

Spatial and size distribution of Queen Conch (*Lobatus gigas*) veligers in relation with ocean surface currents in Lac Bay, Bonaire

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Preface

Sometimes, when you are lucky, life smiles at you and presents to you an opportunity you cannot refuse. For me luck came to me after a meeting on research topics in Bonaire, where Klaas Metselaar told me about the Queen Conch restoration project of STINAPA. This project turned out to be exactly what I had hoped for. The only problem was: I had to find myself a partner willing to go with me. Luck kept smiling at me though. As I attended a lecture after the meeting I came to sit next to Ineke Willemse whom I told about the Conch restoration project and the fact that I needed to find a partner in crime. While we talked I suddenly realised that this supposedly hard to find partner was right in front of me.

Ineke and I did our research in collaboration with STINAPA as part of the Queen Conch restoration project. This project works on restoring the population of Queen Conch in Bonaire and raises awareness with the locals considering the importance of conserving this species.

Hereby I would like to thank everyone that made my time in Bonaire both possible and amazing.

First of all: Ineke Willemse. Thank you so much for an awesome time! For snorkelling, diving and laughing together, for our porch moments and our occasional nightly shutting of the panels to prevent us from raining out of bed. I also want to thank you for motivating me while writing my report and for your input when I got stuck. Asking you to join me was the best decision I could have ever made!

Secondly I would like to thank our supervisor in Bonaire: Sabine Engel. Thanks for all the time you have spent with us, for picking us up from the airport, for showing us around the island, and for your critical thinking concerning our research. My other supervisors Rudi Roijackers and Klaas Metselaar also deserve special thanks. Rudi thanks for your realistic but sometimes sceptical views, for reviewing my report, and for helping me get through my rough patch. Klaas Metselaar thank you for your enthusiasm and for constantly bouncing ideas of me that helped me determine the right research path.

Additionally I want to thank Ramon de Léon for providing the research facilities (car and house) and the possibility to work in collaboration with STINAPA. I would like to thank Rita Peachey for providing us with the lab facilities of CIEE; Graham Epstein, Rachel Wright, Abi and Franziska for both assisting us in the lab and for making the days in the lab fun (gangnam style... Remember?). I would also like to thank the staff of Dive Friends Bonaire, especially Frank, Eunan and Suus for their patience and for teaching us how to dive. Furthermore, I would like to thank Jeroen Goud for providing me with the right fixation techniques for veligers, and Edwin Peeters for assisting me with statistics.

Gevy Soliana: Thank you for always steering the boat in the right direction, for making sure our research was performed correctly, for fishing, for laughing together, for teaching me Papiamento (mi nota gusta hopi cangreu), and for making Ineke and me feel safe while diving; knowing you snorkelled above us keeping an eye out was a really secure feeling.

I want to thank the rangers from WSNP for always making us feel welcome when we got home, for fixing the car whenever it was broken, for helping us out whenever something in our house wasn't working e.g. with the toilet (yes guys, we are girls: we are not that technical ☺). Thank you Ruthsel, Clifford, Henry, Johny, Cultura (George), George, and Nestor.

Thanks to Fabian, Ruben and Fonsjie for making it possible to perform plankton samples in the open ocean towards Las Aves Archipelago. Thanks Funchi for the fun we had while cutting mangroves.

And thanks to our roommates: Lotte, Iris, Tatiana and Vinni. Living together at Casa Scientifica was great fun!

Summary

Since the 1970s the demand for Queen Conch (*Lobatus gigas*) meat increased due to the growth of tourism. This resulted in the collapse of the fisheries on this species and in CITES taking the species up in their Appendix II. Despite the various regulations little recovery was noticed. Fishery on the Queen Conch in Bonaire has been reduced since the 1930s and is prohibited in the present. Even though there are regulations against fishing, poachers still harvest this species. One of the problems, next to overfishing, is that harvested conchs get younger every year. Because veligers of the Queen Conch do not actively swim they are dependent on ocean currents for their dispersal. It is hereby that veligers can be transported for hundreds of kilometres resulting in the possible dependency of the Queen Conch population of Lac Bay on distant larval sources. Bonaire is located in downstream currents from Los Roques, Venezuela. Therefore there is a possibility that the majority of Bonaire's Conch population may originate from sources in that direction. So where do veligers in Lac Bay come from? How many are present? Where are the veligers located? And what is the influence of ocean currents on their dispersal? Plankton was collected by using a conical plankton net with a mesh size of 200µm and with a diameter of 0.5m. Samples were taken at the surface. After towing samples were fixated by either a 4% formaldehyde-seawater solution or a 96% ethanol solution. Veligers were located and identified microscopically. Before identification took place veligers were divided in four size classes: 200-300 µm, 300-600µm, 600-900 µm, and >900 µm to help determine their origin. However, identification was difficult therefore an additional group was introduced: the cf. veligers. Additionally the direction of the surface currents and the flow of currents below the direct surface of Lac Bay were determined. The plankton samples that were taken in Lac Bay provided data on the occurrence of Queen Conch veligers and their spatial and size distribution throughout the bay and in the direction of Las Aves Archipelago. Surface currents data provided insights in the velocity and direction of currents that ran through the bay. Veligers found during this study ranged from 0.0 to 0.00035 individuals per litre. Veligers in the smallest size classes were most abundant, which could mean that the source of the veligers is in the close vicinity of Lac Bay. Additionally, veligers were more abundant around the reef possibly due to the fact that Queen Conch forms spawning aggregations near reef tracts, in addition phototaxis might have played a role. What the effect is of currents on the dispersal of Queen Conch veligers has to be further determined by performing more research.

Introduction

General introduction

The Queen Conch (*Lobatus gigas* Linnaeus 1758 known until 2008 as *Strombus gigas*) is a large (up to 30 cm shell length) well studied marine gastropod found throughout the Caribbean (Stoner and Smith, 1998, Castro et al., 2009, Stoner, 2003, Stoner and Ray, 1996, Schweizer and Posada, 2006). The flesh of the conch has been a food source in this area for hundreds of years, while the shells were used for ballast, tools, building, jewellery and decoration (Davis, 2005). Since the 1970s however, the international demand for the meat increased due to the growth of tourism in the Caribbean (Berg, 1976). This resulted in the collapse of the fisheries on this species (Engel, 2008). The species used to be the second most valuable benthic fisheries species in the Caribbean (McCarthy, 2007) with fisheries on spiny lobster being number one (Davis, 2005). Due to a decline in the population of Queen Conch the species was enlisted as commercially threatened in 1985 by the Convention on the International Trade in Endangered Species (CITES). However declines persisted and therefore the Queen Conch was put in Appendix II of CITES in 1992 (McCarthy, 2007, Stoner, 2003, Stoner and Ray, 1996). Appendix II requires nations to monitor exports and manage conch stocks closely (McCarthy, 2007), it lists species that are not necessarily threatened with extinction now but that may become so unless trade is closely controlled [1]. Despite that the estimated harvest value of Queen Conch in 1992 was \$30 million (McCarthy, 2007). By 2003 most Caribbean countries implemented the CITES regulations (Castro et al., 2009), but despite those various regulations little recovery has been noticed (Stoner, 2003). In 1976 prices for Queen Conch were approximately \$2 per kilogram (Berg, 1976). In 2005 however, Queen Conch meat had a value of up to \$30 per kilogram with prices continuing to increase as the conch stocks are more and more threatened (Davis, 2005). The increasing prices for landed conchs resulted in fisherman exclusively fishing on the Queen Conchs (Schweizer and Posada, 2006). Therefore overfishing is the primary cause for the decline in population. Although habitat degradation might also be a factor, especially the loss of important nursery habitats close to the shore plays an important role (Davis, 2005).

Life cycle of the Queen Conch

The Queen Conch is a native species in the tropical waters of the Caribbean region (Abbot, 1974 in Stoner and Ray, 1996). It is the largest of the six conch species that inhabit the shallow seagrass beds and the deeper parts of the reefs of the Caribbean (Davis, 2005). The Queen Conch is dioecious, meaning the species has distinctive male and female sexes (McCarthy, 2007, Davis, 2005). It has a year round reproduction with a peak during the summer months, i.e. June to September (Castro et al., 2009, Aranda and Pérez, 2007). After 3-5 days the eggs hatch (Stoner and Davis, 1997) and the veligers start living in the top 5 meters of the water column where they drift passively on ocean surface currents (Stoner and Ray, 1996) and feed on phytoplankton for 2 to 5 weeks (Stoner, 2003, Stoner and Ray, 1996, Stoner and Smith, 1998). After hatching the veliger is roughly 300µm in shell length and has two velar lobes (fig. 1). These lobes split into four after five days and have divided into six

lobes by the eight day. The lobes are used for locomotion, respiration and feeding on phytoplankton (Davis, 2005).

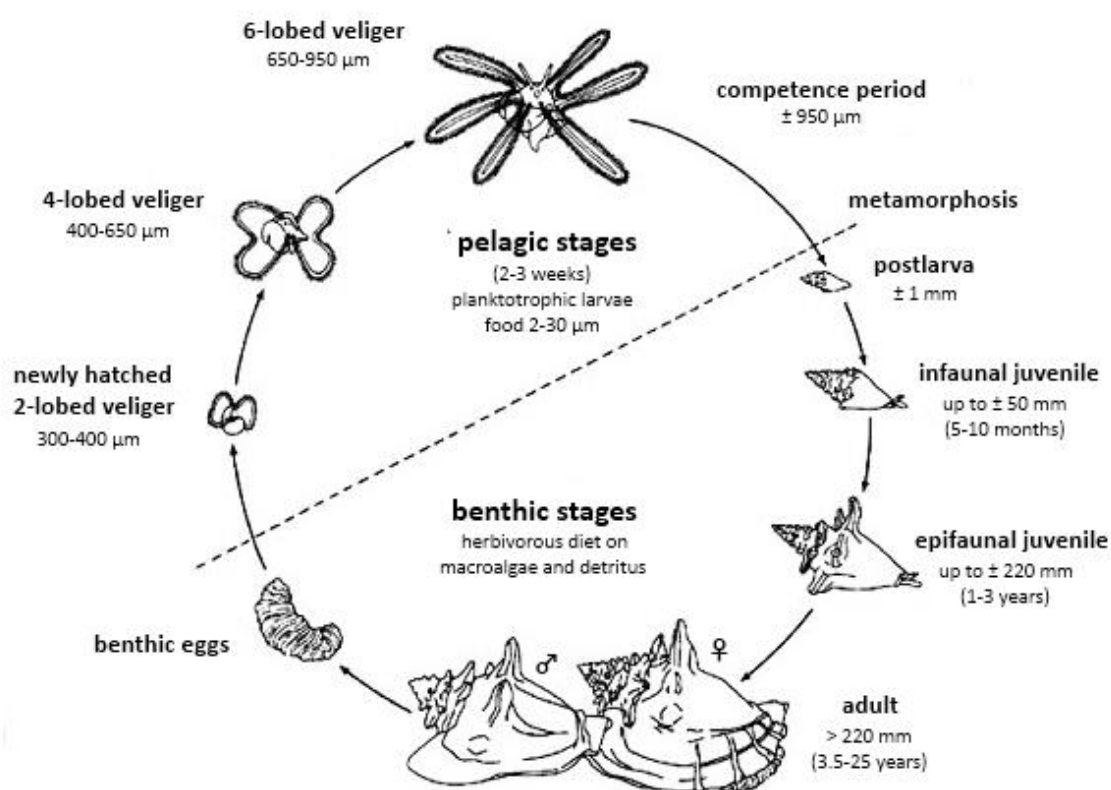


Figure 1: Life cycle of the Queen Conch (*Lobatus/Strombus gigas*) after Bower-Dennis [2] adapted by (Willemse, 2013).

