THE HABITAT AND NURSERY FUNCTION OF THREE TYPES OF ARTIFICIAL REEFS FOR COMMERCIALLY AND ECOLOGICALLY IMPORTANT SPECIES OF FISH

Martijn Peters
Marnik van Cauter
AROSSTA
Artificial reefs on Saba and Sint- Eustatius
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The Habitat and nursery function of three types of artificial reefs for commercially and ecologically important species of fish

A study regarding the habitat and nursery function of three different type of artificial reef: layered cakes, reef balls and rock reef for the commercially and ecologically important families of fish on Sint Eustatius and Saba

Leeuwarden, June 2019

Client & Supervisor

Alwin Hylkema

Lecturer: Coastal & Marine management

Van Hall Larenstein, University of Applied science

Agora 1, PO Box 1528, 8901 BV Leeuwarden Nederland

Supervisor

Patrick Bron

Lecturer: Coastal and Marine management

Van Hall Larenstein, University of Applied science

Agora 1, PO Box 1528, 8901 BV Leeuwarden Nederland

Authors

Martijn Peters

Coastal & Marine Management

Martijn.peters@hvhl.nl

Student number: 000009141

Van Hall Larenstein, University of Applied science

Agora 1, PO Box 1528, 8901 BV Leeuwarden Nederland

Marnik van Cauter

Coastal & Marine management

Marnik.vancauter@hvhl.nl

Student number: 000010664

Van Hall Larenstein, University of Applied science

Agora 1, PO Box 1528, 8901 BV Leeuwarden Nederland

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Here you can read our thesis 'The habitat and nursery function of three types of artificial reefs for commercially and ecologically important species of fish'. The research has been done within the AROSSTA (Artificial reefs on Saba and Sint Eustatius) project. The study has been conducted during a 5-month time frame in which we formulated our bachelor thesis for the University of Applied sciences Van Hall Larenstein in Leeuwarden. To perform this research, we spend three months (March-May) on the Island Saba, where we collected our data and were, we worked in close collaboration with the SCF and CNSI.

We want to thank Patrick Bron and Alwin Hylkema, lecturers at the Van Hall Larenstein for always being of assistance and being supportive during the whole process. They gave us their expertise and support in which way we were able to conduct this research. Furthermore, we would like to thank Tom Van Ee and Lars Ter Horst for their data collection on the island of Sint Eustatius.

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We hope you enjoy reading this report.

Marnik van Cauter & Martijn Peters

ABSTRACT

The coral reef ecosystem provides important services such as tourism revenue, food, pharmaceutical products and coastal defence. Coral reefs are under a severe amount of threats such as pollution, overfishing and climate change. These threats result in a decrease of coral reefs and so a decrease in three- dimensional structure. The structural complexity of the coral reef ecosystem is crucial as it is often used as nursery and refuge for different living organisms. Artificial reefs are commonly used to increase the three-dimensional structure and increase suitable substrate for the recruitment of reef-building corals. AROSSTA (Artificial reefs on Saba and Sint Eustatius) uses three types of artificial reefs the layered cakes, the reef balls and the rock reef. These reefs are deployed on three different locations, one location on Saba (Big Rock Market) and two locations on Sint Eustatius (Twin Sisters and Crooks Castle). This research studies the habitat and nursery function for commercially and ecologically important species of each type of artificial reef. The important commercial species are consisting out of the families of snappers *(Lutjanidae),* Grunts *(Haemulidae)* and groupers (*Serranidae)*, and ecologically important species are consisting out of families of Surgeonfish *(Acanthuridea)* and Parrotfish *(Scaridae)*. The habitat and nursery function was divided into three criteria for both functional groups of fish. This was fish biomass for the habitat function and juvenile abundance and percentage for the nursery function. In total, ten fish-surveys were conducted on all AROSSTA locations between March and May 2019. During the surveys, all fish were identified on the species level and categorised in length classes of 5cm (0-5, 5-10). The total biomass and abundance of adults and the abundance and percentage of juveniles were calculated for each species group for every survey. A multi-criteria analysis (MCA) was used to give a score for each type of artificial reef, using previously mentioned criteria. The study found that the reef balls had the overall highest score,with a 7 (meaning 'good' in the MCA). When looking only at the commercially important species, the reef balls did the best with a score of 8 ('good' in the MCA), and the layered cakes did the best for the ecologically important species with a score of 6 ('intermediate' in the MCA). The layered cakes did best as a nursery with the highest score for commercially valued species and the shared highest score for ecologically important species. It is recommended that a combination of reef types is used to obtain the best result as nursery and habitat for ecologically and commercially important species of fish. The use of artificial reef as fish aggregation device should be discouraged, further research on the implications of the effects on fish stocks is recommended.

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1. INTRODUCTION

Worldwide coral reefs cover only 0.2 per cent of the ocean's surface, but they are home to more than a quarter of all marine species (Hazzard and Veron, 2007). This makes coral reefs one of the most diverse ecosystems on this planet (Bellwood et al., 2003). These ecosystems provide several ecosystem services supporting the livelihood of local communities (Moberg and Folke, 1999). Coral reefs provide a source of food, pharmaceutical applications, coastal protection, and tourism revenue (Spurgeon, 1992). However, coral reefs are threatened by a combination of anthropogenic changes (Salvat, 1987). The rising sea temperature, pollution, and unsustainable fishing and tourism have led to the mass bleaching of reef-building corals, and the depletion of fish stocks and diversity (Cesar, 2000; Roy and Smith, 1971; Wilkinson et al. 1999). The bleaching of corals is recognised as the biggest threat to coral reef ecosystems (Wilkinson et al. 1999). Depletion of reef-building corals results in the decrease of the three-dimensional structure on the reef (Mumby and Steneck, 2008). The structural complexity provided by corals is among the essential traits of a reef ecosystem, providing refuge and nursing habitat to organisms living on the reef(Graham and Nash, 2013). A majority of studies on the importance of structural complexity in reef ecosystems have found a positive correlation between the abundance of the physical structure and fish assemblage, biomass, and density (Cinner et al., 2009; Graham et al., 2009; Graham and Nash, 2013). The high three-dimensional structure is crucial for juvenile fish as they can find refuge from predation within the physical structure, several studies found increased juvenile mortality and decreased abundance when structural complexity was low (Marinelli and Coull, 1987; Yeager and Hovel, 2017). The conjuncture of these events has led to a negative feedback loop within coral reef ecosystems. The reduced structural complexity causes decreased fish recruitment leading to less ecologically and commercially important fish. The decrease in ecologically important species results in a drop of the grazing of macroalgae, which in turn leads to increased macroalgae cover, decreasing the coral recruitment leading to less three-dimensional structures (Mumby and Steneck, 2008). Coral reefs eventually end up in a negative feedback loop (figure 1a) which makes them less resilient and unable to recover after recurrent disturbances. (Hughes et al. 2010) Coral reefs provide an effective and suitable fishing habitat for commercial and recreational fisheries. The reefs provide a nursery and feeding ground for different economical important species. With a decrease in the coral reef ecosystem, there is a decrease in suitable fishing grounds and nursery, which results in a loss of profit for small scale fisheries (Cocheret et al. 2002).

The islands of Sint Eustatius and Saba, Dutch Caribbean (figure 3), are no exception with a decline of 22% coral cover from 2005 till 2015. (De Graaf et al., 2015). Further degradation of the coral reef habitat will have a significant effect on the abundance and diversity of coral reef fish species (Wilson et al. 2005). Herbivorous species such as parrot and surgeonfish (*Acanthuridea & Scaridae)* are seen as the single most important functional group of coral reef fish. They play a critical role in controlling macroalgae, which otherwise will dominate the reef surface (Russ, 2003). Where grazers are ecologically valuable, groupers, snapper and grunts (*Lutjanidae, Serranidae* and *Haemulidae*) are known for their commercial value (De Graaf et al., 2015). Due to coral reefs high complexity, they serve as a nursery habitat for these species (Coker et al. 2009). The nursery function of an ecosystem is determined by abundance and the ratio between juveniles and adults (Osenberg et al., 2002). Habitat degradation leads to a lack in coral reef complexity which threatens the nursery function of the coral reef ecosystem, juvenile fish are not able to hide from predatory fish resulting in increased mortality, and so reduces the abundance of ecologically and commercially important species. (Pratchett et al. 2011 ; Yeager and Hovel, 2017).

Artificial reefs are seen as an effective means to restore coral reef ecosystems. They are man-made or natural objects placed on the seabed in a selected marine environment (Parker et al. nd). Although artificial reefs are already used as fish aggregating devices for centuries, research on their function in habitat restoration only started in the 1960s (Randall, 1963; Ino, 1974). By adding structural complexity to a reef ecosystem, and so creating refuge and additional (nursery) habitat, a previously damaged ecosystem stuck in a negative feedback loop can restore itself (Mumby and Steneck, 2008). This initiates a positive feedback trajectory (figure 1b) (Clark, 2002; Graham and Nash, 2013; Mumby and Steneck, 2008). It is debated that artificial reefs solely function as an aggregation device and attract fish rather than increase the production of an ecosystem (Wilson et al., 2001). To prevent a wrong interpretation of the functionality of artificial reefs, the nursery function of the reef has to be studied (Brickhill et al., 2005).

