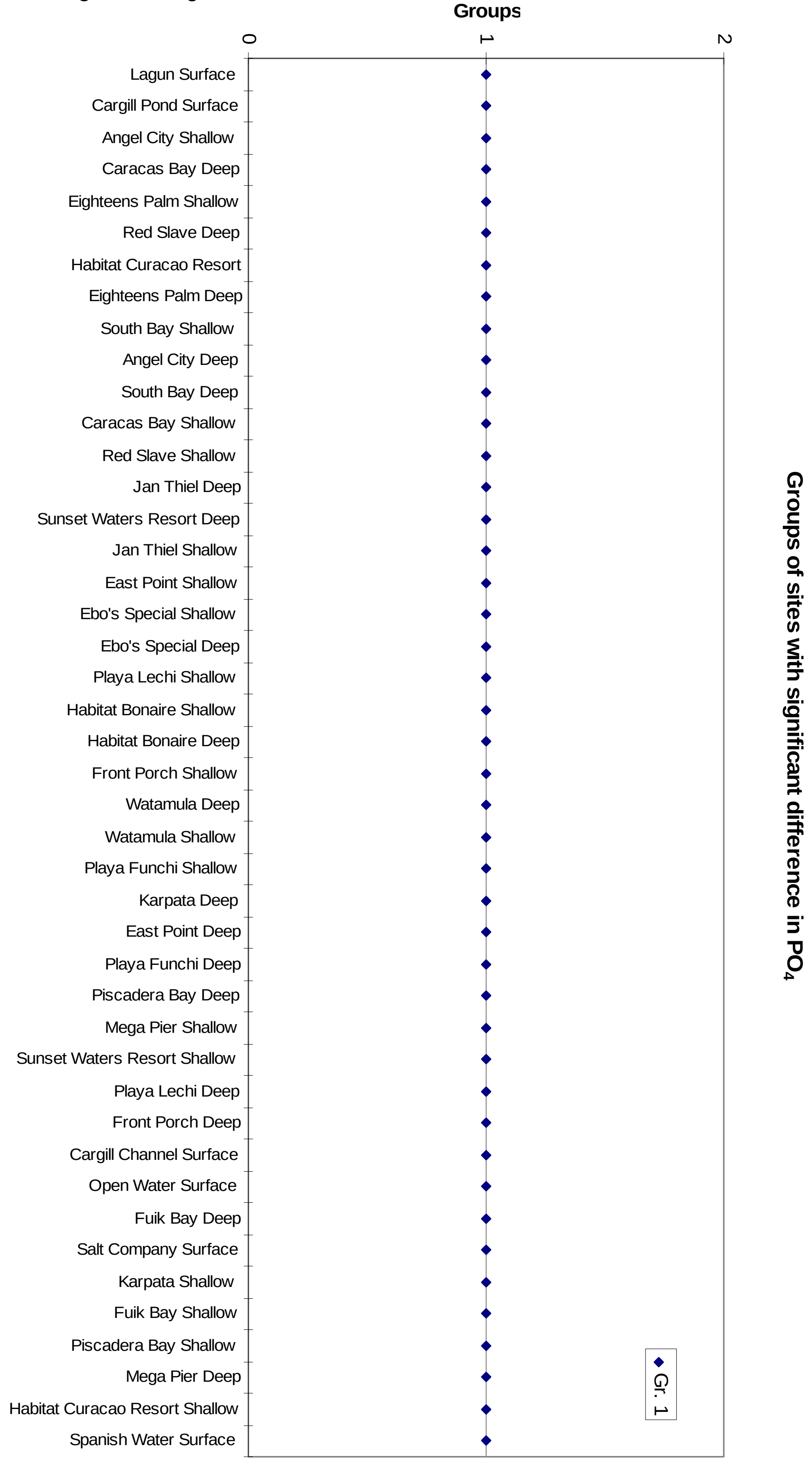


Graph. Groups of Sites with Significant Differences in Isotope ratio $^{15}N/^{14}N$ of Algae
Four different groups presenting the outcome of the Tukey test. The locations are in order of cover percentage from highest to lowest.