The duration of this larval stage of the Queen conch is roughly 21 days (Davis, 2005). Veligers hatch with yolk reserves but start feeding after roughly 8 hours. After 21 days the veliger is ready for metamorphosis at approximately 1.2mm shell length (Davis, 2005). However, the veligers can postpone their physical change for more than 60 days until a suitable habitat is encountered (Stoner, 2003). Positive phototaxis and negative geotaxis keep veligers at the surface of the water column thereby enhancing their dispersion, as ocean surface currents are fastest at the surface. These phenomena decrease with age (Barile et al., 1994) so when veligers are ready for metamorphosis and they encounter a suitable habitat (i.e. substrates that provide high rates of post-settlement growth) they settle to the benthos (Stoner, 2003). Once settled juvenile Queen Conchs remain infaunal (i.e. buried in the sand) for most of their first year (Stoner et al., 1988). Thereafter the juveniles emerge in seagrass beds (Stoner et al., 1988, Davis, 2005). Queen Conch individuals migrate to deeper waters as they age (Stoner et al., 1988). The individuals live in waters generally less than 75 meters deep but are commonly found in waters no deeper than 30 meters. It is likely that conchs are limited to that depth because of seagrass and algae cover (McCarthy, 2007). After reaching sexual maturity, i.e. the conch has formed a flaring lip with a thickness of 8 to 12 mm (personal

communication Engel, 2013), the adults return to shallow inshore waters (Stoner et al., 1988) and form spawning aggregations near reef tracts (Davis, 2005). After (internal) fertilization has taken place the females lay their eggs on patches of bare sand (McCarthy, 2007). The adult Queen Conch has a hardened tip (the operculum) at the end of the foot, which propels it forward. The eyes are highly developed and are located on the tips of two protruding stalks. The Queen Conch is estimated to have a life span of 25 years (Davis, 2005).

Research area

Lac Bay is the largest shallow lagoon in The Netherlands Antilles and it is located at the southeast coast of Bonaire (N 12°07'35.6'', S 12°05'30.3'', W 068°14'30.3'', and E 068°12'51.1'') (Lott, 2001). The entire area of Lac, including the surrounding mangrove forests is roughly 3.9 km from north to south and 3.0 km from east to west. Of this the water surface covers approximately 7.5 km² of the Bay (van Moorsel and Meijer, 1993).

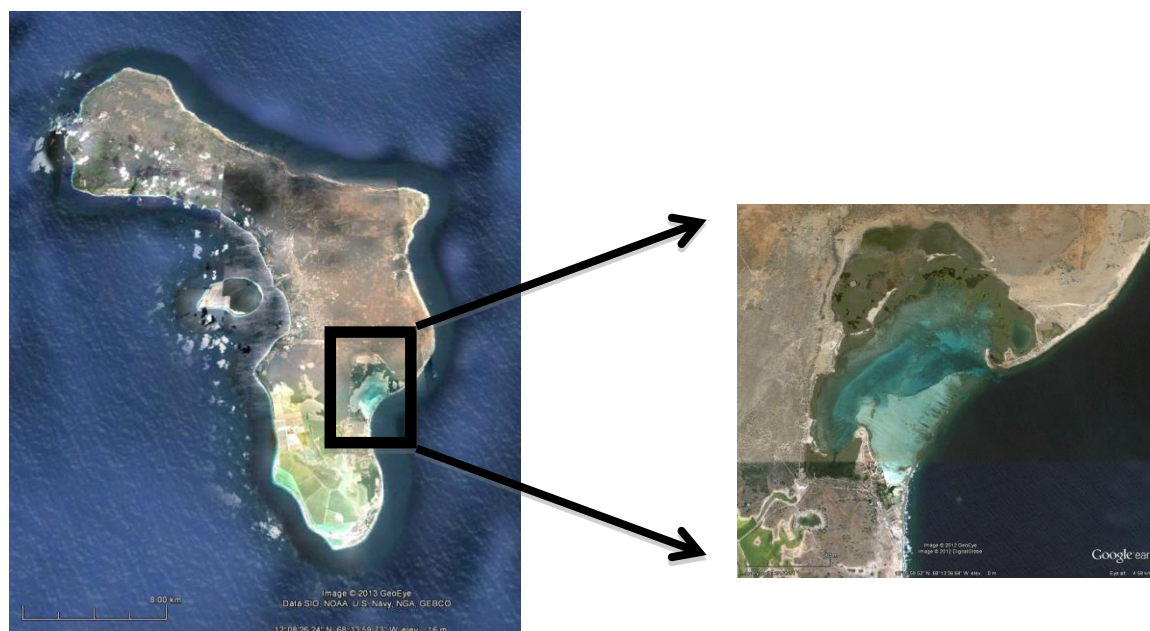


Figure 2: Bonaire, Netherlands Antilles, in the enlargement a detailed map of Lac Bay is depicted.

The bay has an open connection to the sea (fig. 2) and is exposed to the eastern trade winds (Lott, 2000). The main basin of Lac is composed of a clear water shallow bottom lagoon with seagrass beds, mixed macro-algae meadows and bare patches of sand (Lott, 2000). A fringing reef extends from across the channel at Cai (north-eastern tip of Lac Bay) to the south-eastern part (Sorobon) of Lac (Engel, 2008) with coral patches situated in the shallower high energy wave zone (Lott, 2000). Since 1970 Lac Bay has been a RAMSAR site (Lott, 2000).

The bay has historical importance to Bonaire since it has been an important food source for the Bonairian people (Lott, 2001). Next to that the expansive seagrass beds are considered to be suitable nursery habitats for Queen Conchs (Lott, 2001) as well as juvenile reef fishes since they provide food and shelter against predators (Nagelkerken et al., 2000). Additionally, the vast sea grass beds of Lac Bay provide food for sea turtles (Nava, 2011).

Situation in Bonaire, Netherlands Antilles

According to Wagenaar Hummelinck and Roos (1969) the conch fishery in Bonaire has been reduced since the 1930s. Engel (2008) additionally states that the Queen Conch fisheries collapsed in 1969 and is virtually non-existent in the present. In Bonaire, Netherlands Antilles, harvesting Queen Conch is prohibited. Even though there are regulations against fishing this species, poachers harvest the flesh of this mollusc (Engel, 2008). The major problem in Bonaire is that harvested conchs get younger every year, with most of them not having formed a flared lip, meaning they have not reached sexual maturity yet (Engel, 2008). Because veligers do not actively swim they are dependent on ocean currents for their dispersal (Stoner and Davis, 1996 in Stoner and Ray, 1996, Stoner and Smith, 1998). It is hereby that veligers can be transported for hundreds of kilometres meaning the Queen Conch populations can depend on distant larval sources (Barile et al., 1994, Aranda and Pérez, 2007). According to Lott (2000) Bonaire is located in downstream currents from Los Roques, Venezuela, hereby indicating the possibility that the majority of Bonaire's Conch population may originate from Los Roques.

The present study will address this issue. According to Davis (2005) nursery grounds are commonly less than 6 meters deep. As it is, Lac Bay has a maximum depth of 5 meters and it has suitable benthic components for a nursery habitat of Queen Conch (Lott, 2000), therefore it might be an excellent nursery ground for the species.

The main question this report will try to answer is: What is the larval dispersal of the Queen Conch (*Lobatus gigas*) in Lac Bay, Bonaire and how do ocean currents influence this dispersal? The following questions will result in answering this:

- Where do the veligers in Lac Bay come from?
- How many veligers are present in Lac Bay? Where are they located?
- What is the influence of currents on the dispersal of veligers in Lac Bay?

Methodology

Veligers

Plankton samples were taken at eight sites situated in Lac Bay during the expected peak of the spawning season of the Queen Conch (i.e. July – October 2012). The sites were chosen randomly (fig. 3). For reason of comparison 6 additional samples were taken outside Lac Bay in the direction of Las Aves Archipelago (i.e. Isla Aves), Venezuela (fig. 4).