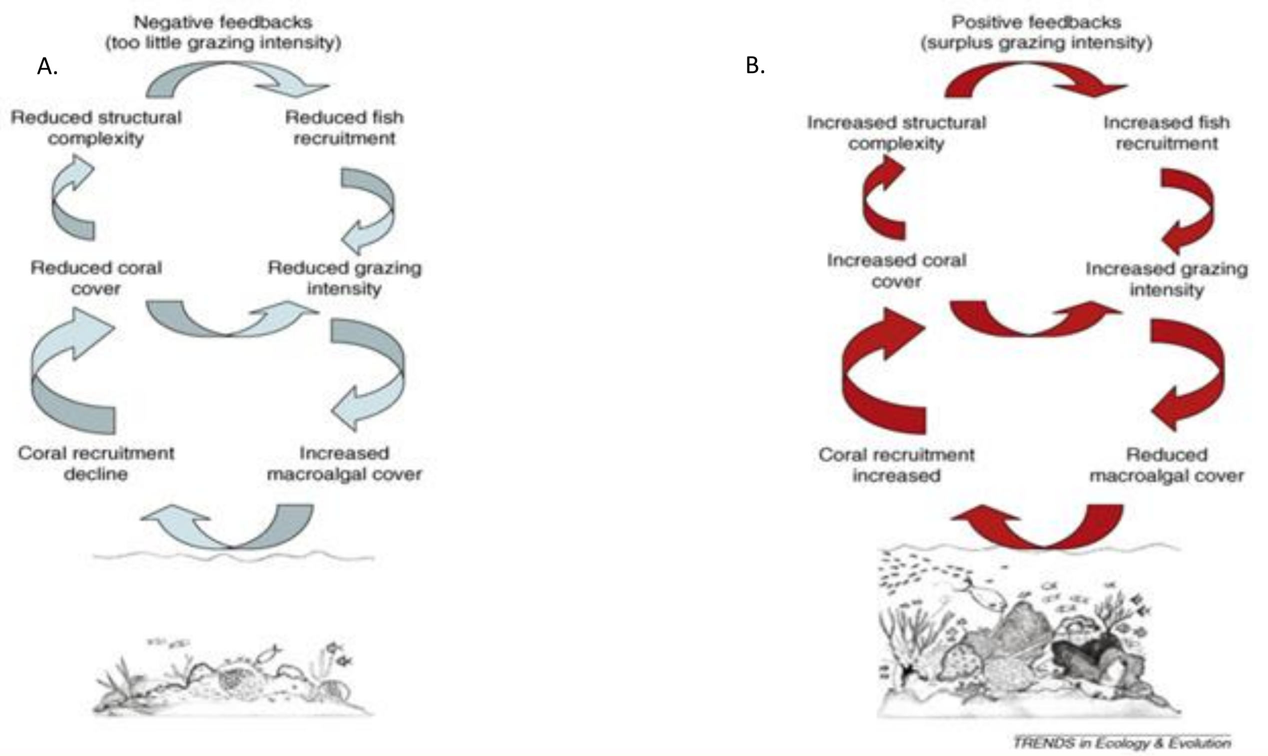

Figure 1: A schematic overview of a reef ecosystem in : A. negative feedback loop and B. in a positive feedback loop (Mumby and Steneck, 2008)

AROSSTA (Artificial Reefs on Saba and Sint Eustatius) is a project initiated by Van Hall Larenstein. This project compares three types of artificial reef: layered cakes (LC), reef balls (RB), and the pile of rocks (RO) (Figure 2). The AROSSTA project studies the fish abundance, grazing impact, coral recruitment and growth on the artificial reefs. This project has focussed on the habitat and nursery function of the different types of artificial reef for ecologically and commercially essential families of fish.

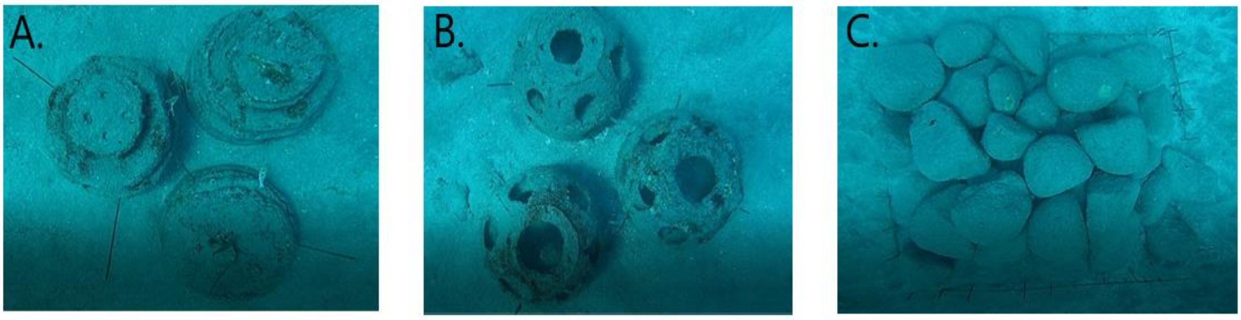

Figure 2 : Artificial reef types used in the AROSSTA project: A.= layered cakes, B.= reef balls ,and C.= Rock reef

1.1 PROBLEM DESCRIPTION

Artificial reefs are often used to restore marine ecosystems (Jensen and Seaman, 2000). However, there is a discussion on attraction rather than the production of these reefs. Due to this, the function of these artificial reefs as a nursery is crucial in determining their addition to the natural ecosystem (Sanders and Ruiz, 2007). This function is especially important for the key ecological and commercial species of fish (Cocheret et al. 2002). Former studies have looked into the nursery and habitat function of a single type of artificial reef (Sanders and Ruiz, 2007; Spieler et al., 2001). No studies had been done taking into account multiple types of artificial reef. By studying multiple types of artificial reef, it was possible to determine which type of artificial reef serves the best as a nursery and habitat for commercial and ecological important families of fish.

1.2 PROBLEM STATEMENT

There is a lack of knowledge about the three types of artificial reefs' function as habitat and nursery for ecologically and commercially important families of fish. Having a better understanding created an insight into the habitat and nursery function of artificial reefs which benefit the local community by an eventual increase in artificial reefs and fish abundance.

1.3 RESEARCH AIM

The research aimed to determine the reef type that functions best as habitat and nursery for a combination of both the key ecological and commercially important families of fish*.

1.4 RESEARCH QUESTION

Based on the problem and aim, the following research question was formulated:

> *Which type of artificial reef functions best as habitat and nursery for a combination of both ecologically and commercially important species*?*

1.4.1 SUB-QUESTIONS

1. What is the biomass of the key ecological fish species* on the artificial reefs?
2. What is the biomass of commercially valued fish species* on the artificial reefs?
3. What is the abundance and percentage of juvenile fish of ecologically important species* on the artificial reefs?
4. What is the abundance and percentage of juvenile fish of commercially important species* on the artificial reefs?

1.4.2 HYPOTHESIS

The three-dimensional structure is crucial for juvenile fish; a decrease in habitat complexity increases juvenile mortality (Yeager and Hovel, 2017). It was expected that due to the high structural complexity of the layered cakes, they would serve the best as a nursery for ecologically and commercially important species.

* Important ecological families are defined as all fish within the families: Surgeonfish (*Acanthuridea) and* Parrotfish *(Scaridae)*, commercially prominent families are Snappers (*Lutjanidae),* Groupers *(Serranidae)* and Grunts *(Haemulidae)*

1.5 READING GUIDE

In chapter 2: stakeholders and legislation, background information will be given considering the project. There will be explained which stakeholder is associated with the project and how each of the stakeholders affects or influences the project. The fisheries management/ methods of the islands will be explained. After that, more will be said considering sustainability within the project and the association with other projects. In chapter 3: Methodology, more will be said about the data collection methods and the data analysis. In chapter 4: Results, the found results will be given. In chapter 5: Discussion, the found results will be critically discussed. In Chapter 6: Conclusion, the formulated research questions will be answered with the found data. Chapter 7: recommendations, holds relevant advice about the usage of the artificial reefs will be given.

2. STAKEHOLDER & LEGISLATION

2.1 STAKEHOLDERS

Van Hall Larenstein is secretary of the AROSSTA project and focusses on research that contributes to a sustainable society. It has much experience in conducting applied research and a broad network in tropical marine ecology. Van Hall Larenstein also is an educational institution, and the projects provide internship possibilities for students. Because of their status as University of applied sciences, the integration of knowledge gathered by applied projects within the educational program is a crucial motive of the Van Hall Larenstein. Van Hall Larenstein's role as secretary of the project means they are involved throughout the whole process of AROSSTA. Van Hall Larenstein has experience with conducting applied research where they often initiate projects in collaboration with Wageningen University and Research, this is also the case with the AROSSTA project. During the research, Van Hall Larenstein supplied two thesis supervisors who assisted within the study. These supervisors were given a weekly update and were available for questions research related. During the planning of the project, these supervisors would provide suggestions and recommendations concerning the validity and possibility of the project! They would give a critical view of the collected data and the method of processing and presenting the results.

Wageningen Marine Research, part of Wageningen University and Research, is a Dutch knowledge institute focussed on applied research in marine ecology. As they have a direct connection with Wageningen University and Research, they also have an interest in integrating research within educational programs. They have experience with the 'building with nature' concept and provide expertise and counselling on this. For example, they have projects using oyster banks to create mangroves and so protect the coast of Bangladesh (Baptist, n.d.). Wageningen Marine Research gives the possibility for students of Van Hall Larenstein to work in the field and get experience in marine research. Wageningen conducts numerous studies in the Dutch Caribbean, making them a valuable partner. They are primarily involved in the design phase of the project. As Wageningen Marine Research conducts several projects in the Dutch Caribbean, they work closely with the Caribbean Netherlands Science Institute as they facilitate on-site data collection on Sint Eustatius. During the data collection period, Wageningen supplied a fund to afford the housing and cost of living. For further issues concerning the stay on the island, Wageningen was available for questions and assistance if necessary.

The Caribbean Netherlands Science Institute (CNSI) is a research organisation based on Sint Eustatius and orientated on research in the Dutch Caribbean. It aims to facilitate research and education to address local problems on sustainable island communities (CNSI, n.d.). This connects very well to the AROSSTA project, making one of the key partners. The CNSI facilitated research equipment and accommodation for students and has much experience with researching in the Dutch Caribbean and aided assistance in the project. The CNSI was mainly involved in the design and data collection period of the project. During the processing of the data, the CNSI had a lab and working space available. The CNSI has a close relationship with STENAPA working together on projects and providing research in the national parks.

Saba Conservation Foundation (SCF) and **Sint Eustatius National Parks (STENAPA)** manage the marine parks around and on Sint Eustatius and Saba. The organisations both aim to protect and restore the terrestrial and marine natural heritage on the islands (SCF, n.d.; STENAPA, n.d.). The organisations are the questioners in the AROSSTA project and requested a strategy on how to combat the negative feedback trajectory present in local coral reefs. They are interested to know which type of artificial reef would be most suitable to restore the local ecosystems. The organisations have much knowledge of the research sites and so provided advice and counselling when needed. SCF provided dive tanks and boats with a captain to collect the data on Saba. During the data processing period, the SCF supplied a working area with facilities. These organisations work together with Van Hall Larenstein and Wageningen University and Research by providing internships and facilitating research. The AROSSTA project also has partners that are active in the local business sector.

Golden Rock Dive Centre is a local dive school. It rents out the gear needed for data collection but also has experience in underwater logistics and work. Golden Rock Dive Centre already had a close relationship with the CNSI and STENAPA, facilitating all tanks needed for research and occasionally renting out their boat for projects. Apart from having a direct financial benefit from the project, they also have an interest in the possibilities of artificial reefs as potential dive sites. They are primarily involved in the on-sight assistance of data collection.