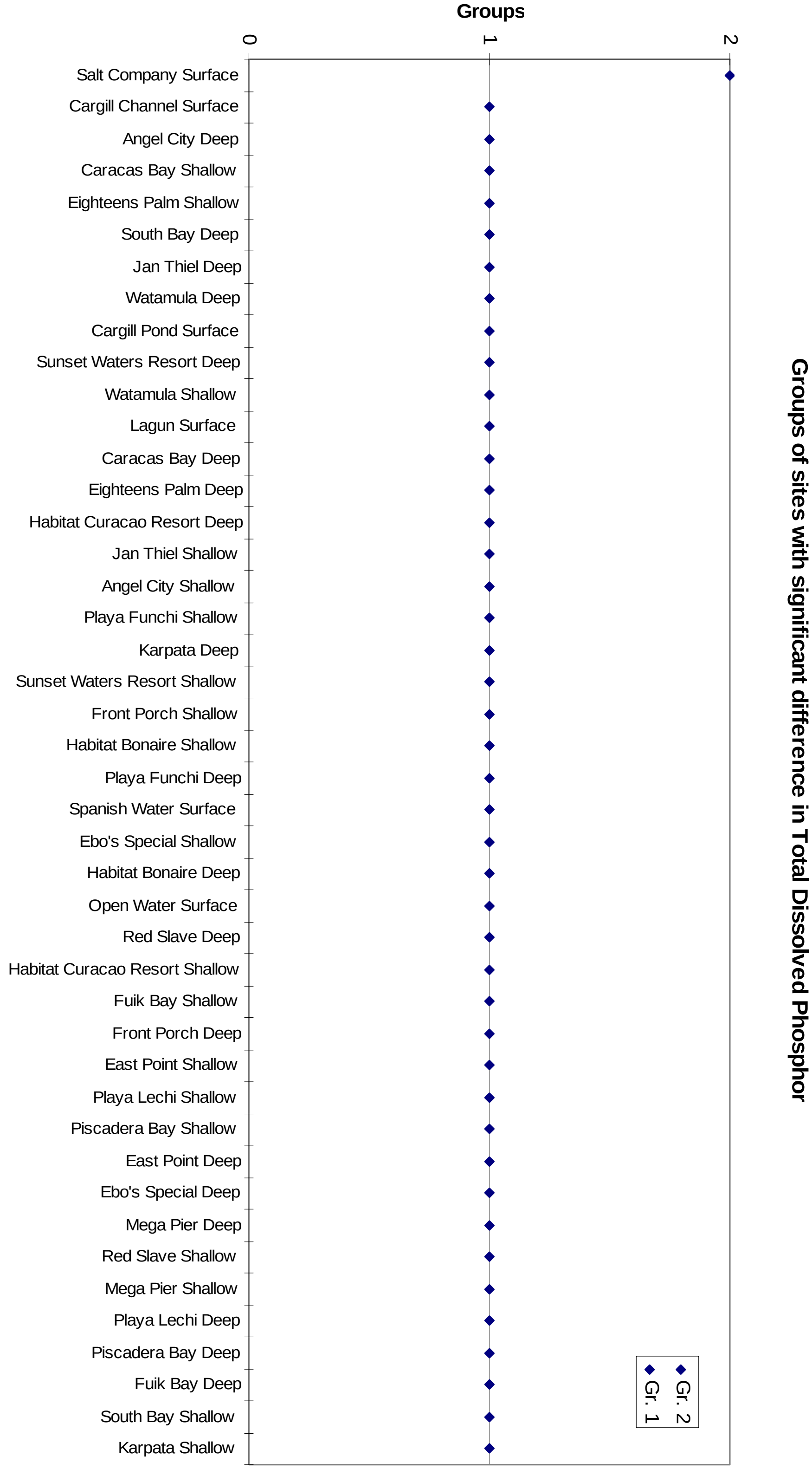


Graph. Groups of Sites with Significant Differences in PO_4

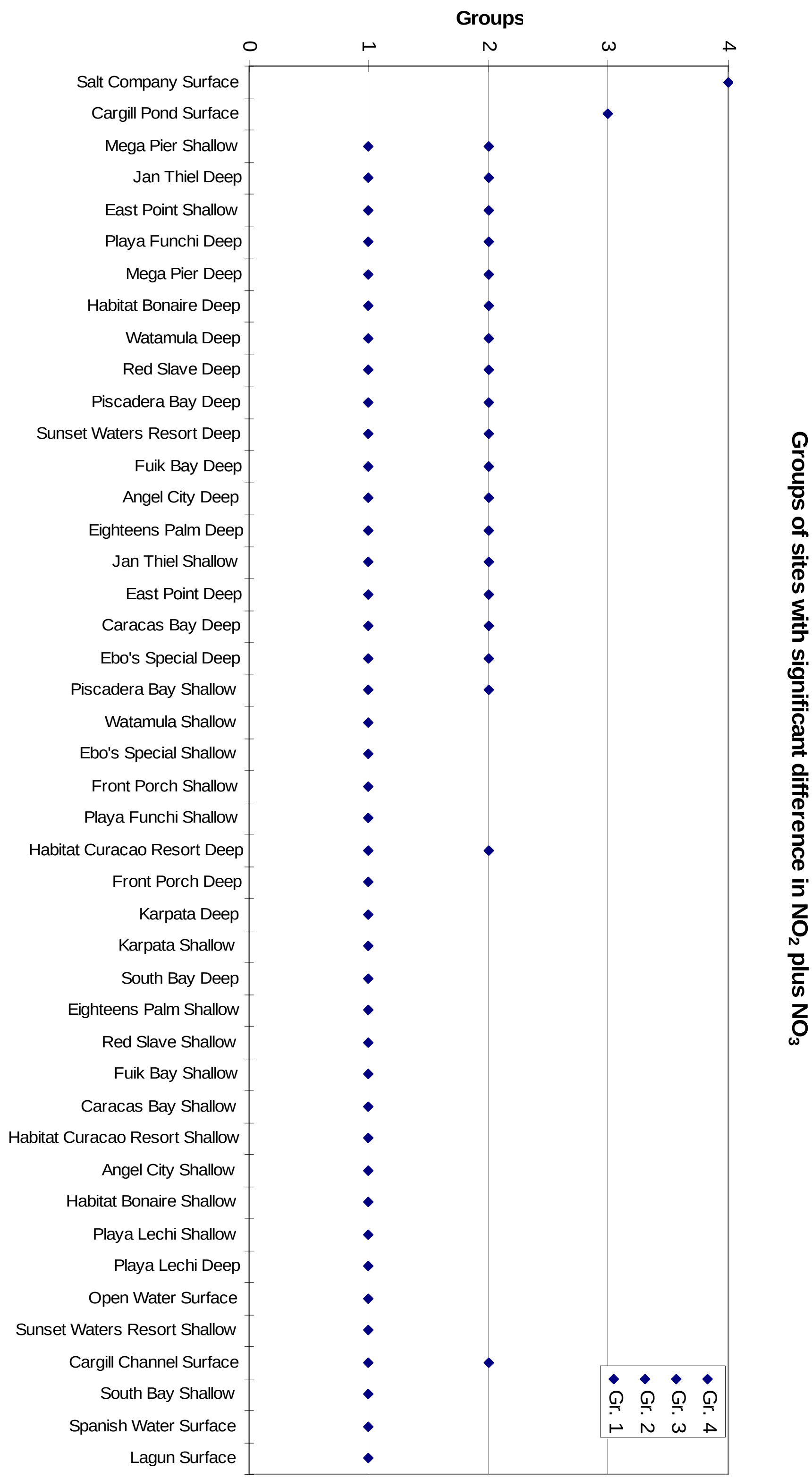
One group presents the outcome of the Tukey test. The locations are in order of cover percentage from highest to lowest.



