AROSSTA
Artificial Reefs on Saba and St. Eustatius

van hall larenstein
university of applied sciences

A review on the suitability of artificial reefs for ecosystem enhancement

Bachelor Thesis – Coastal and Marine Management

Man-made structures to antagonize man made problems

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Preface

My passion for coral reef ecosystems started in September 2015 when I conducted my orientation internship at a coral restoration organization on the small island of Koh Tao, Thailand. I remember that feeling of astonishment and freedom when I dove down to the reef the very first time as if it happened yesterday. I was hooked immediately.

During this five-month internship I learned a lot about the complexity of these incomparable ecosystems and I got in contact with the use of artificial reefs the first time. Conducting hands-on coral restoration work was one of the most rewarding things I ever did. I thought to myself: “I want to do this for a living!” and until today nothing changed about that.

During the course of my study I chased that thought and I conducted my project internship on the island of Bonaire in the Caribbean. Here I executed my own research on growth rates of *Acropora cervicornis* corals on artificial reef structures. Constantly improving my knowledge on this subject, my interest in coral restoration kept on growing.

The idea to conduct my thesis research for the AROSSTA project came in mind while we were still struggling with the research report for the project on Bonaire. The overall poor availability of knowledge on efficient use of artificial reefs in ecosystem restoration was the perfect starting point.

I want to thank Alwin and Jorien for being the best attendants, always pushing me in the right direction and supporting this research with information and constructive ideas. I also want to thank Patrick for the clear and fair feedback you provided. It was a pleasure to work with all of you.

Abstract

The use of artificial reefs for purposes of ecosystem restoration and enhancement is gaining popularity due to recent declines of marine ecosystems. In particular the global decline of natural coral reefs and fish populations demands suitable approaches for improvement. However, is the availability of information on suitable applications of artificial reef construction variables and management aspects for this purpose limited. To synthesize a collection of knowledge a literature review combined with personal specialist communication has been executed. Several artificial reef construction variables have been tested on their potential impact on coral growth/recruitment and fish aggregation. Furthermore, was impact on fishing management and enforcement on the fish abundance of artificial reefs investigated. Results indicate that structure materials influence the successfulness of artificial reefs in terms of coral restoration. The structural complexity of reef modules has been found to have significant influences on the fish abundance of man-made reefs. The environmental appearance of artificial reef deployment areas has been proven to be of importance for both purposes. Limited data availability compromised the significance of the present study in terms of evaluating the impact of fisheries management and enforcement. Nevertheless, it can be stated that fishing management is an important factor to consider when it comes the use of artificial reefs for the purpose of ecosystem restoration. This study provides guidelines for the effective use of artificial reef construction variables and management aspects to improve future restoration efforts.

Content

1. Introduction

1.1 Coral Reef Ecosystems

Coral reefs are one of the most productive and diverse ecosystems. These structure-rich environments provide habitat to a quarter of all marine creatures, although they amount to less than 1% of the entire marine environment (Cesar, 2003). Next to the importance for hundreds of species, these underwater oases are of immense importance for mankind. The high biomass production makes coral reefs a valuable protein source and the stable, three dimensional structures provide natural coastline protection. Furthermore, the attractive underwater landscapes provide income opportunities for the marine tourism sector (Mulhall, 2009). Despite their importance, coral reefs are endangered on a global scale. The health status of coral reefs can be determined by its fish abundance and coral growth and scientists predict, that most coral species and the associated ecosystems could become extinct within the next few decades (Munday, 2004). Global warming, ocean pollution and overfishing have led to numerous events that decimated coral populations. Increasing ocean water temperatures causes bleaching events, where corals reject their zooxanthellae, which are symbiotic photosynthetic algae, that provide the corals with energy. These occasions can wipe out whole reefs within weeks. Anthropogenic ocean pollution favours the outbreaks of coral diseases and overfishing destroys the balance of natural processes on coral reefs (Bryant, 1998). The resulting decimation of these habitats has led to an increase in coral reef restoration projects, in which the use of artificial reefs has become an important approach (Abelson, 2006).