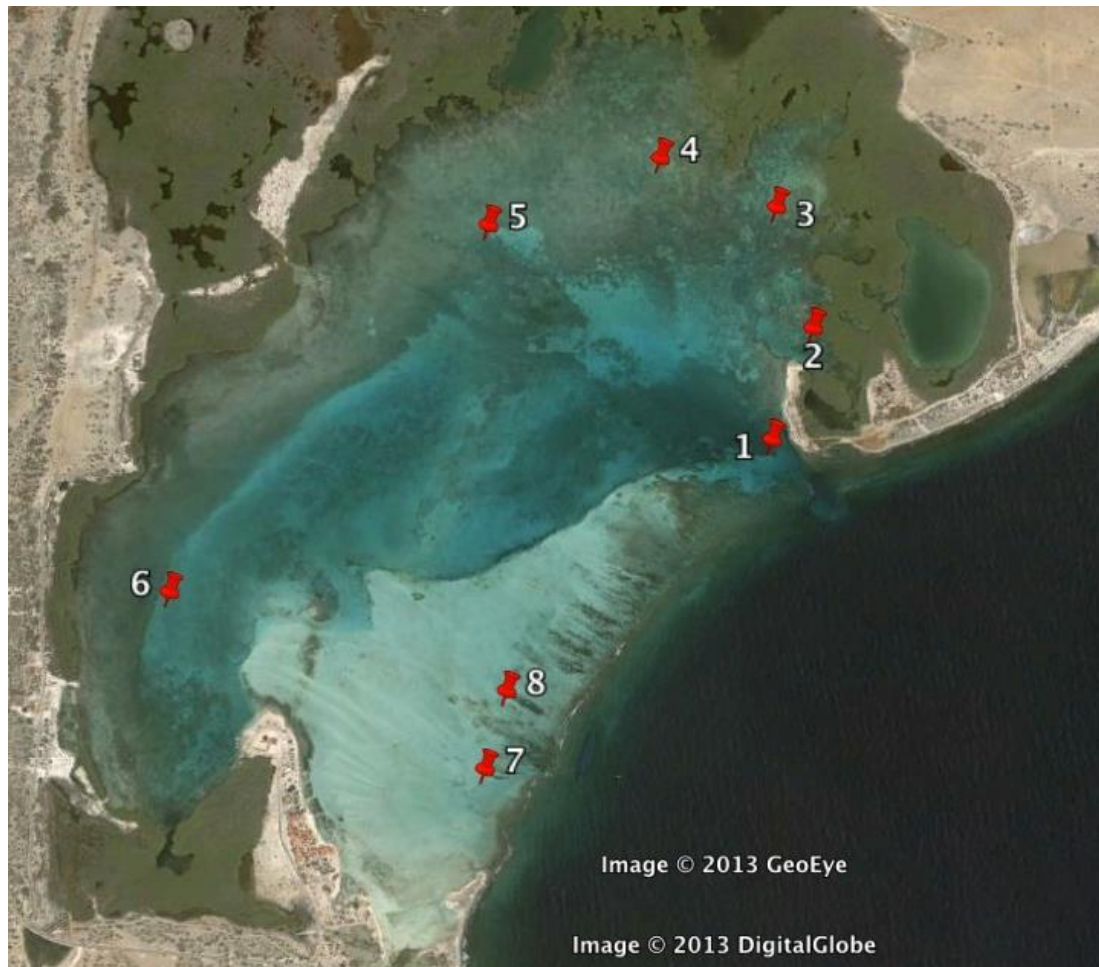


Figure 3: Sites chosen for plankton tows in Lac Bay, Bonaire (Google Earth 6.2.2.7373, 2013). For GPS coordinates of the sites see Appendix I.

Plankton was collected by towing a conical plankton net (200 μm mesh, 0.5m in diameter) behind the boat for approximately 15 minutes at a speed of roughly three to four km/h. Exceptions to this method were site 7 & 8. Because these sites were in shallow waters, the net needed to be towed next to the boat and held by hand to prevent damaging it.

Situated in the mouth of the net was a flow meter that was later used to calculate the volume of water that was filtered. Samples were taken at the surface based on Stoner and Davis (1997), i.e. in the top meter of the water column.

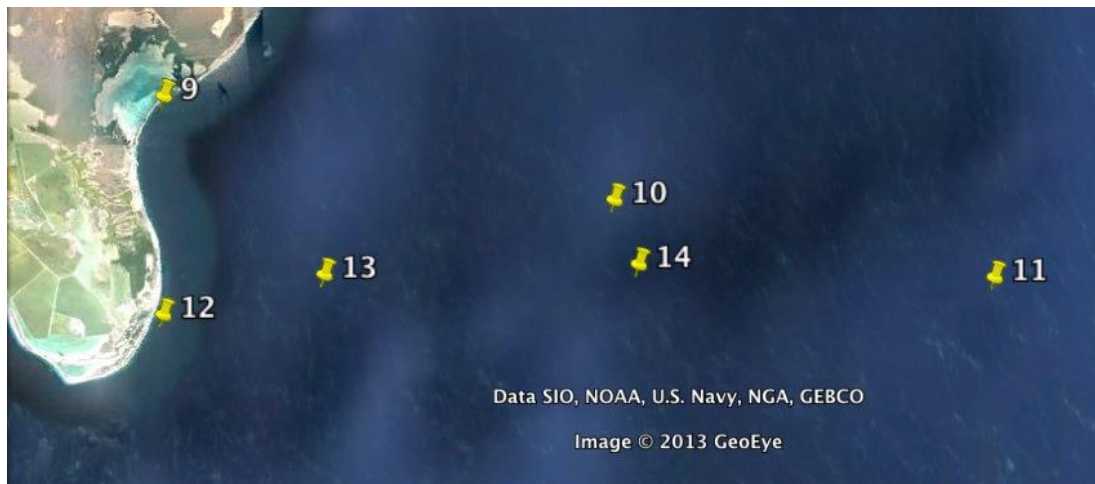


Figure 4: Sites chosen in the direction of Las Aves Archipelago, Venezuela (Google Earth 6.2.2.7373, 2013). For GPS coordinates of the sites see Appendix I.

The plankton net was towed in a circle around 4 buoys that were 30m apart from one another, with the exception of site 1 since it was too deep to place buoys. After retrieving the net from the water the sample was sieved so it would only contain organisms $>200\ \mu\text{m}$, and put in a jar. Thereafter samples were fixated in two solutions; 50% of the samples were fixated in 96% ethanol, which made genetic analysis possible (not part of this research); the other half of the plankton samples was fixated in a 4% formaldehyde-seawater solution, which is better for long term fixation and preservation of the larvae and reduces morphological distortion (Black, 2003, Goswami, 2004).

Formaldehyde preservation took place on site while the samples that needed to be preserved in ethanol were taken to the lab where veligers were separated from the seawater by sieving (explained below) and fixated in 96% ethanol.

This procedure was repeated twice for all the sites in Lac Bay over a time span of 3 months (from August till the end of October 2012) and resulted in 8 duplicate samples (indicated in the results as 1.1, 1.2, 2.1, 2.2, etc.) from Lac Bay and 6 additional single samples outside the bay, i.e. in the direction of Las Aves Archipelago, Venezuela.

The plankton tows taken in the direction of Las Aves Archipelago were taken over a short distance.

Once the samples were taken into the lab a microscopic search for veligers was conducted. Veligers were located by using a magnification of 4, identified by using a magnification of 10, and counted by using a counting chamber. The veligers were identified according to Davis et al. (1993). Before identification took place the samples were put through 4 sieves with mesh sizes of $900\ \mu\text{m}$, $600\ \mu\text{m}$, $300\ \mu\text{m}$ and $200\ \mu\text{m}$. Thus, veligers were put in four different size classes: veligers between $200\text{--}300\ \mu\text{m}$ (I), $300\text{--}600\ \mu\text{m}$ (II), $600\text{--}900\ \mu\text{m}$ (III), and veligers $>900\ \mu\text{m}$ (IV). This division is expected to help determine the size and thus the potential origin of Queen Conch veligers.

However, during the microscopic search for veligers mistakes in their classification could have been made. This is due to difficulties in the identification, i.e. whether organisms were real veligers or larvae that looked like veligers. The distinction was

especially difficult with the veligers in small size classes (I and II). Therefore an additional group was introduced: the cf. veligers (figure 8). Furthermore, no lobes were found which added to the difficulty of identifying the veligers of the Queen Conch.

Lac Bay surface currents

Over a period of 3 months (August till October 2012) the direction of the surface currents of Lac Bay was determined. To do this, bright yellow watertight Otter boxes that contained a GPS device (i-gotU GT-600 USB travel-/photo blogger) and a temperature logger (TL-300: TL-BAA42715, TL-BAA42716, TL-BAA42717, TL-BAA42741) were used. Boxes were weighed down so that 95% was submersed and the top could still be seen. The boxes were set free at 9 locations in Lac: 6 at the reef edge of the Bay, 2 at the mangrove edge in the north and 1 behind the tip of Sorobon in the south of Lac (fig. 5). At the starting point wind direction (using a compass), wind speed (using the anemometer) and the time (i.e. time in) were noted. To prevent losing the equipment one person followed it in a kayak. The kayaking was done in such a way to prevent disturbing the movement of the Otter boxes; i.e. along the current, in front and slightly next to the box.

After this the tracks were exported to Google Earth (V6.2.2.7373) for analysis. Information from windfinder.com [3] was used for additional data on windspeed and direction.



Figure 5: Starting points for the surface current tracks in Lac Bay, Bonaire (Google Earth 6.2.2.7373, 2013). For the GPS coordinates see Appendix II.

Currents throughout the water column

To determine the flow of the currents below the direct surface of Lac Bay information was gathered from 52 data points, 42 of which were put as a grid over the bay (fig. 6); ten others were randomly chosen (fig. 7). These measurements were done within a time span of 2 months (i.e. September and October 2012). The distances between the grid points were 400 meters in the direction north to south, and 300 meters between northwest/ southeast oriented points.

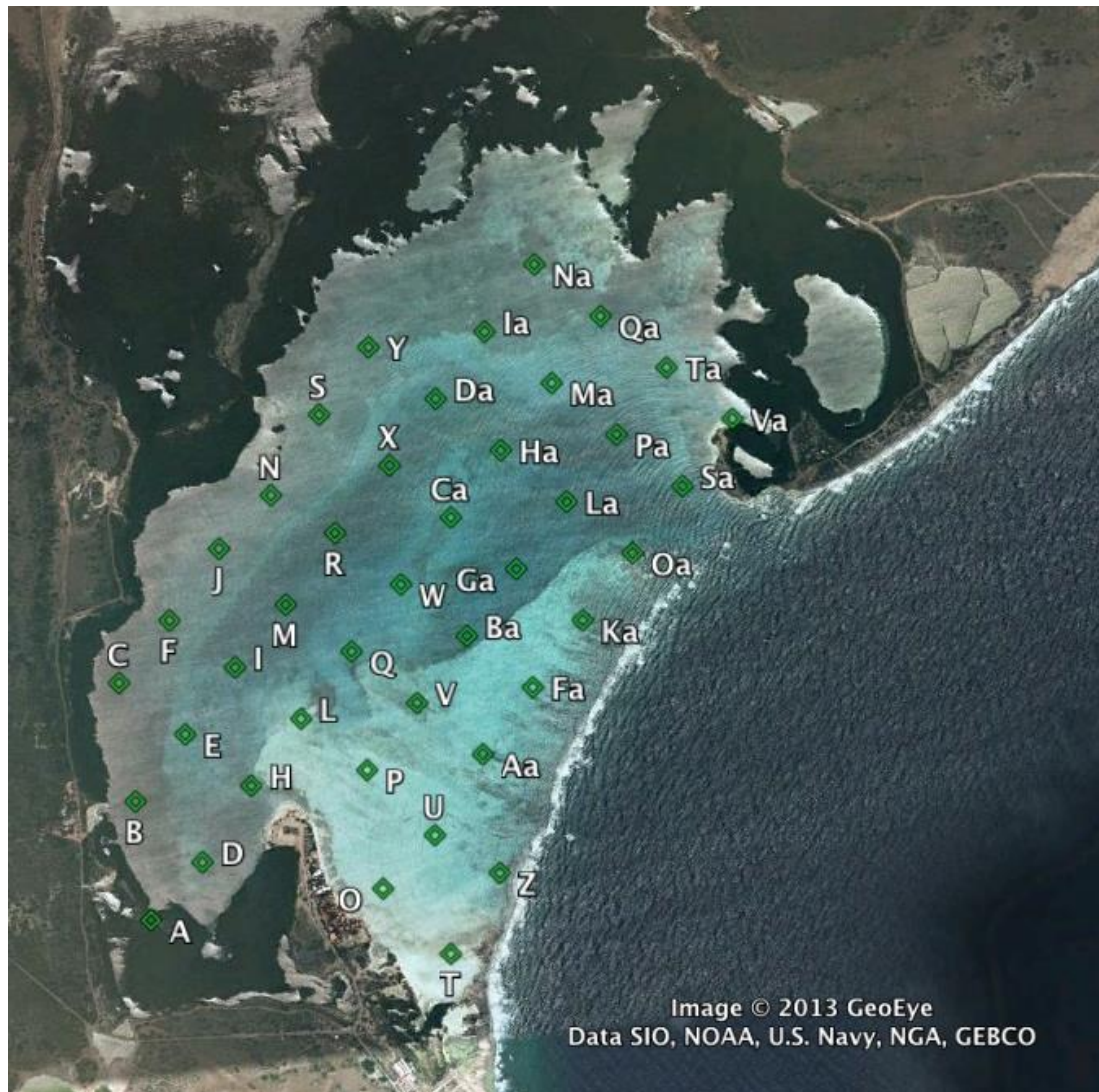


Figure 6: Grid points over Lac Bay (Google Earth 6.2.2.7373, 2013). For the GPS coordinates see Appendix III.