2.2 FISHERIES MANAGEMENT

Saba: in 1987, the Saba National Marine Park was established; the Saba conservation foundation manages this park. The Saba marine park includes all the surrounding waters of Saba to a depth of 60m (180ft). To have effective management considering the tourism sector and the fisheries, the SCF developed a zoning plan for the marine park. The marine park was divided into four zones (mooring zone, no-take zone, recreational zone, multi-use zone) (SCF, n.d.). The artificial reefs are placed in the 'multi-use zone' here recreational fishing is permitted for people who have a licence (recreational fishing is defined to fishing with a reel and rod or handline or speargun while freediving). The commercial Saban fishing fleet consists out of 8 boats which mainly fish for redfish and lobster. Their fishing method consists of the use of fish and lobster pots; these are dropped for a certain amount of days on the Saba Bank. Fishermen interviews indicated that there are between 2500 en 3000 traps deployed on the Saba bank (De Graaf., et all. 2017). There is however no commercial fishing within in the Saba marine park. (Saba bank officer: Ayumi Kuramae-Izioka 29-04-19)

Sint Eustatius: The Sint Eustatius marine park was established in 1996 by STENAPA (Sint-Eustatius National Parks). The marine park consists of an area approx. 2750 ha till a depth of 30m (90ft). Two marine reserves were established within the marine park, the northern reserve and the southern reserve. Within the marine reserves, it is not allowed to fish, with an expectation of trolling by rod and reel. (DCNA, 2018) The total fishing pressure consists of about 22 fishermen on the island mainly fishing with lobster and fish traps. (Personal communication Gordo, 01/12/18) However, the number of traps is smaller than on the island of Saba, this because Saba exports their catch and on Sint-Eustatius fish is locally sold and lobsters exported to Sint Maarten. (Personal communication Kimani-Watson, 3/12/18)

2.3 FISHERIES METHOD

The fishing grounds around Sint Eustatius a relatively shallow compared to fishing grounds on Saba. On Saba, the fishing efforts mainly focus on redfish (snappers & groupers). On Sint Eustatius there is no selective fishing method, snappers and groupers are preferred. However, they take every consumable fish. Different snapper and grouper species thrive at a depth between 100-130m (300 - 400 ft). Around Sint Eustatius the continental shelf has a steep drop from 80 to 600m (250 to 2000 ft), to reach the most effective fishing grounds traps fishermen place traps on the edge of the continental shelf for redfish. The placement method results in a significant number of lost traps which ‘fall’ of the edge and get lost in deeper water. Different fishermen on Sint Eustatius do not want to take this risk to lose valuable fishing traps and fish in shallow waters just outside the marine park. The Caribbean spiny lobster *(Panulirus argus)* thrives at a depth from 2 m till maximum 80 m (6- 240ft). Because of this shallow depth range, the fisheries for spiny lobsters are done in shallow water. On Saba, lobster traps are placed on the shallow waters of the Saba bank while on Sint Eustatius the traps are placed on the continental shelf just outside and often even in the marine park. Due to the shallow water fisheries on Sint Eustatius, there is a significant amount of by-catch of reef fish such as the Ocean surgeonfish *(Acanthurus tractus)* and the blue tang *(Acanthurus coeruleus).* These species thrive at depths from 2-40 m (6- 120ft) while at these depths most lobster fisheries occur, which results in the by-catch of these ecologically important species. (Gordo and Kimani Watson, 10/2018 – 01/2019)

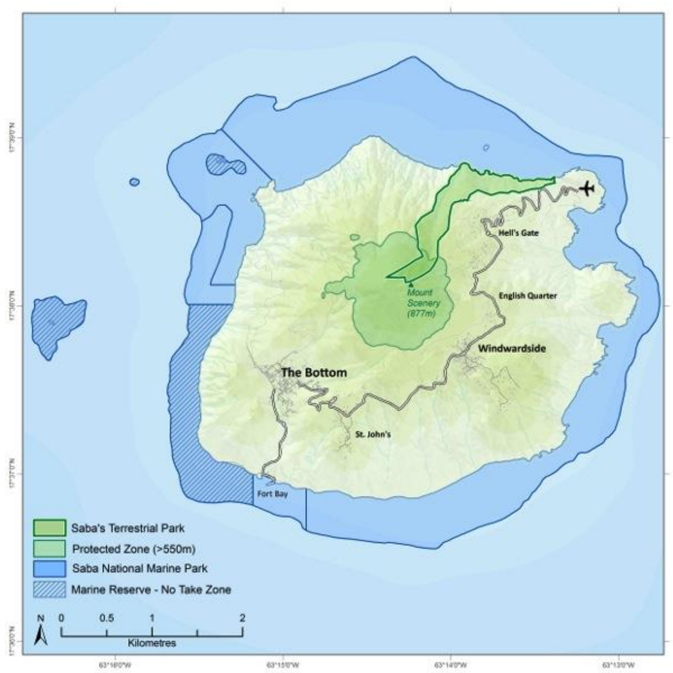

Figure 3: The Island of Saba with surrounding waters and their protective status (DCNA, 2014).

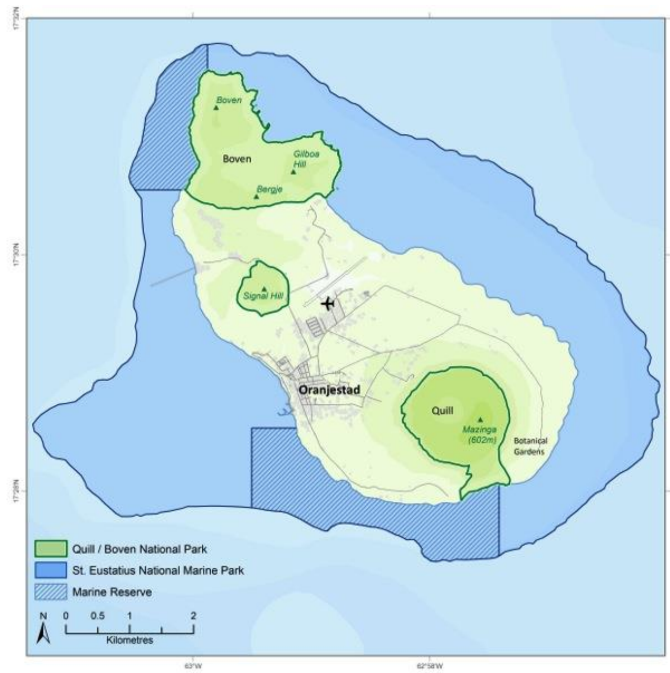

Figure 4: The Island of Sint Eustatius with surrounding waters and their protective status (DCNA, 2014).

2.4 STAKEHOLDER INVOLVEMENT

Several stakeholders were involved in the design of the proposal. Van Hall Larenstein provided two supervisors, Alwin Hylkema and Patrick Bron, with extensive experience in the field of marine ecology and applied research. Through two meetings with these supervisors and one digital feedback moment, they helped to form a feasible research proposal and assisted on methodology. Wageningen Marine Research provides compensation for accommodation and working on Saba. Contact with SCF was established via WhatsApp and email, together with Ayumi (Saba bank national park officer), planning of the necessary fieldwork was formed. Data collection on Sint Eustatius is provided by Tom Van Ee and Lars Ter Horst (thesis students). They established contact with the local stakeholders and arranged data collection on Sint Eustatius. Local fisherman on Sint Eustatius gave an insight into the commercially valued species in the area, this was through informal conversation during the second data collection period (Gordo & Kimani Watson, 10/2018 – 01/2019).

2.5 SUSTAINABILITY

Sustainability has been becoming a more popular and important subject. It is important to work in a sustainable way of living where the future has been taken into consideration. AROSSTA tackles the three critical parts of sustainability: PPP (people, planet, profit). The project work towards sustainability by creating artificial reefs and restore the loss of three-dimensional structures **(planet)**. The coral reef ecosystem is not only ecological important but contributes a significant revenue. Coral reefs provide three economic valued services: Coastal protection, fisheries, tourism. The recreational value of Caribbean coral reefs is estimated at $1654 per hectare each year (Chong, Ahmed and Balasubramanian, 2003). This indicates there is a significant economic interest with the coral reef ecosystem **(profit).** Previous studies have shown that with an increase in three-dimensional structures, there would also be an increase in fishing yield for small scale fisheries (Graham, 2014). AROSSTA works together with different parties on Saba and Sint Eustatius to achieve the restoration of these commercially and ecologically important ecosystems. The presence of the AROSSTA project generates revenue to the community. Direct revenue includes housing, boat rental, dive-equipment rental and tourism **(people).**

By considering the people, the planet and profit aspect, AROSSTA aims towards a self-sustaining ecosystem which can keep providing for the local communities in the present as well as in the future.

2.6 POLICY & MANAGEMENT

Saba and Sint Eustatius are public entities of the Netherlands and are completely under Dutch legislation (statiagoverment, 2011). The DCNA (Dutch Caribbean Nature Alliance) is the non-profit regional organisation created to protect the natural environment of the 6 Dutch Caribbean islands. The DCNA aims to help and assist the nature protection organisations within the Dutch Caribbean (DCNA, 2014). In the case of AROSSTA, this means SCF (Saba conservation foundation) and STENAPA (Sint Eustatius national parks). In 2013 the 'Nature policy plan' was formulated for the islands Bonaire, Saba, Sint Eustatius. This plan provided a framework for the upcoming five years for the development of nature policy plans. Stakeholders developed the nature policy plan throughout the Dutch Caribbean, parties such as civil servants, nature conservationists and businesses all gave their input. The nature policy plan is used to ensure the right use of 7,5 million euro's for nature conservation over the upcoming years. The DCNA formed a list of species with a high necessity for conservation. These species are now protected in the Dutch Caribbean. The SCF (Est. 1987) is responsible for preserving and managing Saba's natural and cultural heritage, including the marine parks (Saba bank and National marine park). A zoning plan around the island prohibited fishing and anchoring at certain locations to protect the marine environment (SCF, 2018), (DCNA,2014). STENAPA is an NGO (Est. 1996) and responsible for the marine parks and national parks on the island. The marine park consists out of two actively managed reserves, the northern reserve and the southern reserve. There is a ban on fishing and anchoring in these parks (DCNA, 2014), (STENAPA, 2017). The AROSSTA project operates on a regional level in the marine parks of Saba and Sint Eustatius, so close collaboration with SCF and STENAPA is a necessity. Currently, the AROSSTA project is in the data collection period (monitoring) or also called the execution phase. Data about the efficiency of each type of artificial reef is collected over a period of two years. With this research, AROSSTA fits within the goals formed by the SCF and STENAPA. Striving to a biodiverse ecosystem and healthy coral reefs around the islands.