1.2 Caribbean Sea and the Gulf of Mexico

The Caribbean Sea is one of the areas on this planet, that experienced massive loss of coral coverage on the reef ecosystems in the past decades (Meesters, 2014). It used to be home to approximately 9% of the world's coral reefs in the 1980's, but former life coral coverage on Caribbean reefs of 50% has dropped drastically ever since, due to bleaching events and coral diseases (Jackson, 2012). In this area, reef related tourism generates 50% of the gross national product and around 43 million people are dependent on coral reefs (Meesters, 2014). In recent times this resulted in unprecedented efforts for coral reef restoration. Nowhere else in the world are there more conservation projects in place that focus on the problem of reef degradation, with the use of artificial reefs in most cases (Mote Marine Laboratory, 2016).

The Gulf of Mexico forms a less suitable habitat for coral reefs than the Caribbean Sea due to the effects of great riverine systems and upwelling. The sediment enriched water, that streams into the ocean, originating from big rivers increases the turbidity of coastal areas. Effects of upwelling increase the nutrient concentrations in coastal areas which again leads to higher ocean turbidity due to the resulting growth of plankton (Mumby, 2004). Both factors lead to the creation of unfavourable conditions for coral reefs, which depend on clear water with high amounts of light penetration (Mumby, 2004). Therefore, less than 1% of the shallow water areas of this semi-enclosed sea are covered by coral reefs (Jordán-Dahlgren, 2018). The Gulf of Mexico is however a key area for commercial fisheries and due to many cases of overfishing in this area, conservationists and fishermen here focus on the use of artificial reefs for fish aggregation with both aims of ecosystem enrichment and increasing yields (Shipp, 2009).

1.3 Artificial reefs

An artificial reef can be defined as a man-made structure, which is sunken for a purpose. People have used artificial structures in the marine environment for hundreds of years (Seaman, 2000). The most common purposes of artificial reefs are food production, habitat protection or restoration, and recreation. The first use of constructions under water, can be traced back to the 17th century, when fishermen placed reefs to increase fish biomass, to achieve better yields (Whitmarsh, 2008). Artificial reefs provide hard substrate and structure, which is critical habitat in marine environments and has a great appeal for fish and the colonization of sunken structures can be very rapidly after deployment (Bohnsack, et al., 1994). Additionally, the hard substrate provides suitable surfaces for algae to grow and shelter from predation or tidal currents for small benthic fauna (Pickering & Whitmarsh, 1996). The resulting algae growth and aggregation of small fauna, which often form the basis of marine food chains, continuously attracts fish and other marine biota, since the increased food availability results in a high feeding efficiency. Especially in marine environments with little or no structure, the placement of an artificial reef can attract all kinds of marine creatures, which also provides opportunities for ecosystem restoration (Lukens, 1997). In terms of coral restoration, artificial reefs have the potential to provide hard substrate for corals to settle and grow. They can replace the calcium structures of natural reefs, which have been destroyed in many cases. Coral growth and fish aggregation however, vary significantly on different artificial reefs (Fitzhardinge & Bailey-Brock, 1889).

Fritzhardinge, et al. (1989) tested coral settlement and growth on different artificial materials in the coastal area of Hawaii. The results showed distinct differences in coral settlement between the materials used during this study, being concrete, rubber and metal. Between these three materials, metal was found to be the most suitable for coral settlement, while rubber was considered to be unsuitable, since no coral settlement was asserted. Results of this study also conclude differences in coral settlement on the same materials in different depths, which is justified by decreasing light penetration with increasing depth. A study on the aggregation of lobsters on artificial reefs showed significant differences in structure occupation of the same species in different habitat types. Researchers deployed identical concrete structures in natural benthic habitats which only differed in the availability of seagrass and hard bottom with the result, that seagrass availability was the key factor structure occupation (Sosa-Cordero, 1998). Bohnesack, et al. (1994) found that the size of an artificial reef (number of structures) had influence on fish aggregation both in terms of species abundance and number of individuals. They concluded that the fish density on small artificial reefs was higher, and that bigger species prefer to occupy bigger artificial reefs. A literature review, executed by Pickering & Whitmarsh, (1996) concluded that the design of artificial reef structures is essential to maximise their productive potential especially in terms of attracting particular fish species. They found evidence that dice shaped artificial reefs were preferred by rockfish (*Scorpaenidae*), while fin-fish (*Actinopterygii*) showed preference for cylinder shaped structures.