At each of the points the total depth of the water (depth meter: speedtech), the speed (SWOFFER model 3000) and direction (compass) of the current, and the speed (anemometer and SWOFFER) and direction (compass) of the wind was measured. To verify measured data concerning wind direction and speed windfinder.com [3] was used. Two measurements were done in water that was deeper than 1 meter, one measurement 30 cm below the surface, the other 30 cm above the bottom of Lac. When the water was 1 meter or shallower only one measurement was done, i.e. 30 cm below the surface of the bay. A diver checked the direction of the current on the

bottom by using a bright orange streamer. To keep the SWOFFER steady a cement block with a hole in it was used after the first two days of measuring. Data was saved on the SWOFFER 3000 and later processed and exported to Google Earth (V6.2.2.7373) for analysis.



Figure 7: Points chosen randomly over Lac Bay (Google Earth 6.2.2.7373, 2013). For the GPS coordinates see Appendix III.

Since there was no space in the boat for more materials and the SWOFFER was not operational yet at the dates of plankton sampling an interpolation was done for the current speed using the nearest point of the grid (i.e. with a different date). Average wind speeds and direction of the dates of plankton sampling were taken from windfinder.com [3].

This resulted in different wind velocities used in figure 18 and 19.

Statistical analysis

For the analysis Excel 2008 V12.0 (071130) for Mac was used together with SPSS for Windows (V19.0.0.1 and V20.0.0).

Regressions were performed in both programs between the amounts of veligers per litre as the dependent variable; independent variables included sample sites, time, distance to the reef, size classes, current velocity, wind velocity, and total depth of the water column. Additionally a paired T-test (see Appendix V) was performed to distinguish whether there was a significant difference in the amount of veligers found in duplicate samples, i.e. whether there was a difference between veligers found during day 1 and day 2.

Results

The plankton samples that were taken in Lac Bay provided data on the occurrence of Queen Conch veligers and their spatial (fig. 8) and size (fig. 9 and 12) distribution throughout the bay and in the direction of Las Aves Archipelago. Figure 9 shows a spatial distribution of the veligers in Lac Bay and towards Isla Aves grouped according to the major zones in the Bay, i.e. mangrove edge, the reef, and towards the direction of Las Aves Archipelago.

Lac Bays surface currents data provided insights in the velocity and direction of currents that run through the bay (Appendix II and III).

During the research period the pH of the water in Lac Bay varied between 7.2 and 8.4 (8.3 ± 0.07), the water temperature between 27.9 and 30.6 °C ($29.3^{\circ}\text{C} \pm 0.7^{\circ}\text{C}$), the salinity of the water between 32.8 and 37.3 ppt ($35.2 \text{ ppt} \pm 1.1 \text{ ppt}$), and the dissolved oxygen levels of the water were between 4.9 and 7.8 mg/L ($6.1 \text{ mg/L} \pm 0.7 \text{ mg/L}$). The wind came from the south, southeast, or east. On some occasions it came from a northern direction.

The relation between the amount of veligers per litre and their spatial distribution for Lac Bay (i.e. site 1.1-9) and Las Aves Archipelago (i.e. site 10-14) is plotted in figure 8. This is done for two groups of larvae: the ones that were classified as veligers (i.e. veligers) and the ones that were classified as larvae that look like, and thus could be, veligers (i.e. cf. veligers).

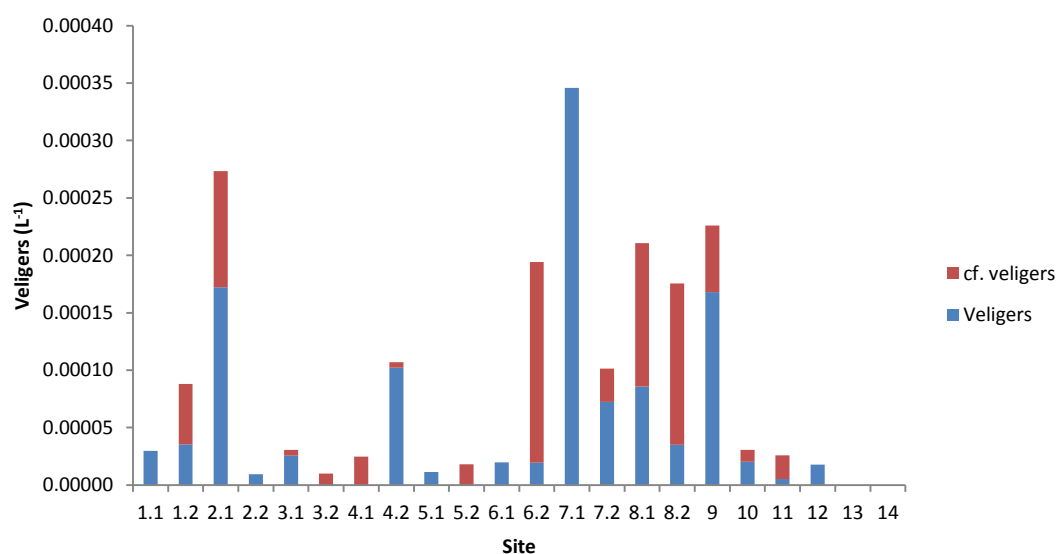


Figure 8: Spatial distribution of the total amount of veligers in Lac Bay, Bonaire. Sites 1 to 8 are situated in Lac Bay, duplicates are indicated as 1.1, 1.2, 2.1, 2.2, etc.

The spatial distribution of the four different size classes (i.e. 200-300, 300-600, 600-900 and >900 µm) is depicted in figure 9. A distinction is made in the locations where the samples were taken: the deep channel at the northern point of Lac Bay (1.1, 1.2), near the mangrove edge (2.1 – 6.2), in the proximity of the reef (7.1 – 9) and the ones taken in the direction of Las Aves Archipelago (10-14). Figure 10 also illustrates the spatial distribution of the four different size classes only in this figure the cf.

veligers are depicted. Figure 11 illustrates the number of veligers per size class at the sample sites taken in and outside Lac Bay.

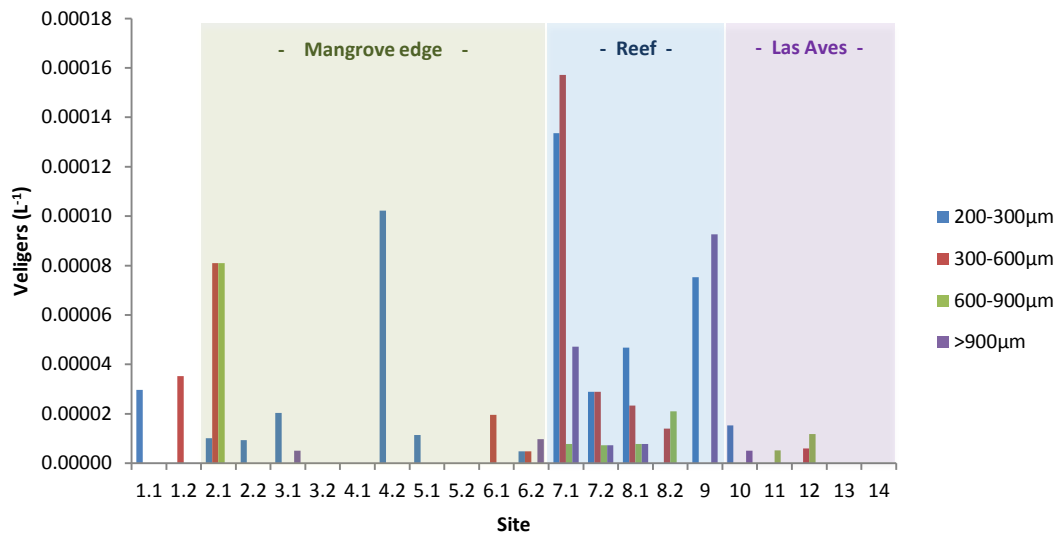


Figure 9: Size distribution of veligers/L in and outside Lac Bay, Bonaire.

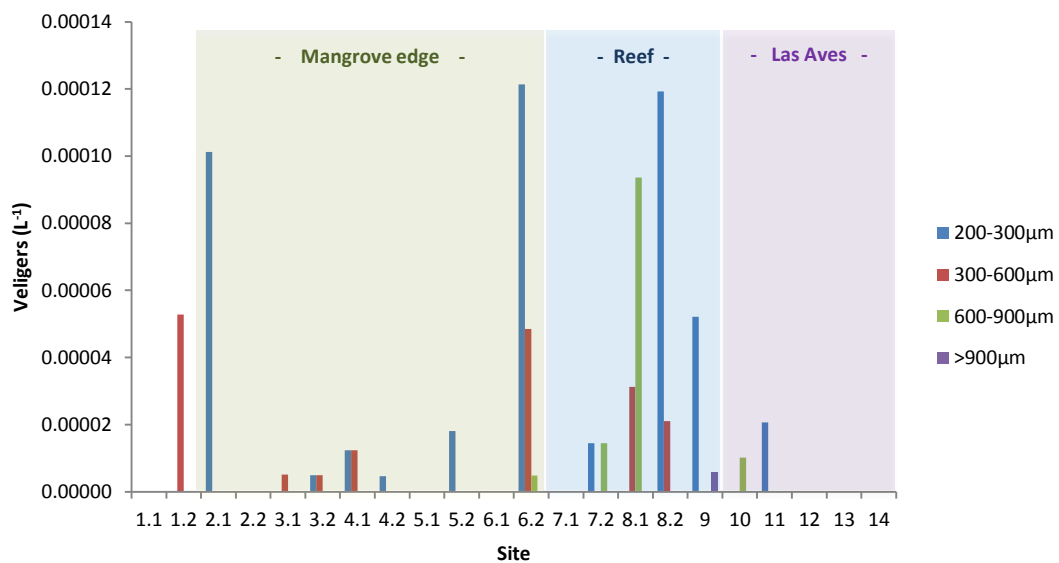


Figure 10: Size distribution of cf. veligers/L in and outside Lac Bay, Bonaire.