2.7 AROSSTA AND OTHER CORAL RESTORATION PROJECTS

RESCQ (Restoration of ecosystem services and coral reef quality) is an EU-project and is funded by the Dutch ministry of economic affairs (WUR, 2016). The project aims to restore coral reefs with resilient species. For this project, coral nurseries are set-up on Saba, Sint Maarten, Sint Eustatius and the Turks and Caicos Islands. Coral fragments are grown from a ladder construction and used for restoring the damaged reefs. Fast growing coral species such as Elkhorn *(Acropora palmata)* and Staghorn *(A. cervicornis)* are used to grow, after that the coral fragments are transplanted to a selected restoration site (RESCQ, n.d). RESCQ by Wageningen Marine Research (WUR) works together with SCF (Saba conservation foundation), STENAPA (Sint Eustatius National parks), NFSXM (Nature Foundation Sint Maarten), TCRF (Turks and Caicos reef fund), the coral nurseries are managed by the nature foundation from each island they are situated on (WUR, 2016).

RESCQ and AROSSTA both work towards coral restoration and the preservation of this ecosystem for the future. AROSSTA works closely with the partners within the RESCQ project (WUR, STENAPA, SCF). It is essential there is adequate cooperation between AROSSTA employees and RESCQ employees as some services of the SCF need to be shared between the two projects such as the boat and office. AROSSTA is also depended on STENAPA as they manage the marine park on Sint Eustatius. The close cooperation between these projects is essential so that information could be exchanged, and coral reef restoration could be accomplished as fast as possible.

3. METHODOLOGY

3.1 RESEARCH AREA

Data collection took place from the 1st of March till the 23rd of May, 2019. The data is collected at three different locations around two different islands in the Dutch Caribbean. The artificial reefs are located near the islands Saba and Sint Eustatius (Figure 5). Saba used to have 2 locations were artificial reefs were constructed. Hurricane Irma in 2017, destroyed one of the sites. The left-over site 'Big rock market' (1) (N: 17.36772, W063.14264) is located in the South of Saba at a depth of 15 meters. The island of Sint Eustatius (Southeast of Saba) has two research sites. 'Crooks Castle' (2) (N:17.47220, W: -062.98911) which is located in the southern marine reserve at a depth of 15 meters and 'Twin sisters' (3) (N: 17.51715, W: -063.00337) which is located in the northern marine reserve at a depth of 17 meters. On each of the research sites, the three types of artificial reefs are constructed. Each research site also has one control patch which is surveyed. BRM on Saba has two pile of rocks due to the damage on the pile of rocks situated in Ladder bay.

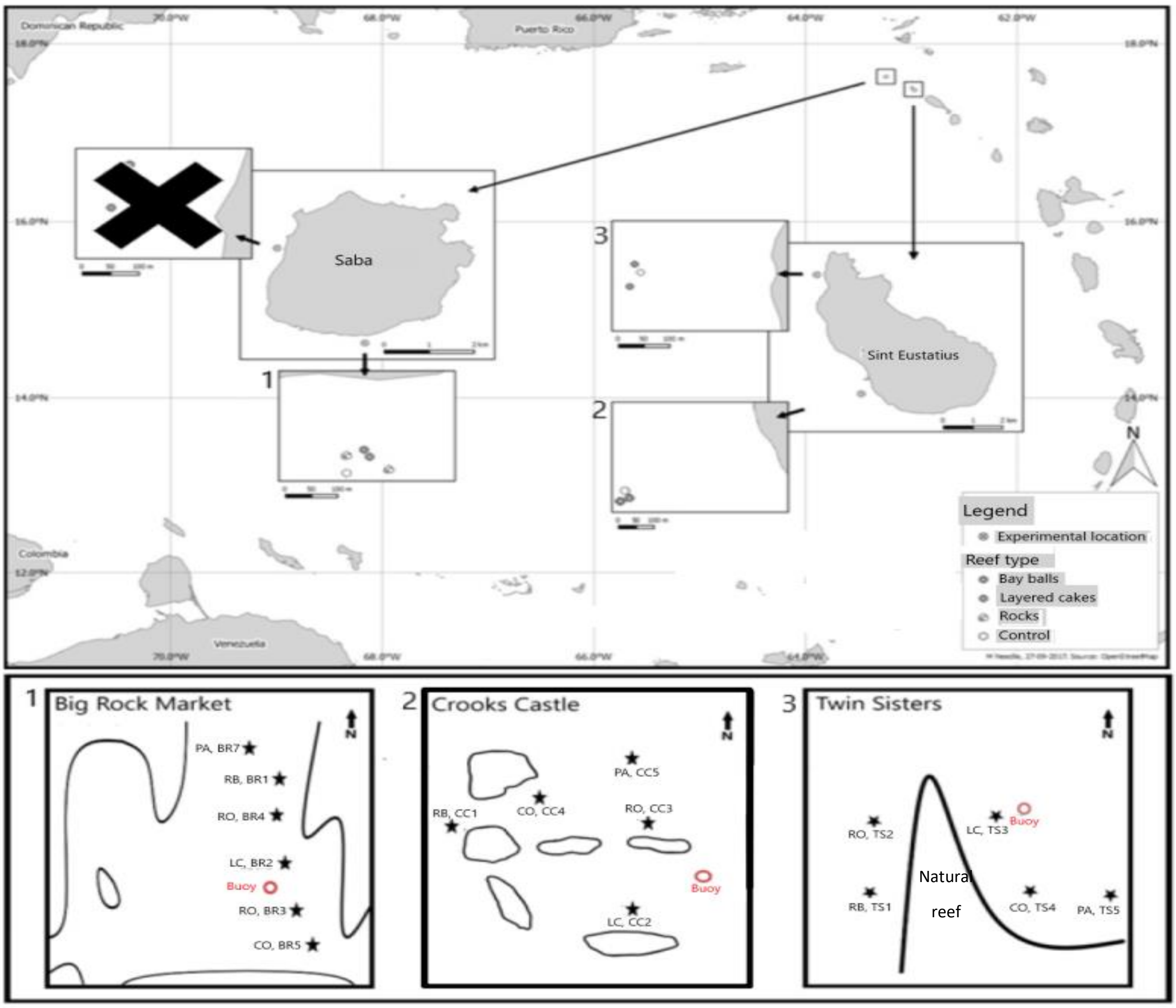

Figure 5: AROSSTA research sites . The top map shows place of the islands and spots on the map. The sites are displayed in detail below in the maps below. All reefs are displayed with their unique code.

3.2 FISH SURVEY

Ten fish counts were conducted on each type of artificial reef, including the control patch for each research site (Saba: Big Rock Market, Sint Eustatius: Twin Sisters, Crooks Castle). The amount of repetition achieves a high statistical power (power= >0,80). It was aimed to conduct two fish surveys each week for a period of 8 weeks. The surveys were conducted while diving.

The survey will start at one of the outer artificial reefs (figure 6). The divers descended to the bottom at a distance of 10m from the artificial reef. The first diver swam slowly towards the artificial reef. At 5 meters from the experimental plot, the fleeing fish were recorded. When 2 meters from the experimental plot, a 3-minute stationary count was conducted, fish were recorded on the survey sheet. Diver 2 is swimming slowly behind diver 1 filming the survey for future reference and the identification of unknown species. All the fish within 1 meter sideways and 2 meters upwards of the artificial reefs were included in the survey (figure 7).

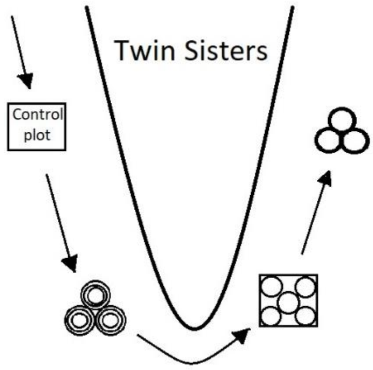

Figure 6: Survey direction, Twin sisters

During the survey, fish were identified and given a count as well as a size estimation. All fish entering the cylinder were included. After 3 min. The reef was searched for hiding fish, unknown species were described as detailed as possible. After the survey, a picture was made of the survey sheet. This was repeated with every artificial reef. The fish surveys were conducted by an AROSSTA formulated protocol which is found in *(Appendix 2: Fish survey protocol).*

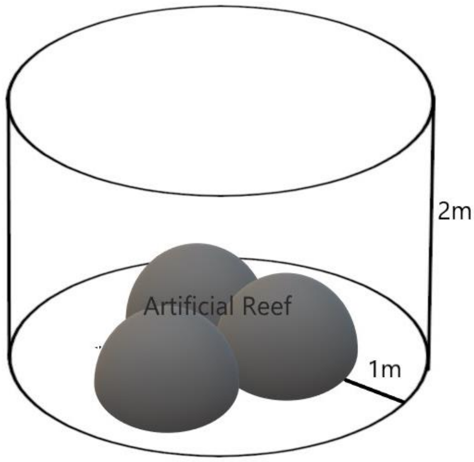

Figure 7: Cylinder, fish included in survey

3.3.1 COMMERCIALLY IMPORTANT SPECIES

All species within the families Snappers (*Lutjanidae),* Grunts *(Haemulidae)* and Groupers *(Serranidae)* are defined as commercially important species, these are the species mainly targeted by commercial fishermen around the islands of Saba and Sint Eustatius and there for taken into account in this project. Appendix III holds a table with all found species

3.3.2 ECOLOGICALLY IMPORTANT SPECIES

All the species of Surgeonfish (*Acanthuridea)* and Parrotfish (*Scaridae)* are defined as commercially important species. These species play an important function in ecosystem maintenance in the Caribbean. Appendix III holds a table with all found species

3.3 HABITAT FUNCTION

The habitat function was determined by the biomass of fish on the artificial reefs. To calculate fish biomass, collected data from the fish surveys were used. With this data, an estimation of biomass was made based on the length-weight relationship per species. The following formula was used to calculate the weight of the fish:

$$\log w = \log a + b \log L$$

In this formula w= weight in gr, and L= length in mm. Log a and b are both species-specific constants. FishBase has published these constants for Caribbean reef fish (Frouse and Pauly, 2018). These constants can be found in Appendix III. Fish were estimated on length in categories of 5 cm (0-5, 5-10), the mean of the size category was used in the formula. As all artificial reefs have the same surface area (m2), no further calculations were needed. In several occasions, there was chosen to leave fish out of the mean biomass calculation because their biomass was higher than the cumulative biomass of the other fish. This was done with two stingrays and several barracudas for the total biomass of the layered cakes and reef balls on Big Rock Market and Crooks Castle, and one Nassau grouper on the patch reef on Big Rock Market.