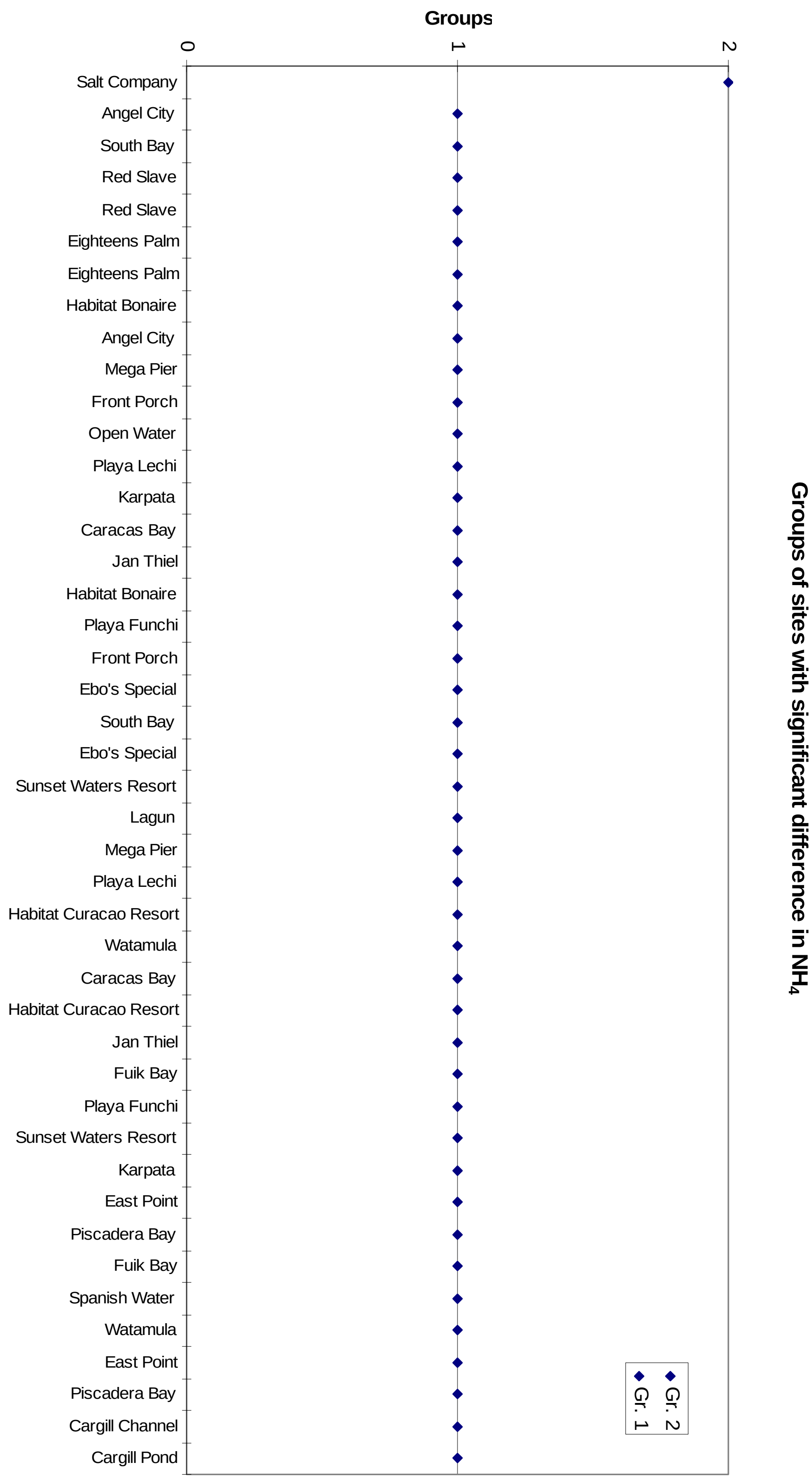
Graph. Groups of Sites with Significant Differences in Total Dissolved Phosphor
Two groups presenting the outcome of the Tukey test. The locations are in order of cover percentage from highest to lowest.



Graph. Groups of Sites with Significant Differences in NO_2 plus NO_3
Four groups presenting the outcome of the Tukey test. The locations are in order of cover percentage from highest to lowest.



Graph. Groups of Sites with Significant Differences in NH_4
Two groups presenting the outcome of the Tukey test. The locations are in order of cover percentage from highest to lowest.



Graph. Groups of Sites with Significant Differences in Dissolved Inorganic Nitrogen
Two groups presenting the outcome of the Tukey test. The locations are in order of cover percentage from highest to lowest.