Figure 8 and 10 show the cf. veligers to illustrate the difficulties in classification of veligers. However, further analyses were carried out without the cf. veligers. So only 'true' veligers were taken into account in the following figures.

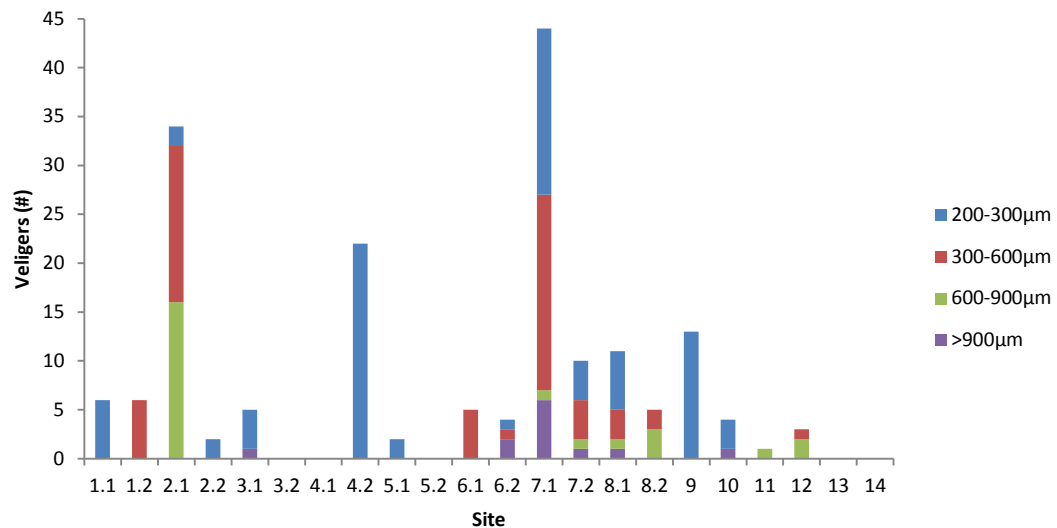


Figure 11: Number of veligers found in Lac Bay and in the direction towards Las Aves Archipelago. Numbers are depicted per size class and per site.

In order to distinguish between the abundance of veligers from different size classes in the samples taken in Lac Bay and the ones taken outside the Bay (i.e. towards Las Aves Archipelago) two different groups are shown in figure 12.

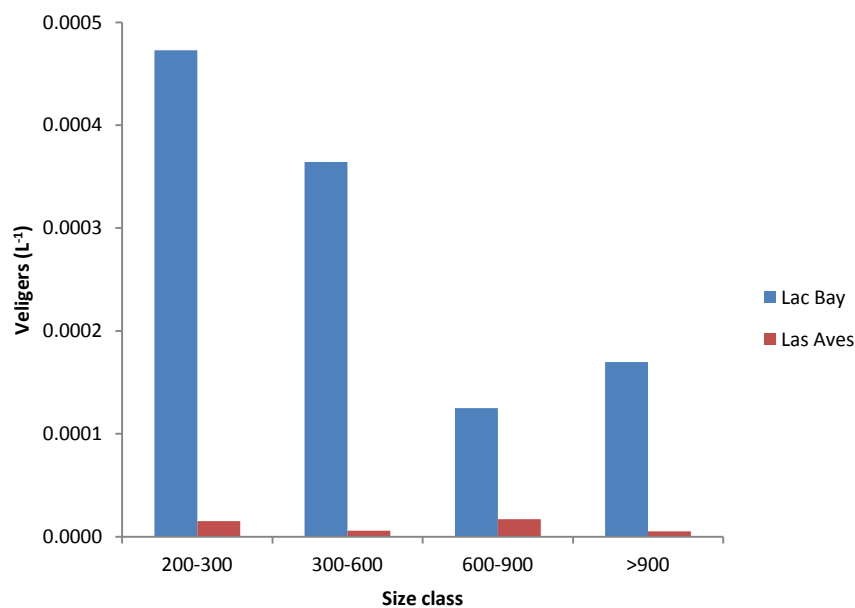


Figure 12: Abundance of veligers in different size classes. From both Lac Bay and Las Aves Archipelago.

The relation between the amounts of veligers encountered at different sampling sites is plotted against the distance to the reef (see Appendix IV for the reef reference point) in Lac Bay (fig. 13). In order to distinguish between the amount of veligers in the Bay and the amount outside the Bay, i.e. towards Las Aves Archipelago, the relations for the respective locations are given in figure 14 and 15.

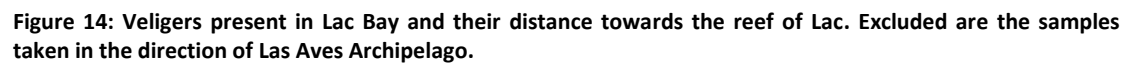
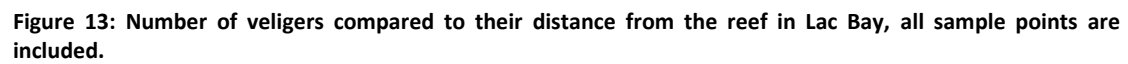


Figure 16 shows the relation between the amount of veligers encountered at the different sample sites in Lac Bay, i.e. 1.1 – 8.2 and the current velocity at the sampling sites. Current velocities were measured on different dates than plankton samples were taken (due to time and space limitations). Therefore the current velocities in figure 16 were interpolated from later measurements.

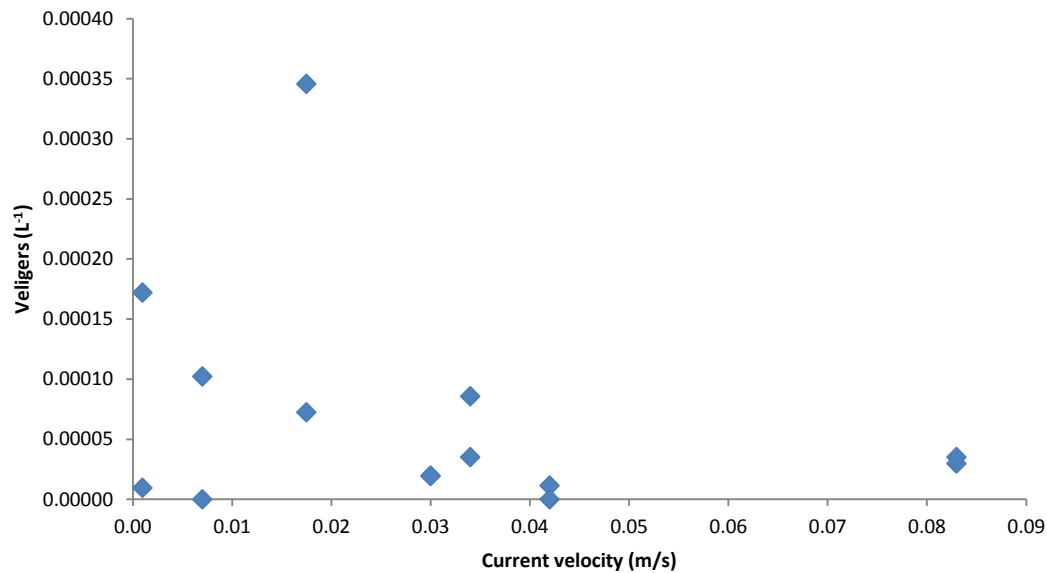


Figure 16: Amount of veligers per litre against the current velocity in Lac Bay, Bonaire.

Figure 17 illustrates the relation between the amount of veligers in Lac Bay (1.1 – 8.2) and the wind velocity at the sampling sites. Average wind velocities, from the Internet [3], belonging to the date of sampling were used.

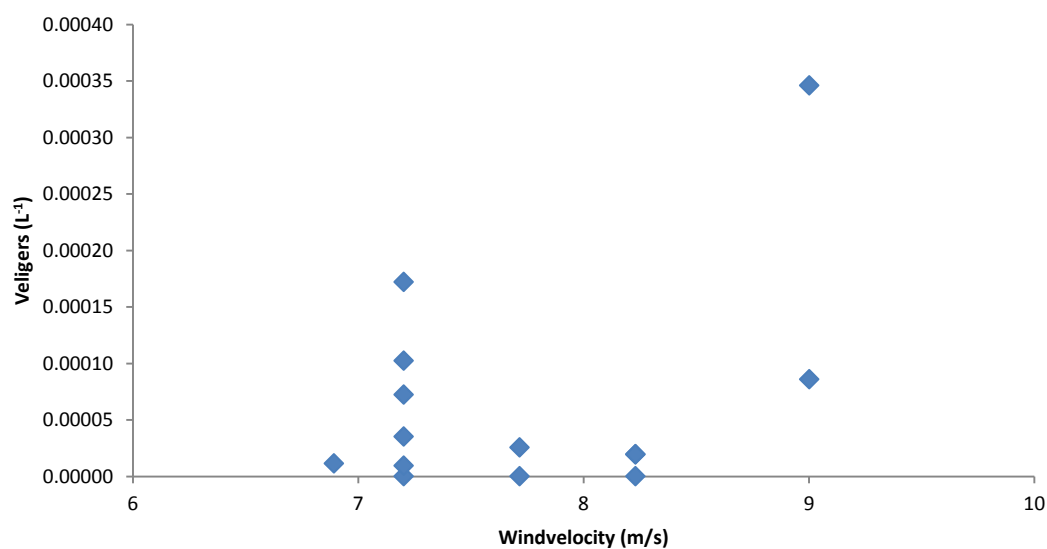


Figure 17: The amount of veligers per litre against wind velocity.

Since wind and current velocity are related figure 18 represents the relation between wind and current velocity measured at the grid points in Lac Bay. This time wind and current velocities were measured on the same day.