3.4 NURSERY FUNCTION

For the nursery function, two indicators were used, juvenile abundance and percentage. This to prevent conclusions based on percentages of a low amount of fish. The mean fish count on every reef type was used. Juveniles are defined as all fish smaller than their species-specific length at first maturity (Lm), which can be found for every species in Appendix III.

3.5 STATISTICAL ANALYSIS

All statistical test was executed using SPSS 25. For the total, ecological and commercial biomass and abundance homogeneity were tested using Levene's test of equal variances, the datasets were not homogenous ($p < 0.01$). The Kolmogorov-Smirnov test was used to determine normality. No normal distribution was found for ecological and commercial biomass on any of the reef types ($p < 0.01$). The data did not meet the required assumptions for a parametric test. The non-parametric Kruskal-Wallis test, with Games-Howell post-hoc, was used.

This was the same for the abundance of juveniles of both ecological and commercially valued fish. Were Levene's test of equal variances found that the data was not homogenous ($p < 0.01$). The Kolmogorov-Smirnov test found no normal distribution for ecological and commercial juvenile abundance in any of the reef types ($p < 0.01$). Again, the data did not meet the required assumptions for a parametric test. The non-parametric Kruskal-Wallis test, with Games-Howell post-hoc, was used.

3.6 MULTI-CRITERIA ANALYSIS

To perform an MCA, the indicators were divided into habitat and nursery function. Both functions were weighted equally. The nursery indicators were weighted half of the habitat indicators. This because two indicators were used to define a nursery habitat. Indicators can be scored 2-10 for the habitat function and 1-5 for the nursery function. Every indicator has its values for the scores. Table 1 shows the scoring of each indicator connected to a value. The range of the MCA is determined by five scores with equal size between the highest and lowest mean value found.

Indicators/**Score**	**Very bad**	**Bad**	**Intermediate**	**Good**	**Very good**
Habitat	**2**	**4**	**6**	**8**	**10**
Grazer biomass	<40.5	40.5-81	81-121.5	121.5-162	162>
Commercially valued biomass	<32.3	32.3-64.6	64.6-96.9	96.9-129.2	129.2>
Nursery	**1**	**2**	**3**	**4**	**5**
Juvenile percentage grazers	<16.4%	16.4%-32.8%	32.8%-49.2%	49.2%-65.6%	65.6%>
Juvenile abundance	<0.3	0.3-0.6	0.6-0.9	0.9-1.2	1.2>
Juvenile percentage commercially valued species	<15.9%	15.9%-31.8%	31.8%-47.7%	47.7%-63.6%	63.6%>
Juvenile abundance	<0.4	0.4-0.8	0.8-1.2	1.2-1.5	1.5>

Table 1: Index multi-criteria analysis

4. RESULTS

During the data collection period, a total of 1917 fishes were counted on the artificial reefs. 129 fish were part of the commercially valued families, and 140 fish were part of the key ecological families. On the artificial reefs, there were five species found within the commercially valued families of fish and seven species within the ecological families of fish. The Coney *(Cephalopholis fulva)* was the most abundant species for the valued commercial group, and the Ocean Surgeonfish *(Acanthurus tractus)* was most abundant for the key ecological. This chapter contains the collected data on biomass and juvenile abundance for every type of reef.

4.1 BIOMASS & ABUNDANCE

The mean overall biomass (± SD) was highest on the layered cakes (1072 ± 1129g), followed by, reef balls (635 ± 666g) and the rock reef (490 ± 323g) (figure 8) The Kruskal-Wallis test found a significant difference between reef types, $\chi^2(3) = 66{,}3$ p=<0,01. However, the Games-Howell post hoc only found a significant difference between the reef types and the control patch.

The effect of reef type on total fish abundance (counts) was similar to the mean biomass. The fish abundance (± SD) was highest on the layered cakes (26.5± 11.5). It was followed by Reef balls (14.0± 10.2) and rock reef (11.5 ± 4.9) (figure 9). A significant effect between reef types was found using the Kruskal-Wallis test, $\chi^2(3)=81.4$ p=<0,01. The Games-Howell post hoc test found significant differences between the layered cakes in combination with reef balls and the rock reef (p<0.01), this was also the case for all reef types in relation to the control patch.

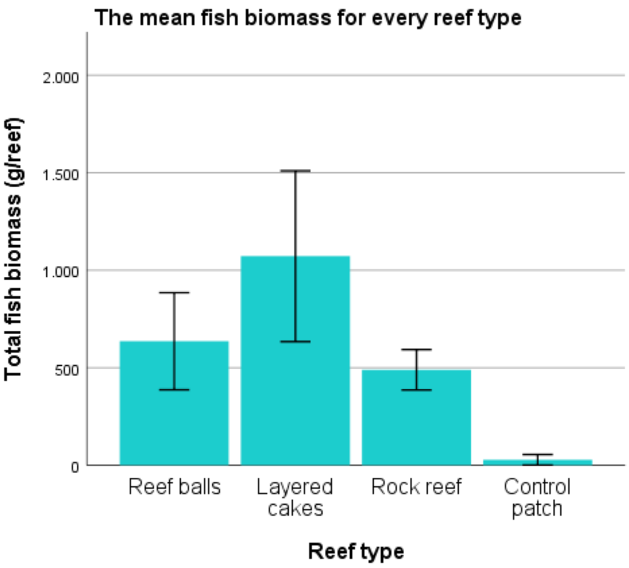

Figure 8: mean fish biomass in gram (± SE) for every type of reef type

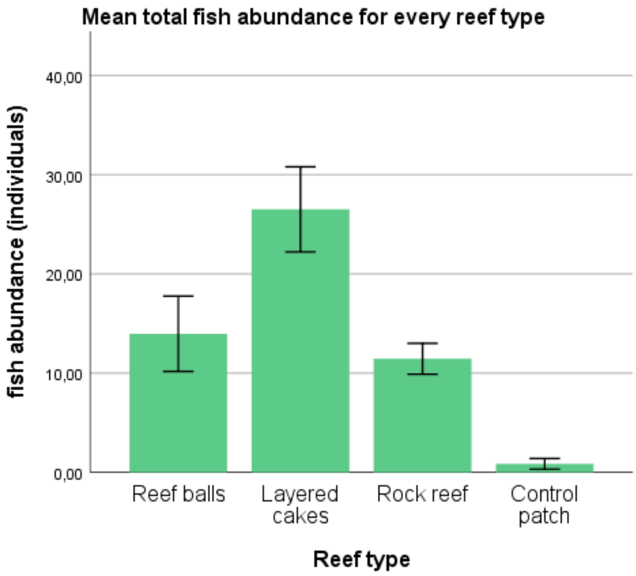

Figure 9: Mean total fish abundance (± SE)

4.1.1 BIOMASS & ABUNDANCE COMMERCIAL VALUED SPECIES

The highest mean commercial biomass (± SD) was found on the reef balls (100.3 ± 188.3g), followed by the layered cakes (67.7± 106.5g) and Rock reef (66.1 ± 94.0g), figure 10 shows the mean commercial biomass of every reef. The Kruskal-Wallis test found that Reef type had a significant effect on the commercial biomass, $\chi^2(3)=38.4$, $p=<0.01$. However, with a post-hoc there was only a significant difference found between the reef types and the control patch.

This, however, was different for the mean amount of commercial valued fish present (± SD) on the artificial reefs, displayed in figure 11, which was higher on the layered cakes with a mean of 1.7 fish (± 1.3). The reef balls and rock reef both had a mean of 1.0 fish (±1.1). A Kruskal-Wallis test found a significant difference between reef types, $\chi^2(3)=47.2$, $p < 0.01$. Post-Hoc analysis found a notable difference between layered cakes and rock reef ($p= 0.045$) and between all reef types and the control group ($p < 0.01$).

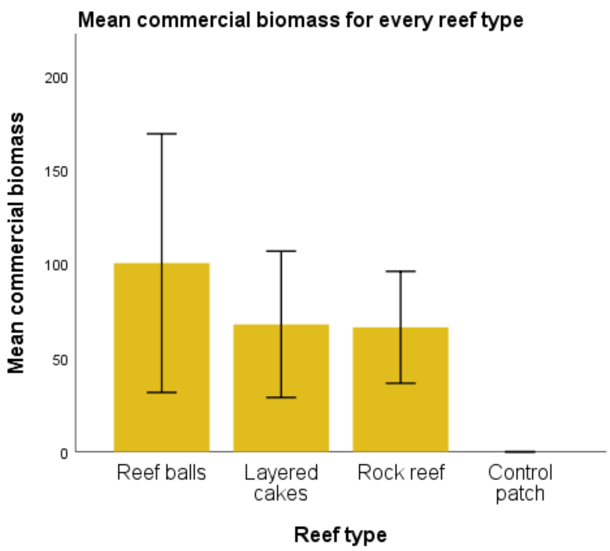

Figure 10: mean commercial biomass in gram (±SE) for every reef type

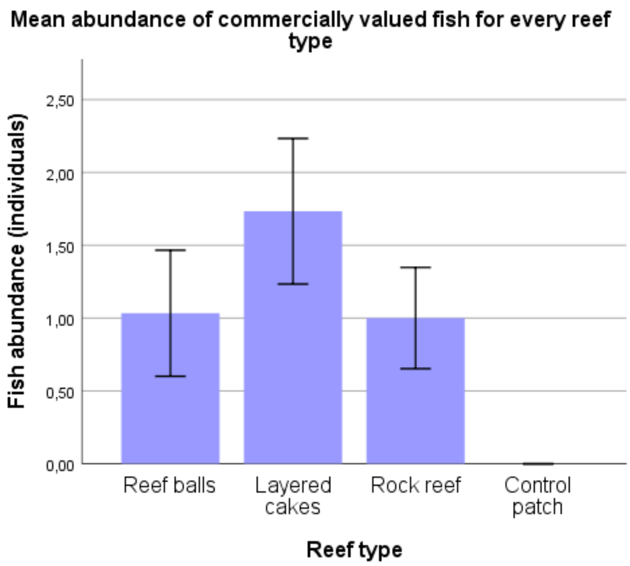

Figure 11: Mean abundance (± SE) of commercially valued species

4.1.2 BIOMASS & ABUNDANCE ECOLOGICALLY IMPORTANT SPECIES

The highest mean ecological biomass (±SD) was found on the rock reef (157.5 ± 194.2g), followed by reef balls (93.3 ± 144.5g) and layered cakes (91.3± 173.5g). This can be seen in figure 12. Reef type had a significant effect on the ecological biomass, $\chi^2(3)=30.6$, $p=<0.01$. However, with a post-hoc there was only a significant difference found between the reef types and the control patch ($p < 0.01$).