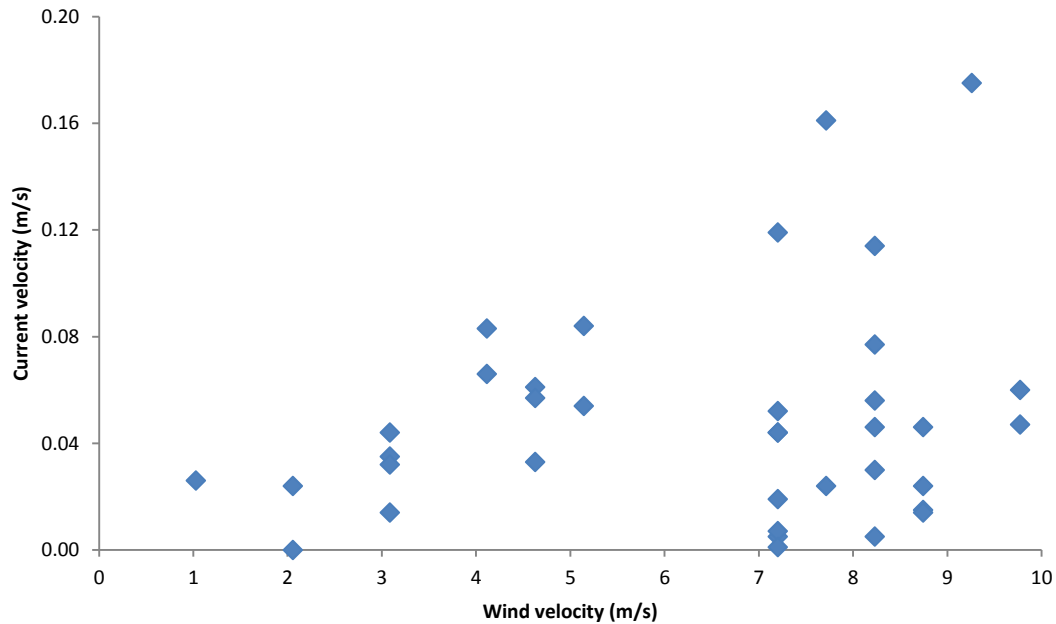


Figure 18: Relation between current velocity and wind velocity.

The relation between the amount of veligers encountered at the different sampling sites in Lac Bay and outside the Bay, i.e. towards Las Aves Archipelago, and the time at which the samples were taken is plotted in figure 19. Take into account that $T_0 = 08.00$ h at the 14th of August.

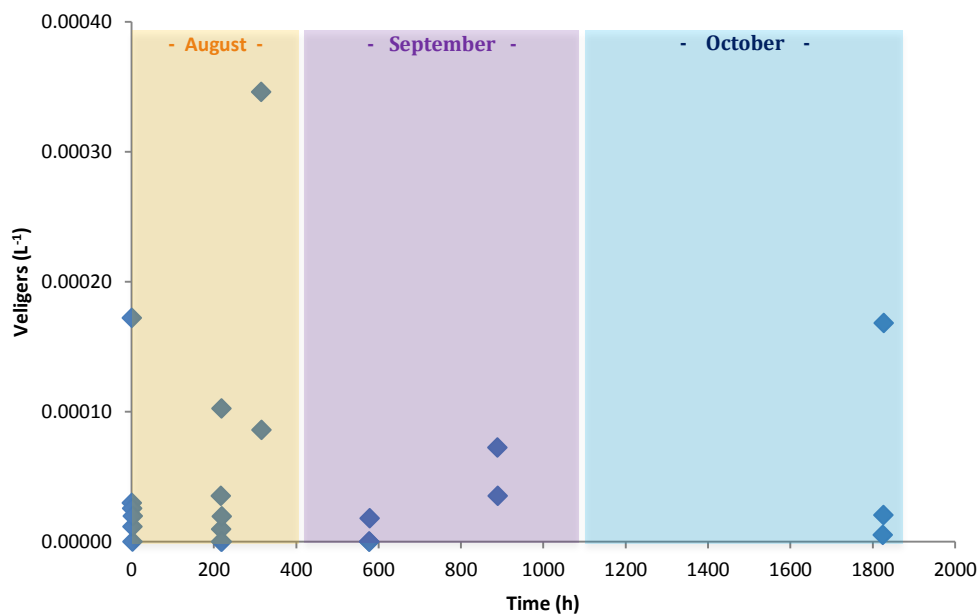


Figure 19: Distribution of Queen Conch veligers in Lac Bay, Bonaire during the period of sampling.

The sample sites in Lac Bay were chosen randomly and therefore the water belonging to the specific plankton samples all differ in depth. Figure 20 shows the relation between the amount of veligers and the total depth of the water at which surface plankton tows were taken.

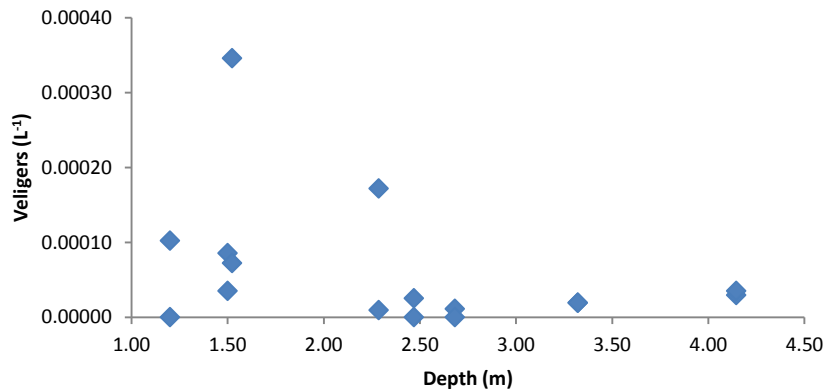


Figure 20: Amount of veligers as a function of the total depth of the site. Veligers were taken in the top most meter of the water column.

The following figure (fig. 21) illustrates the current velocity, current direction and the wind velocity taken with the Otterboxes at specific dates in Lac Bay. The figure is presented in chronological order. For the actual data of the measurements see table 3 Appendix II.

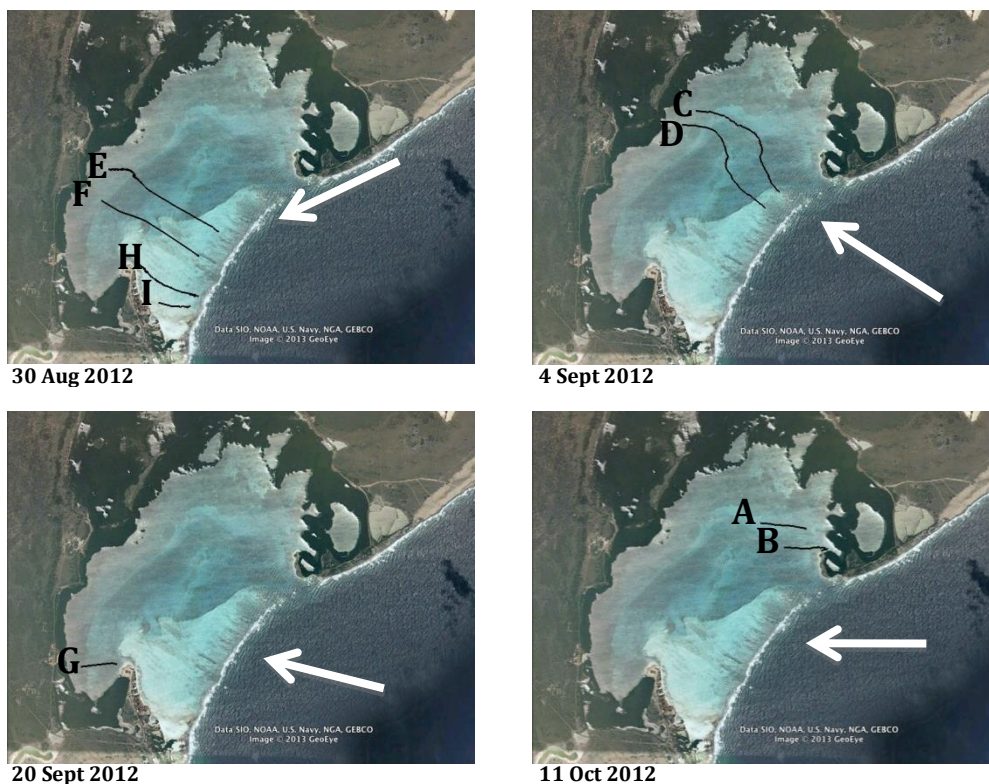


Figure 21: Surface currents in Lac Bay, Bonaire. The white arrow indicates the wind direction (Google Earth 6.2.2.7373, 2012).

Discussion

This research was on veligers of *Lobatus gigas* in Lac Bay, Bonaire. It was an explorative study as to where these veligers came from, how many were present, whether there was a relation with ocean surface currents, and if ocean surface currents were responsible for their dispersal.

The number of veligers found during this study ranged from 0.0 to 0.00035 individuals per litre, which is consistent with the literature (Aranda and Pérez, 2007, Stoner and Ray, 1996). Some studies reported veliger abundances with an order of magnitude less than the present study (Stoner et al., 1997, Stoner, 2003) while others, conducted in a marine fishery reserve, reported abundances of veligers with an order of magnitude higher than the numbers found during the present study (Stoner and Ray, 1996).

Since veligers in small size classes (i.e. 200-300 and 300-600 μm) are more difficult to identify, there is a higher uncertainty in those size classes. Lobed veligers were found only once. Overall 57.3% of the veligers were identified as being true veligers of the Queen Conch. This means that numbers of Queen Conch veligers could be higher when the encountered veliger-like organisms (i.e. the cf. veligers) also happened to be true larvae of the Queen Conch.

A higher abundance of veligers was found in the two smallest size classes (i.e. 200-300 and 300-600 μm). This could either mean that the source of the veligers is in the close vicinity of Lac Bay (Stoner et al., 1996) or that the natural mortality of the older veligers is high (Stoner and Davis, 1997).

Despite the strong currents veligers were more abundant around the reef. In fact all size classes of veligers were present in the reef area of Lac Bay. This could indicate the reef as a good habitat for Queen Conch veligers. The fact that there were veligers in the proximity of the reef, even though there was a strong current seems odd because ocean currents are the main dispersal mechanism for Queen Conch larvae (Barile et al., 1994, Stoner and Ray, 1996). Why then, were veligers abundant at the reef? A plausible explanation for this fact is that according to Davis (2005) Queen Conchs form spawning aggregations near reef tracts. Paris et al. (2008) mentioned that veliger exchanges between Queen Conch populations can only happen between nearby populations, hereby contradicting the theory that larvae can be dispersed over a large distance during their larval stage (Stoner, 1996, Barile et al., 1994). Since the Las Aves Archipelago is situated only 30 kilometres upstream from Lac Bay and surface currents of the Caribbean are typically 0.5m/s (Barile et al., 1994), veligers would take roughly 17 hours to cover the distance of 30 kilometres. Veligers take approximately three weeks to develop into metamorphically competent larvae with a size of $>950\mu\text{m}$, therefore veligers of 17 hours are still small enough to fall under the smallest size classes found in the present study, i.e. 200-300 μm and 300-600 μm . Since veligers found during this study are mostly small, it is therefore plausible that their origin is with nearby reefs, such as Las Aves Archipelago and the reef in front of Lac Bay. Additionally Perez *et al.* (2003, in Aranda and Pérez, 2007) recognized the Alacranes reef of Yucatan, Mexico, as an

important larval source for the Queen Conch. Since all other sample sites near the reef of Lac Bay have relatively high amounts of veligers there is reason to believe that particularly the reef in front of Lac Bay is an important source of veligers. Therefore it is plausible that the veligers in Lac Bay have their origin in the spawning aggregations of adult Queen Conchs near the deeper parts of the reef tract in front of and outside the bay. The question that remains is how bigger and older (i.e. 600-900 and >900 μm) veligers are able to stay in the proximity of the reef? According to Lee et al. (1994 in Stoner et al., 1997) gyres play a role in retaining and recruiting Queen Conch larvae. This may suggest that gyres on a much smaller scale can retain recently hatched larvae and that the small scaled gyres can deposit the veligers back to their original spawning grounds as veligers that are almost ready for metamorphosis (Stoner et al., 1997). Still more research is needed to determine the possibility of Queen Conch veligers to stay in the proximity of the reef.