A significant effect was found out of a two-way ANOVA for ecological biomass in relation to the combination of location and reef type, $F(6, 118) = 2.20$, $p = 0.048$, $\eta p2= 0.10$. However, the data did not meet the required assumptions for a parametric test.

For the abundance (±SD) there were close numbers found, with reef balls having a mean of 2 fish (± 2.8) on the reef, rock reef 1.8 (± 1.8) fish and layered cakes 1.7 (±1.3), this is displayed in figure 13. There was a significant difference found using a Kruskal-Wallis test, $\chi^2(3)=30,9$, $p=<0,01$. This significance was, however, only found between the reef types and the control patch.

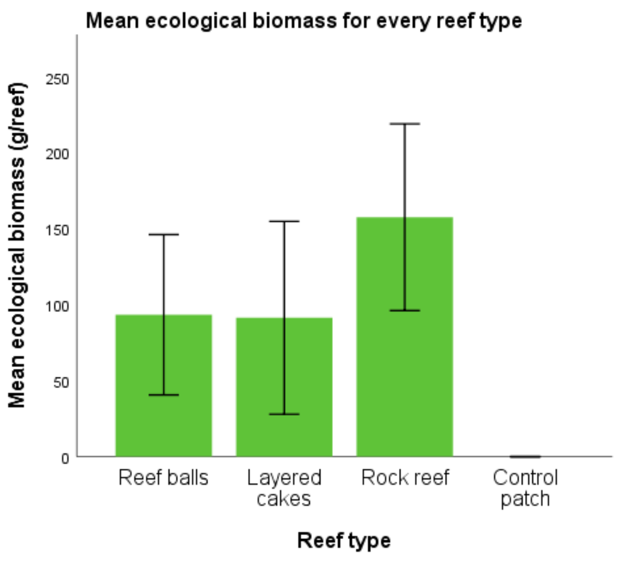

Figure 12: mean ecologically important species biomass in gram (±SE) for every reef type

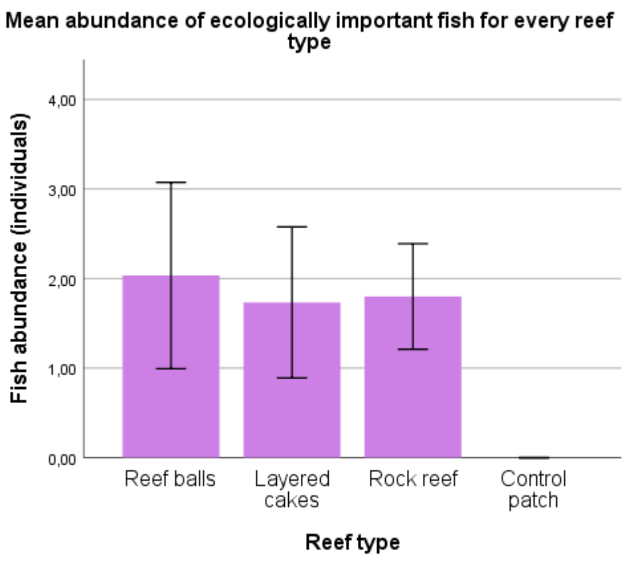

Figure 13: mean abundance of ecologically important fish (±SE) for every reef type

4.2 NURSERY

4.2.1 NURSERY FUNCTION COMMERCIALLY VALUED SPECIES

The highest mean amount of juveniles for commercially important species was found on the layered cakes (1.23 ± 1.07), followed by the reef balls (0.50 ± 0.73) and rock reef (0.40 ± 0.63). The reef type had a significant effect on the commercial juvenile abundance, $\chi^2(3)=41.9$, p=<0.01. Moreover, there were significant differences found between the reef types in a post-hoc analysis. Layered cakes had a significant difference with Reef balls (p=0.02) and rock reef (p=<0.01). The reef balls and rock reef had no significant difference (p=0.93).

Figure 14 shows the abundance of juveniles in proportion to adults. The percentage of juveniles was highest with an average of 72.3% on the layered cakes. This was 48.5% for reef balls followed by the rock reef with 40%.

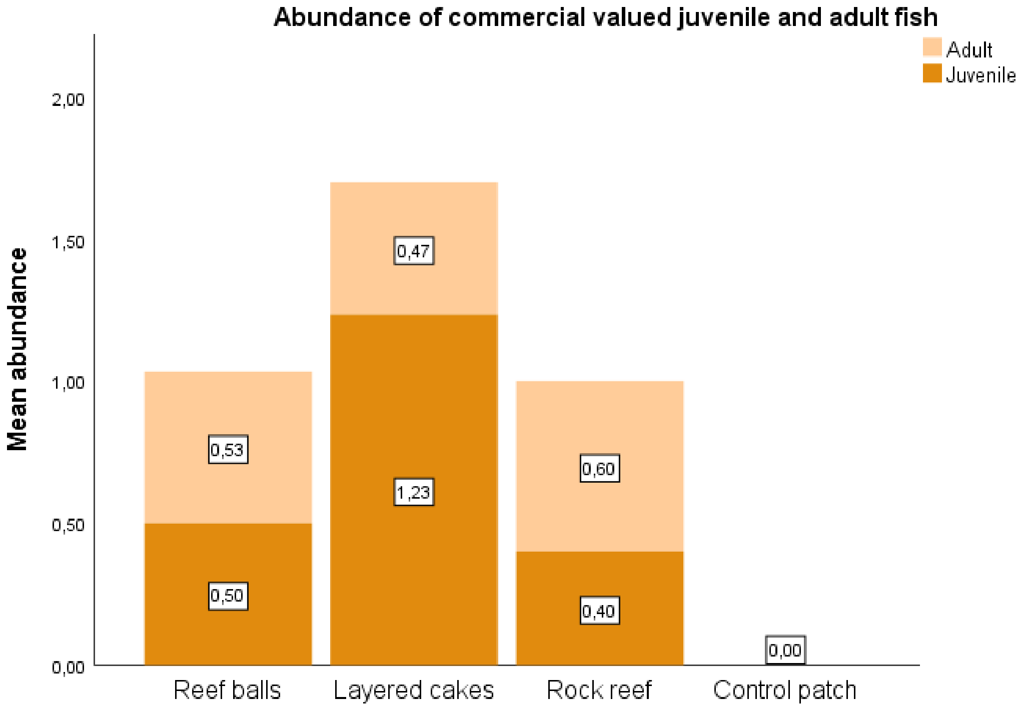

Figure 14 : A stacked bar chart displaying the mean amount of commercially valued adults and juveniles.

4.2.2 NURSERY FUNCTION ECOLOGICALLY IMPORTANT SPECIES

The abundance (± SD) of ecologically important juveniles was highest on the reef balls (0.67± 1.26), followed by layered cakes (0.57± 1.00) and the rock reef (0.28± 0.75). A Kruskal-Wallis test found a significant difference, $\chi^2(3)=14,2$, $p=<0,01$. A Games-Howell post-hoc found this significance to be between the reef types and the control group.

Figure 15 shows the abundance of juveniles in proportion to adults. The layered cakes have the highest percentage of juveniles for the ecologically important families with 48.7%. The reef balls were slightly lower with 47.8% followed by, the rock reef had 14.6%.

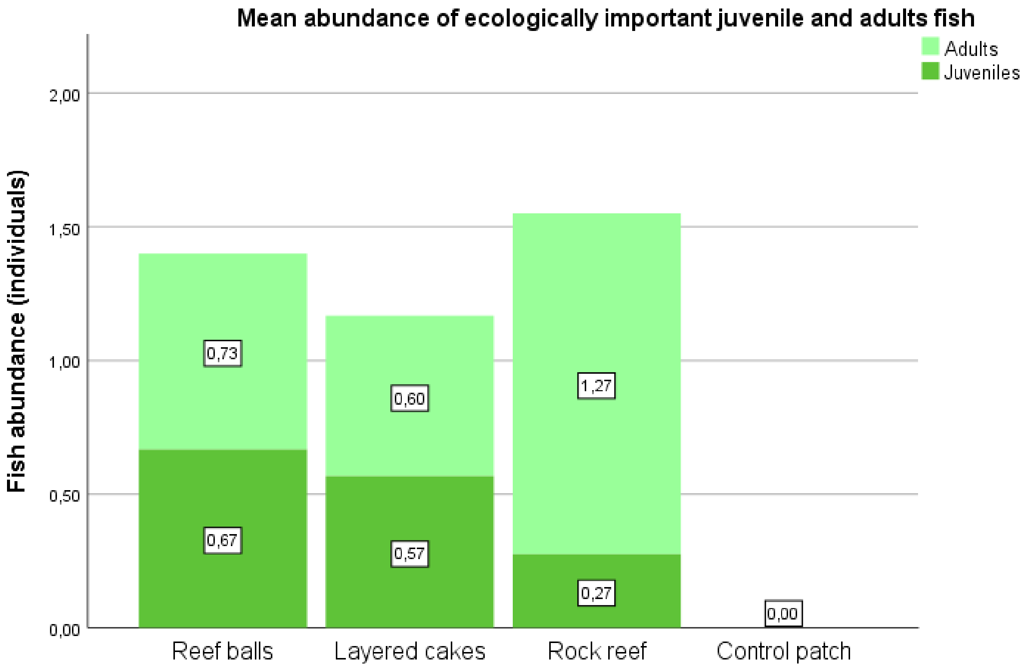

Figure 15: A stacked bar chart displaying the mean amount of ecologically important adults and juveniles.

4.3 MULTI-CRITERIA ANALYSIS (MCA)

The reef balls scored best in the MCA with a mean score of 7 followed by, the layered cakes with a 6.8 and the rock reef with 5.5. TS3 which were the layered cakes on Twin Sisters scored highest as individual reef with an 8.5. Table 2 and 3 both show the results of the MCA. Table 2 shows the scoring for every reef based on the multi-criteria analysis index given in the materials and methods (table 1), A table with the original values can be found in Appendix III. Table 3 displays the overall score of the reefs, here there is a division made between ecological and commercial.

Reef type	Location	Ecological biomass(g)	Juvenile abundance	Juvenile percentage	Commercial Biomass (g)	juvenile abundance	Juvenile percentage
Reef balls	BR1	2	1	1	6	1	1
	CC1	10	5	4	2	4	5
	TS1	4	2	3	10	4	5
	Mean	6	3	3	8	4	4
Layered cakes	BR2	4	1	1	2	4	5
	CC2	4	4	5	6	3	4
	TS3	10	3	3	8	5	5
	Mean	6	3	3	6	4	5
Rock reef	BR3	10	4	3	6	1	2
	BR4	8	1	1	6	2	2
	CC3	10	3	2	4	2	5
	TS2	6	2	3	4	2	5
	Mean	8	2	1	6	2	3
Control	BR6	2	1	1	2	1	1
	CC4	2	1	1	2	1	1
	TS4	2	1	1	2	1	1
	Mean	2	1	1	2	1	1

Table 2: Scores of reefs according to the multi criteria analysis index (red (very bad), orange (bad), yellow (intermediate), light green (good,) dark green (very good).

Reef type	BR1	CC1	TS1	Reef Balls	BR2	CC2	TS3	Layered cakes	BR3	BR4	CC3	TS2	Rock Reef
Ecological	2	9.5	4.5	5.5	4.5	6.5	8	6	8.5	5	7.5	5.5	5.5
Commercial	4	5.5	9.5	8	5.5	6.5	9	7.5	4.5	5	5.5	5.5	5.5
Overall	3	7.5	7	7	5	6.5	8.5	6.8	6.5	5	6.5	5.5	5.5

Table 3: Calculated grades (1-10) per artificial reef, divided in ecological and commercial. <3.5 = very bad (red), 3.5-5 = bad (orange), 5-6.5 = intermediate (yellow), 6.5- 8 = good (light green) and 8> = very good (dark green).

5. DISCUSSION

Habitat function

The reef balls had the highest biomass of commercially important species. However, the differences between the biomasses of the commercially important species on the three different artificial reef were not significant. The highest abundance of the commercial important species was found on the layered cakes. The most observed species was the Coney *(Cephalopholis fulva).* Followed by the Red hind (*Epinephelus guttatus*) and Tomtate *(Haemulon sciurus)*. The abundance of the Coney, Hind and tomtate is not a surprise, all species are according to IUCN 'least of concern' in the area (IUCN., 2011 ; IUCN., 2016 ; IUCN., 2018). The high abundance on the layered cakes could be explained by the most observed species were small or juvenile individuals, and the layered cakes could offer shelter and protection from predatory fish due to their small hide-outs. The reef balls compared to the layered cakes and the pile of rocks have the most spacious shelter areas. The holes in the reef balls have an average diameter of 25 cm. While for the layered cakes, the spaces are between 8,5 and 12 cm. The adult individuals are ambush predators and bigger in size, they mainly hunt for small fish and crustaceans (Pereira & Ferreira., 2012). A study on the three-dimensional structure found an increase in commercially valued species when the structure of the reef decreased, while this was based on large scale reef dynamics this could explain the highest biomass on the reef balls (Alvarez-Filip et al., 2015). Another study found a reduction in juvenile abundance after decreased structural complexity, which could explain the high abundance rather than biomass on the layered cakes (Graham et al., 2007). There is speculated that spaces in the reef balls are easily accessible for these species and form a perfect habitat to ambush their prey. Based on observations during the data collection, there is suspected that the shape of the reef balls provides no safe hide-out for potential prey species making them vulnerable and easy prey for larger commercially valued individuals.

The data showed that the rock reef had the highest biomass for important ecological species. However, between the three different types of artificial reefs, there was not a significant difference in the biomass of ecologically important species. It was expected that the abundance would be the best on the rock reef due to their high structural complexity. However, the highest abundance was found on the reef balls. The difference between the abundance of the three types of the artificial reef was so small it could be considered negligible. The most common observed important ecological species were the Ocean surgeon fish (*Acanthurus tractus*) and Blue tang *(Acanthurus coeruleus).* The rock reef has due to their high three-dimensional structure a large grazing surface (Bruggemann et all, 1994). The observed species are relatively small and low in biomass individual (max 30 cm) (Reefguide. 2016). Due to their size, these species can easy hide in the small hide-outs of the rock reef together with a relatively big surface area, it is a suitable foraging ground for the ecologically important species.

Nursery function

It was found that the layered cakes have a significant difference in the abundance of juvenile commercial important species with the rock reef and reef balls. The layered cakes had a percentage of 71 % juveniles and 29 % adults. This could be explained by the design of the layered cakes, the hide-outs are smaller with an average distance of 12 cm between the layers. The hide-outs run deep till the centre of the layered cake, which makes it hard for predatory fish to hunt the juveniles. According to Beets and Hixon (1994), it was observed that juvenile groupers ranging 3-8 cm used small burrows beneath the base of an artificial reef as a hide-out. This complies with research finding that structural complexity is crucial for small-bodied fish and positively influences the food chain length (Alvarez-Filip et al., 2011). There were often small fish, such as the yellowhead wrasse, observed. These small fish are suitable prey for juvenile commercial valued species (Freitas, et all, 2017). These studies support the found results, the abundance in prey species together with the design of the layered cakes explain their leading role as a nursery for commercially important species.

It was found that there is no significant difference between artificial reefs for the abundance juveniles of ecologically important species. The reef balls have the highest mean, but the ratio juveniles/ adults are close to the ratio on the layered cakes. The differences are so small it could be explained by the natural habitat variation. In comparison between the ratio of commercially important species and ecologically important species. It is seen that the commercially important species have a bigger amount of juveniles in relation to the total abundance of commercially valued species than the ratio juvenile/ adult of ecologically important species. This could be explained, that the juvenile ecological important species prefer the natural reef as habitat but the artificial reef as a foraging area (Bruggemann et all, 1994).

Reef preferences for different species groups

This study shows that commercially and ecologically species prefer different reef types as habitat and nursery. The commercially important species have higher biomass on the reef balls, this was the rock reef for the ecologically important species. The total biomass is highest on the layered cakes**.** During the data collection surveys, it was often observed that some species would show territorial behaviour, this was mostly done by the Sergeant-Major *(Abudefduf saxatilis*) and long spine squirrelfish (*Holocentrus rufus)*. Their territorial behaviour probably led to a decrease in biomass of ecologically and commercially important species on the layered cakes. There was, however, found that the abundance of commercially important species was highest on the layered cakes. This because of these territorial fish target larger fish, as they form a bigger threat to their territory. Providing smaller individuals with a safe spot to stay. There was found that the usage of reef types is different within the two species groups. Reef balls had the highest biomass of commercially valued species, this was the rock reef for ecologically valued species.

Difference in location

While there was no significant difference found between the three locations, it might be possible that the difference in location affect the way the different reef types perform. When looking at the individual reefs per location, there is seen that the ecological biomass on Big Rock Market was lowest on the reef balls (14.2g). This is contradictory to the reefs on Crooks Castle where mean ecological biomass was lowest on the layered cakes (45.6g). This effect is presumably caused by the considerable variation in reef habitat between the locations of the reefs. There was observed that the natural reefs on Saba had a more three-dimensional structure and a larger abundance of fish compared to the natural reefs on Sint Eustatius. This observation can be verified by looking at reef health assessments performed in the area, which results matched these observations (DCNA, 2018). When the natural reef is healthier, the demand for additional three-dimensional structure diminishes and deployed artificial reef will lose inhabitancy.

The large spread found within the data could be caused by the low number of actual reefs surveyed. Together with the varying habitat surroundings between locations, this may have caused a large spread.

Multi-criteria analysis

Biomass rather than abundance was chosen in the multi-criteria analysis as it matches several other studies done on (artificial) reef assessment (De Graaf et al., 2015; Fabi et al., 2002; Global Coral Reef Monitoring Network, 2016; Sherman et al., 2002).

The values used in the categorising of the multi-criteria were solely based on the data found in this study. Due to this, the ranking is a comparison between the surveyed reefs. Where the analysis was preferably based on literature of overall reef health assessment. There was chosen not to, because of the already small differences between the reefs. Also, the size of the experimental reefs demanded a different data collection method than used in natural reef surveying. In natural reef surveying, fish are counted alongside a transect line. While a stationary count was used for the artificial reefs. The reefs are still in an early stage of deployment, and the isolation of the reefs can result in fish aggregation around the reefs (Bohnsack, 1989). Even though the multi-criteria analysis was based on found values. When looking at a reef health index used in the assessment of Sint Eustatius's natural reef in 2015, values on biomass match with the found results on the artificial reefs. In this study the rock reef would be categorised as 'good' for ecologically important species, while the other reef types would be categorised as 'poor'. The reef balls would score 'very good' on commercially valued biomass and the other reef types 'good'. In this research the natural reef scored 'very good' for both categories (De Graaf et al., 2015). Further comparison to the natural reef would be feasible if artificial reefs were deployed on a large scale, imitating the scale of a natural reef.

Implications with the fisheries sector

Saba and Sint Eustatius have different regulations and enforcement concerning the fisheries sector. the zoning system on Saba allows fishing around the artificial reefs (SCF., 2019). However, fishing pressure in this area is negligible. This is due to the presence of the Saba bank in less than 2 km from Saba (WUR., 2013). There are no advantages for the fishermen on Saba to fish on these artificial reefs as the presence of commercial valued species is negligible compared to the natural reef on the Saba bank (WUR., 2013). There is a continued amount of fishing pressure on snapper and grouper species in the waters around Sint Eustatius (De Graaf, et al., 2015). The designated marine parks around Sint Eustatius run till a depth of 30 meters, and most fishing occurs just on the edge of the marine park (Personal communication: Kimani Watson., 2018). The artificial reefs on Sint Eustatius were placed in the southern marine reserve, which has a complete fishing prohibition and is a no-take zone (Personal communication: Kimani Watson., 2018). During the data collection, it was observed that fish traps were placed in the marine reserves up to five meters away from the artificial reefs at Crooks Castle. There is a possibility that species inhabiting the artificial reefs might move towards the fish traps. However, until now the small-scale deployment has a negligible impact on the local fisheries sector (Polovina J., 1998). If in the future more artificial reefs get deployed on the currently used location this can have implications for the fisheries sector on Sint Eustatius and Saba. According to Grossman et al. (1997) it is possible that artificial reefs increase the production of organism targeted by commercial fisherman. This can have positive impacts on local fish stocks and ultimately on catches. Direct fishing pressure around and on the artificial reefs, resulting that the artificial reefs do not serve as a habitat but more as a fish aggregation device, is controversial as the attraction of fish from the surrounding ecosystem can lead to the overall depletion of fish stocks in the area (Osenberg et al., 2002; Polovina J., 1998).