According to Barile et al. (1994) veligers have positive phototaxis with low light intensities but they show signs of negative phototaxis with high light intensities. Depths at the reef did not exceed 1.5 meters and light conditions at the different days of sampling did not vary much (personal observation). Therefore the reason for the high amounts of veligers found near the reef might also be explained by the fact that the veligers could not escape the high light intensities that were present during sampling because the water was not deep enough for them to sink to a depth they preferred. Resulting in the fact that all veligers present near the reef were caught in the plankton tow used in present study. This could also explain the fact that less veligers were found in the rest of Lac Bay, i.e. due to high light intensities veligers sank thereby escaping capture in the plankton tow. The fact that early stage veligers are more photopositive than older veligers (Barile et al., 1994) might also be the reason for the higher amounts of small veligers (i.e. 200-300 and 300-600 μm) found in and around Lac Bay since plankton collections were only made in the upper most meter of the water column.

The Queen Conch has a year round reproduction (Aranda and Pérez, 2007), which means that veligers are found throughout the year. There is a peak in veliger abundance from June till September (Aranda and Pérez, 2007, Castro et al., 2009). The present study shows a peak during August, which is consistent with the results of Castro et al. (2009). Results of the present study could be biased by the fact that most samples were taken in August. Whether August is indeed the best time of year to go looking for veligers in Lac Bay has to be determined by doing more research.

During this research plankton samples were only taken during the day. This could mean that due to the negative phototaxis of the veligers at high light intensities (Barile et al., 1994), they migrated beneath the reach of the plankton net. Further research should also focus on collecting plankton samples during night times since Barile et al. (1994) suggest veligers come to the surface at night.

There seems to be a relationship between the total depth of the water column and the abundance of veligers (fig. 20). There seem to be less veligers present in the surface of a deeper water column. This could be because due to the movement of the outboard the resuspension of veligers in shallow waters is high. Meaning that

due to the movement of the propeller the resuspension of veligers that would have normally been out of reach due to sinking could have been enhanced.

Additionally, distance from the reef plays a role in the abundance of veligers. The further away from the reef samples were taken the less abundant veligers were. In addition to the possibility that spawning aggregations are formed near a reef (Davis, 2005) thereby increasing the abundance of veligers in its proximity, another explanation for fewer veligers to be found with increasing distance from the reef of Lac Bay (i.e. in the direction of Las Aves Archipelago) could be that the amounts of veligers were diluted due to the fact that the open ocean is vast. According to Lott (2000) Las Aves Archipelago and Los Roques are possible sources of Queen Conch veligers; present research however cannot confirm nor deny this statement. Literature indicates a high similarity between populations of the Queen Conch in the Caribbean (Stoner et al., 1997) thereby suggesting populations throughout the Caribbean to be dependent on distant larval sources. Whether this is true has to be determined by more DNA research.

According to Barile et al. (1994) ocean currents are the dispersing mechanisms of Queen Conch veligers. A negative trend between the amount of veligers and surface currents was shown, meaning that with high current velocities low amounts of veligers were present. The wind however seems to have a positive effect on veliger abundance. This relation is mostly determined by one point, i.e. sample site 7.1. Without 7.1 the relation is the opposite: the higher the wind the lower the abundance of veligers.

Wind and ocean surface currents are positively correlated (Goldsbrough, 1935). The results of the present study are consistent with the literature. Because no significant relation was found based on the data, other factors, such as the topography and the tides in the Bay, were the main driving forces behind the surface currents of Lac Bay.

During the experiment two different fixative solutions were used, i.e. 96% ethanol and 4% formaldehyde solution. Both solutions were used alternately to reduce the visible deformation of the solutions on the veligers. It would have been better to preserve every sample with both solutions, i.e. after a sample has been taken it should have been split in two to be able to preserve the veligers taken at a specific sample site in both ethanol and formaldehyde. This would have been a more correct way of trying to reduce the deformation error for the difference in preservation solutions. Additionally, it might have been better to buffer the formaldehyde-seawater solutions with borax. Borax was not used in the present study based upon the expert opinion of a curator of the Natural Biodiversity Centre (i.e. Naturalis, Leiden, The Netherlands). It could be that due to the less buffering capacity of the seawater the veligers dissolved.

Recommendations

Based on this study the following recommendations are applicable:

- More research has to be done to explain the reason for veligers to huddle around the reef. This includes determining what the effects of surface currents are in retaining veligers at a certain spot;
- To gain better insight in the year round reproduction of the Queen Conch start sampling for veligers before the peak of the spawning season and take samples at regular intervals (e.g. every two weeks);
- In this study measurements were only done during daytime, it would be preferable to also measure at night to reduce the influence phototaxis has on the outcome of this research;
- More small scaled research has to be done to determine current patterns in Lac Bay;
- Buffer the formaldehyde-seawater solution with borax to prevent veligers from dissolving;
- Sample all data (i.e. plankton, currents, wind, etc.) at the same time and at the site where plankton tows were taken to prevent influences of interpolation.

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- [2] Bower-Dennis, B., Conch Life cycle, from <http://www2.fiu.edu/~goldberg/coralreefs/Mollusc%20Feeding%20Guilds.htm> (visited March 4, 2013)
- [3] Windfinder.com, from <http://nl.windfinder.com/forecast/bonaire> (visited March 7, 2013)

Appendix I

Table 1: Plankton data

Site	Coordinates	Date & time	T from t_0 ¹	200-300 μm		300-600 μm		600-900 μm		>900 μm		Sum all size classes	
				vel/l	cf.vel/l	vel/l	cf.vel/l	vel/l	cf.vel/l	vel/l	cf.vel/l	vel/l	cf.vel/l
1.1	12° 6'8.80"N 68°13'22.80"W	14-08-12 9:00	1.00	2.98E-05	0	0	0	0	0	0	0	2.98E-05	0
1.2	NA (broken GPS)	23-08-12 9:15	217.25	0	0	3.52E-05	5.28E-05	0	0	0	0	3.52E-05	5.28E-05
2.1	12° 6'19.89"N 68°13'18.61"W	14-08-12 9:30	1.50	1.01E-05	1.01E-04	8.10E-05	0	8.10E-05	0	0	0	1.72E-04	1.01E-04
2.2	NA (broken GPS)	23-08-12 9:45	217.75	9.41E-06	0	0	0	0	0	0	0	9.41E-06	0
3.1	12° 6'31.93"N 68°13'22.36"W	14-08-12 10:00	2.00	2.03E-05	0	0	5.08E-06	0	0	5.08E-06	0	2.54E-05	5.08E-06
3.2	NA (broken GPS)	23-08-12 10:15	218.25	0	4.90E-06	0	4.90E-06	0	0	0	0	0	9.80E-06
4.1	12° 6'36.81"N 68°13'34.17"W	14-08-12 10:30	2.50	0	1.24E-05	0	1.24E-05	0	0	0	0	0	2.48E-05
4.2	NA (broken GPS)	23-08-12 10:45	218.75	1.02E-04	4.65E-06	0	0	0	0	0	0	1.02E-04	4.65E-06
5.1	12° 6'30.15"N 68°13'51.66"W	14-08-12 11:00	3.00	1.14E-05	0	0	0	0	0	0	0	1.14E-05	0
5.2	NA (broken GPS)	23-08-12 11:15	219.25	0	1.81E-05	0	0	0	0	0	0	0	1.81E-05
6.1	12° 5'53.61"N 68°14'24.14"W	14-08-12 11:30	3.50	0	0	1.96E-05	0	0	0	0	0	1.96E-05	0
6.2	NA (broken GPS)	23-08-12 11:45	219.75	4.85E-06	1.21E-04	4.85E-06	4.85E-05	0	4.85E-06	9.71E-06	0	1.94E-05	1.75E-04
7.1	12° 5'36.01"N 68°13'51.85"W	27-08-12 11:15	315.25	1.34E-04	0	1.57E-04	0	7.86E-06	0	4.72E-05	0	3.46E-04	0
7.2	12° 5'35.90"N 68°13'52.23"W	20-09-12 9:00	889.00	2.89E-05	1.45E-05	2.89E-05	0	7.23E-06	1.45E-05	7.23E-06	0	7.23E-05	2.89E-05
8.1	12° 5'43.68"N 68°13'49.74"W	27-08-12 12:00	316.00	4.68E-05	0	2.34E-05	3.12E-05	7.80E-06	9.36E-05	7.80E-06	0	8.58E-05	1.25E-04
8.2	12° 5'43.78"N 68°13'49.94"W	20-09-12 9:30	889.50	0	1.19E-04	1.40E-05	2.10E-05	2.10E-05	0	0	0	3.51E-05	1.40E-04
9	12° 5'49.58"N 68°13'30.37"W	29-10-12 12:15	1827.25	7.53E-05	5.21E-05	0	0	0	0	9.27E-05	5.79E-06	1.68E-04	5.79E-05
10	12° 4'11.24"N 68° 6'12.33"W	29-10-12 11:00	1826.00	1.53E-05	0	0	0	0	1.02E-05	5.09E-06	0	2.04E-05	1.02E-05
11	12° 2'57.58"N 68° 0'2.82"W	29-10-12 9:00	1825.00	0	2.07E-05	0	0	5.17E-06	0	0	0	5.17E-06	2.07E-05
12	12° 2'21.65"N 68°13'30.93"W	7-09-12 10:45	578.75	0	0	5.93E-06	0	1.19E-05	0	0	0	1.78E-05	0
13	12° 2'59.98"N 68°10'54.11"W	7-09-12 10:15	578.25	0	0	0	0	0	0	0	0	0	0
14	12° 3'10.06"N 68° 5'48.59"W	7-09-12 9:15	577.25	0	0	0	0	0	0	0	0	0	0