6. CONCLUSION

Sub-question 1: What is the biomass of the key ecological fish species* on the artificial reefs?

The results showed that the rock reef had the highest biomass for important ecological species (157.5 ± 194.2g). They were followed by the reef balls with (93.3 ± 144.5g) and the layered cakes with (91.3± 173.5g). However, there was no significant difference between the reef type and biomass of ecologically important species.

Sub-question 2: What is the biomass of commercially valued fish species* on the artificial reefs?

It was found that the reef balls had the highest mean biomass of commercially important species (100.3 ± 188.3g). It was followed by the layered cakes which had a biomass of (67.7± 106.5g) and the rock reef with biomass of (66.1 ± 94.0g). However, there was no significant difference between the reef type and biomass of commercially important species.

Sub-question 3: What is the abundance and percentage of juvenile fish of ecologically important species* on the artificial reefs? The results showed that highest abundance juvenile ecological important species was found on the reef balls (0.67± 1.26) and with 48.7% juveniles. They were then followed by the layered cakes (0.57± 1.00) with 47.8% juvenile and the rock reef (0.28± 0.75) with 14.6% juvenile ecological important species. However, there were no significant differences between the different reef types and the abundance and percentage juveniles fish of ecologically important species.

Sub-question 4: What is the abundance and percentage of juvenile fish of commercially important species* on the artificial reefs? The results showed that there was a significant difference between the layered cakes and the reef balls ($P=0.02$) and the layered cakes and the rock reef ($p < 0.01$). The highest abundance juvenile commercial important species was found on the layered cakes (1.23 ± 1.07) with 72.3% juveniles, after that the reef balls (0.50 ± 0.73) with 48.5% juveniles and the rock reef (0.40 ± 0.63) with 40% juveniles.

Main question: Which type of artificial reef functions best as habitat and nursery for a combination of both ecologically and commercially important species*?

The three types of artificial reefs performed differently in the multi-criteria analysis. Where for the commercially important species the reef balls performed best for as habitat and layered cakes as a nursery. The rock reef did best as habitat for ecologically important species, and reef balls and layered cakes as a nursery. When looking at the reef with the highest overall score, the reef balls performed best. However, there is seen that all reefs perform best for one of the categories. The choice of a reef type is dependent on the goal the reef type is placed for. When looking at all criteria a combination of reef types could be the best option.

7. RECOMMENDATIONS

The results showed that different species groups prefer different types of artificial reefs. It is critical to know which problem needs to be tackled before a choice can be made between which kind of artificial reef needs to be deployed.

While reef balls scored best, it is recommended to use multiple reef types to best facilitate the habitat and nursery needs for both species groups. This is when a deployment has an aim to restore the natural ecosystem and create habitat and nursery for both species groups.

The biomass of commercially important species was the highest on the reef balls. While these could be used to support local fisheries, there should be additional research on the impacts of direct fisheries on artificial reefs. When solely aimed to increase production without direct fisheries on the artificial reefs, the reef balls would be the recommended option for commercially valued species.

In efforts to tackle dominating algae or the overfishing of ecologically important species, it is recommended to deploy the 'rock reef'. These scored the best as a habitat for important ecological species.

For future research, it would be suggested to use locations with similar surroundings. This way, the data is not affected by the variation in habitat . Furthermore, the deployment of more artificial reefs would increase the n-value. Additionally, researching the use of multiple types of the artificial reef would be recommended.

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APPENDIX I: FISH SURVEY SHEET

Example of fish survey sheet used in collecting data.

Date:		Location (eg T S3):				Temperature:			
Time:		Treatment: reef ball (RB),				Bottom depth:			
Counter:		layered cake (LC), rock				Duration current measurement:			
Filmer:		(RO), Control (CO), Patch				Distance:		Direction:	
Species/Categories	0 - 5	5 - 10	10 - 15	15-20	20 - 25	25 - 30	30-40	40-50	
Bicolor Damselfish									
Brown chromis									
Blue Chromis									
Sergeant Major									
Coney									
Red Hind									
Rock Hind									
French Grunt									
Tomtate									
Red band Parrotfish									
Princess Parrotfish									
Queen Parrotfish									
Redtail Parrotfish									
Squirrelfish									
Blackbar soldierfish									
Flamefish									
Glasseye Snapper									
Ocean Surgeonfish									
Bluetang									
Doctorfish									
Bluehead wrasse									
Yellowhead wrasse									
Slippery Dick									
Rainbow wrasse									
Spotted Goatfish									
Spanish Hogfish									
Rosy razorfish									
Highhat									
Whitespotted Filefish									
Spotted Drumfish									
Cleaner goby sharknose									
Blenny and goby other									
Notes:									

APPENDIX II: FISH SURVEY PROTOCOL

Divers require extensive training in fish identification and size estimation prior to conducting the survey.

Materials

1. Dive computer
2. Secchi disk
3. Go pro + under water light
4. Slates, pencils, and sheets printed on underwater survey paper
5. Compass and weights for current measurement

Method

Divers will start with the outer experimental plot of an experimental block. After finishing the first survey, divers continue to the adjacent experimental plot, survey this plot, and continue to the next plot, etc.

1. Check if all the equipment is present and working and go to the right location
2. Fill in the names of the observers and the date, time and location
3. Check visibility. Use Secchi if necessary. SDD should be at least 5 meter to proceed with survey
4. Start survey dives on alternating outer experimental plots (*eg* start first survey at north side, second at south side, third at north, etc)
5. Descend at least 10 m away from the experimental plot
6. While slowly swimming towards the survey area horizontally, diver 1 will record the fish, while diver 2 is filming the survey for future reference and for identification of unknown sp.. As diver 2 is not to disturb the fish before the counting, he will swim slightly behind/next to diver 1.

All the fish within a virtual cylinder (1 meter sideways of the plot and 2 meters upward from the bottom) around the experimental plot are included in the survey. Fish in the cylinder are identified up to species level, counted and classified in size categories 0-5, 5-10, 10-15, 15-20, 20-25, 25-30, 30-40, 40-50, 50-60, etc, cm TL (from the tip of the snout to the tip of the longer lobe of the caudal fin).

7. Start with filming the survey sheet, so date, time, location, HSDD are visible on film.
8. Start recording fleeing fish at 5 meters distance of the artificial reef.
9. At 2 meters stop swimming and start stationary count for 3 minutes (use go pro to monitor time).
10. During the stationary count, all fish in the cylinder, also fish entering during the survey, are included in the survey. You count a fish only once, even if it repeatedly swims in and out the cylinder.
11. First record all schools, then record the other fish.
12. After 3 minutes, the artificial reefs will be thoroughly searched to record all the hiding fish. New fish entering the cylinder will not be included in the survey. Use a torch if necessary.
13. Unknown fish will be described as detailed as possible (e.g. Large blackish striped grouper) and can be identified later using video footage.

14. Blennies and gobies are lump summed in 1 category. Exception: cleaner gobies of the genus Elacatinus (eg Elacatinus evalynae, sharknose goby) are identified up to species level.
15. Count all lobster and estimate their carapace length
16. Note anything striking on the artificial reefs (eg. Under water visibility only 6 meters)
17. Determine temperature and bottom depth of the experimental plot.
18. When all fish are counted move towards the next experimental plot and repeat step 6 to 16.
19. If all experimental plots are counted, measure the current direction and speed using the buoyant diver method (measure the distance and direction of a 30 s drift)
20. If 50 bar is reached, ascend slowly to 5 meters to make a safety stop for 3 minutes.
21. After safety stop ascend slowly to the surface and signal the boat.
22. Fill in your data as soon as possible, always on the same day! Always make a picture of the original survey sheets.

APPENDIX III: SPECIES TABLE

All observed species within the commercial and ecologically important families of fish.

Species	Max size	a	B	Maturity size
Commercially important species				
Coney	44 cm	0.0174	2.98	14.7 cm
Red hind	76 cm	0.0123	3.06	25 cm
French grunt	30 cm	0.017	3.05	16 cm
Tomtate	25 cm	0.0115	3.15	14 cm
Rock hind	61 cm	0.0153	3.0	25 cm
Ecologically important species				
Blue tang	39 cm	0.0316	2.96	13 cm
Doctor fish	39 cm	0.0295	2.92	17 cm
Ocean surgeonfish	38,1 cm	0.0348	2.689	15.5 cm
Princess Parrotfish	35 cm	0.0135	3	17 cm
Red band Parrotfish	28 cm	0.0174	3.04	15 cm
Queen Parrotfish	61 cm	0.0153	3.062	32 cm
Redtail Parrot fish	46 cm	0.0154	3.041	17 cm

APPENDIX IV: TABLE VALUES USED IN MULTI CRITERIA ANALYSIS

The values used in this multi criteria analysis.

Reef type	location	Ecological biomass(g)	Juvenile abundance	Juvenile percentage	Commercial Biomass (g)	juvenile abundance	Juvenile percentage
Reef balls	BRM	14.5	0	0%	96.0	0.1	8.3%
	CC	189.6	1.5	57.8%	21.5	0.7	87.5%
	TS	76.5	0.5	35.7%	183.3	0.7	63.6%
	Mean	93.3	0.7	47.8%	100.3	0.5	48.5%
Layered cakes	BRM	61.1	0	0%	24.9	1.2	85.7%
	CC	45.6	0.9	81.8%	80.0	1.0	58.8%
	TS	167.3	0.8	42.1%	98.2	1.5	75%
	Mean	91.3	0.6	48.7%	67.7	1.2	72.3%
Rock reef	BRM (BR3)	207.2	0.95	45.2%	87.9	0.4	24%
	BRM (BR4)	123.3	0	0%	65.5	0.2	21%
	CC	218.7	0.6	22.2%	46.8	0.5	71.4%
	TS	80.8	0.4	36.4%	42.0	0.5	62.5%
	Mean	157.5	0.3	14.6%	66.1	0.4	40%
Control	BRM	0	0	0	0	0	0
	CC	0	0	0	0	0	0
	TS	0	0	0	0	0	0
	mean	0	0	0	0	0	0