¹ t_0 = 14-08-12 8:00

Table 2: Plankton data continued

Site	Depth (m)	Wind velocity (m/s)	Current velocity (m/s)
1.1	4.15	4.12	0.083
1.2	4.15	4.12	0.083
2.1	2.29	7.20	0.001
2.2	2.29	7.20	0.001
3.1	2.47	7.72	NA
3.2	2.47	7.72	NA
4.1	1.20	7.20	0.007
4.2	1.20	7.20	0.007
5.1	2.68	6.89	0.042
5.2	2.68	8.23	0.042
6.1	3.32	8.23	0.030
6.2	3.32	8.23	0.030
7.1	1.52	9.00	0.018
7.2	1.52	7.20	0.018
8.1	1.50	9.00	0.034
8.2	1.50	7.20	0.034

Appendix II

Table 3: Otter box data

Track	Start coordinates	End coordinates	Date & time	Time travelled (h)	Wind velocity (m/s)	Distance travelled (m)	Avg box velocity (m/s)
A	12° 6'24.89"N 68°13'25.00"W	12° 6'26.55"N 68°13'40.20"W	11-10-12 10:57	1:30	2.75	465	0.08
B	12° 6'18.75"N 68°13'18.53"W	12° 6'19.12"N 68°13'33.08"W	11-10-12 10:46	1:33	2.85	605	0.11
C	12° 6'4.99"N 68°13'33.38"W	12° 6'30.46"N 68°14'1.39"W	4-09-12 9:31	4:10	6.3	1700	0.11
D	12° 6'0.31"N 68°13'38.23"W	12° 6'26.65"N 68°14'4.87"W	4-09-12 9:23	3:02	7.1	1300	0.14
E	12° 5'52.88"N 68°13'44.29"W	12° 6'11.67"N 68°14'18.38"W	30-08-12 9:55	1:59	8.5	2300	0.33
F	12° 5'45.45"N 68°13'50.79"W	12° 6'2.98"N 68°14'25.05"W	30-08-12 9:40	1:50	8.5	1100	0.17
G	12° 5'44.69"N 68°14'14.59"W	12° 5'42.69"N 68°14'31.17"W	20-09-12 10:42	1:15	6.8	355	0.08
H	12° 5'33.06"N 68°13'50.90"W	12° 5'42.51"N 68°14'9.27"W	30-08-12 12:38	0:47	5.2	1800	0.56
I	12° 5'29.73"N 68°13'53.26"W	12° 5'31.25"N 68°14'3.99"W	30-08-12 12:32	0:28	7.2	385	0.22

Appendix III

Table 4: Swoffer data

Site	Coordinates	Date & time	Wind velocity (m/s)	Current velocity (m/s)	Depth (m)	Salinity (ppt)	Oxygen (mg/l)	pH	Temperature (°C)
A	12° 5'33.00"N 68°14'30.00"W	24-09-12 10:40	8.75	0.024	0.4	36.4	6.51	8.25	28.2
B	12° 5'46.00"N 68°14'30.00"W	24-09-12 10:50	8.75	0.015	1.0	36.2	6.83	8.33	28.7
C	12° 5'59.00"N 68°14'30.00"W	24-09-12 11:20	8.75	0.014	1.0	37.3	6.27	8.13	28.2
D	12° 5'38.50"N 68°14'23.50"W	23-10-12 10:31	8.23	0.005	2.3	34.4	5.41	8.24	28.2
E	12° 5'52.50"N 68°14'23.50"W	23-10-12 10:50	8.23	0.030	3.3	34.9	5.62	8.29	28.3
F	12° 6'5.00"N 68°14'23.50"W	23-10-12 11:15	8.23	0.077	1.3	34.4	5.08	7.92	27.9
H	12° 5'46.00"N 68°14'17.00"W	23-10-12 10:15	8.23	0.056	2.7	34.9	4.96	8.27	28.3
I	12° 5'59.00"N 68°14'17.00"W	15-10-12 10:30	2.06	0.024	3.4	36.4	5.71	8.30	30.3
J	12° 6'12.00"N 68°14'17.00"W	23-10-12 11:45	8.23	0.046	1.0	34.3	7.71	8.33	28.5
L	12° 5'52.50"N 68°14'10.50"W	23-10-12 9:55	8.23	0.114	1.2	35.4	6.14	8.32	28.9
M	12° 6'5.00"N 68°14'10.50"W	15-10-12 10:57	3.09	0.014	4.5	36.1	5.33	8.29	29.9
N	12° 6'17.00"N 68°14'10.50"W	23-10-12 12:00		0.038	1.0	34.3	7.80	8.32	28.5
O	12° 5'33.00"N 68°14'4.00"W	12-09-12 9:45		0.023	0.6		7.57	7.22	29.8
P	12° 5'46.00"N 68°14'4.00"W	12-09-12 10:00		0.073	0.7	35.3	6.18	8.30	29.6
Q	12° 5'59.00"N 68°14'3.95"W	12-09-12 10:15		0.021	3.1	35.3	6.15	8.30	29.6
R	12° 6'12.00"N 68°14'4.00"W	12-09-12 11:00		0.053	4.4	35.6	6.13	8.31	29.7
S	12° 6'25.00"N 68°14'4.00"W	12-09-12 11:20		0.034	1.0	35.6	6.29	8.30	29.7
T	12° 5'25.00"N 68°13'57.50"W	24-09-12 9:30	7.20	0.005	0.3	35.9	7.00	8.37	29.0
U	12° 5'38.00"N 68°13'57.50"W	24-09-12 9:50	7.20	0.119	1.2	35.8	5.90	8.31	29.2
V	12° 5'52.50"N 68°13'57.50"W	24-09-12 10:10	9.26	0.175	1.2	35.8	6.10	8.32	29.2
W	12° 6'5.50"N 68°13'57.50"W	15-10-12 11:20	3.09	0.035	3.4	36.0	5.07	8.27	30.0
X	12° 6'18.50"N 68°13'56.99"W	23-10-12 13:20	8.75	0.046	3.9	35.1	6.17	8.32	28.8
Y	12° 6'31.50"N 68°13'57.50"W	25-10-12 10:53	7.20	0.019	1.0	35.4	6.11	8.27	29.0

Z	12° 5'33.00"N 68°13'50.91"W	23-10-12 9:30	7.72	0.161	1.2	35.3	6.26	8.29	28.6
Aa	12° 5'46.00"N 68°13'51.00"W	18-10-12 10:40		0.034	1.5	32.8	6.56	8.37	30.5
Ba	12° 5'59.00"N 68°13'51.00"W	2-10-12 10:10		0.038	4.0	35.9	5.86	8.33	29.3
Ca	12° 6'12.00"N 68°13'51.00"W	25-10-12 9:58		0.075	3.2	36.3	5.82	8.34	28.8
Da	12° 6'25.00"N 68°13'50.90"W	25-10-12 10:17		0.042	2.7	35.6	5.14	8.26	28.6
Fa	12° 5'52.50"N 68°13'44.50"W	18-10-12 10:24	4.63	0.057	1.5	32.8	6.44	8.39	30.4
Ga	12° 6'5.50"N 68°13'44.56"W	25-10-12 9:38	7.20	0.052	5.1	36.3	5.75	8.35	28.8
Ha	12° 6'18.50"N 68°13'44.50"W	23-10-12 13:45	9.77	0.060	3.8	35.4	6.35	8.38	29.0
Ia	12° 6'31.50"N 68°13'44.50"W	25-10-12 10:35	7.20	0.044	1.2	35.7	6.12	8.32	29.1
Ka	12° 5'59.00"N 68°13'38.00"W	18-10-12 10:08	4.63	0.061	1.5	32.7	6.51	8.39	30.3
La	12° 6'12.00"N 68°13'38.00"W	18-10-12 11:40	5.14	0.084	5.3	33.1	6.31	8.36	30.6
Ma	12° 6'25.00"N 68°13'37.88"W	23-10-12 14:10	9.77	0.047	3.2	34.6	5.99	8.25	28.7
Na	12° 6'38.00"N 68°13'38.00"W	25-10-12 11:10	7.20	0.007	1.2	35.8	7.14	8.36	29.4
Oa	12° 6'5.50"N 68°13'31.50"W	18-10-12 9:50	4.63	0.033	2.3	33.1	5.67	8.35	30.3
Pa	12° 6'18.50"N 68°13'31.50"W	25-10-12 9:16	7.20	0.044	4.0	36.0	5.50	8.30	28.5
Qa	12° 6'31.50"N 68°13'31.50"W	25-10-12 12:00	7.72	0.024	1.8	35.8	6.42	8.35	29.4
Sa	12° 6'12.00"N 68°13'25.00"W	18-10-12 9:00	4.12	0.083	4.1	33.3	5.33	8.28	29.9
Ta	12° 6'25.00"N 68°13'25.00"W	25-10-12 12:18	7.72		2.5	35.9	5.90	8.32	29.3
Va	12° 6'18.50"N 68°13'18.50"W	25-10-12 12:35	7.20	0.001	2.3	35.8	6.08	8.30	29.5
295	12° 5'56.94"N 68°14'7.48"W	2-10-12 9:44		0.056	2.6	35.9	6.24	8.33	29.3
323	12° 5'57.63"N 68°13'54.08"W	2-10-12 10:55		0.035	3.5	35.9	6.23	8.34	29.4
329	12° 6'0.79"N 68°14'11.83"W	15-10-12 9:20	1.03	0.026	3.8	36.1	5.56	8.22	29.8
338	12° 6'3.74"N 68°14'12.80"W	15-10-12 10:00	2.06	0.000	3.8	36.2	5.51	8.28	30.0
383	12° 6'4.82"N 68°13'42.10"W	15-10-12 12:20	3.09	0.044	4.7	35.6	5.34	8.29	30.4
414	12° 5'36.18"N 68°13'50.80"W	2-10-12 9:20		0.018	1.5	35.5	6.10	8.32	29.1
422	12° 6'7.13"N 68°13'49.55"W	15-10-12 11:30	3.09	0.032	3.9	36.0	4.86	8.26	30.1
435	12° 6'6.89"N 68°13'39.79"W	18-10-12 11:05	5.14	0.054	4.2	33.1	6.30	8.36	30.4
453	12° 6'7.06"N 68°13'38.72"W	2-10-12 11:05		0.027	4.1	35.9	6.41	8.36	29.6
472	12° 6'8.59"N 68°13'35.80"W	18-10-12 9:30	4.12	0.066	4.7	33.1	5.80	8.32	30.2

Appendix IV

The middle of the reef in this report is defined as being the geographic middle of the shallow coral patches situated within Lac Bay, i.e. behind the reef outside of Lac Bay.

Table 5: GPS coordinates of the middle of the reef

Site	Coordinates
Middle of the reef	12° 5'43.62"N 68°13'42.71"W

Appendix V

Table 6: Test output SPSS whether differences in veligers were found during the two dates of sampling for sites 1 to 6.

Paired Samples Test								
	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pair 1 Day1 - Day2	,01532	,08522	,03479	-,07411	,10476	,440	5	,678