The findings of these studies lead to the assumption that construction variables that are likely to influence both coral growth and fish aggregation on artificial reefs are the type (shape), material and size of the used structures, the number of structures on a reef, and the type and depth of the surrounding habitat.

1.4 Fishing on artificial reefs

Next to purposes of ecosystem restoration, artificial reefs can be interesting for fishing efforts since they can evidentially produce and attract fish biomass (Bohnsack, et al., 1994). In fact, the first reported use of artificial structures in marine environments was to increase fishing yields since fishing on artificial reefs can provide considerable advantages (Whitmarsh, 2008). Increased and concentrated fish biomass helps fishermen to locate fish, reduce fishing effort and lower the use of fuel and time (Whitmarsh, 2008). In the field of research on fish abundance however, there is general uncertainty about whether the phenomenon of increased fish biomass on artificial reefs is caused by processes of fish attraction or production (Smith, 2015). An increase of new fish biomass due to enhancement of critical habitat and an associated increase in the carrying capacity of the ecosystem could be a real advantage for fisheries as well as for ecosystem restoration. The attraction of already existing fish however, could lead to an ecological depletion of the ecosystem surrounding artificial reefs and increase the potential of overexploitation. Fish that are attracted due to behavioural preferences are much easier to catch than under normal conditions, where they would disperse over bigger areas (Smith, 2015). Although this problem is established as potentially dangerous, only few studies with the aim of investigating overexploitation caused by the use of artificial reefs have been executed and the impact of fishing pressure on the abundance of fish on artificial reefs poorly assessed (Smith, 2015). However, it can form a crucial factor for the formation of fisheries management and is certainly interesting for the use of artificial reefs for ecosystem restoration.

1.5 AROSSTA

One of the numerous organizations that are experimenting with artificial reefs with the purpose of ecosystem restoration is the Dutch university of applied science, Van Hall Larenstein. They started a collaborative initiative with local conservation organisations to effectively restore coral reefs around the islands of St. Eustatius and Saba, located in the Dutch Caribbean, in March 2017. The purpose of this project, named 'AROSSTA' (Artificial Reefs on Saba and Statia), is to study, whether the use of artificial reefs will help to restore existing natural reefs (NWO, 2017).

1.6 Problem description

Sunken structures provide hard substrate, which has the potential to favour coral growth and increase fish biomass. Both qualities are important for the health of coral reefs, which makes the use of artificial reefs a potentially suitable technique for the restoration of these ecosystems. Numerous studies have shown, that construction variables of artificial reefs are key factors for both fish aggregation and coral growth. There is however only limited information available on suitable combinations of construction variables for artificial reefs with the purpose of coral ecosystem restoration. Especially long-term studies on the development of artificial reefs with this purpose are scare (Perkol-Finkel, 2004). Former studies have furthermore suggested, that fishing pressure on artificial reefs could lead to overexploitation. Nevertheless, is the availability of information on fisheries management on artificial reefs and associated impacts poor (Smith, 2015). Both of these information parameters are however crucial for artificial reef projects like AROSSTA, to identify the most efficient use of artificial reef construction variables in terms of ecosystem restoration and for the formation of adequate fisheries management.

1.7 Problem Statement

There is a lack of information on suitable combinations of construction variables for artificial reefs with the purpose of ecosystem restoration in the form of coral growth and fish attraction. There is furthermore, a lack of information on the management and the effects of fisheries on fish abundance of artificial reefs.

1.8 Research aim

This study is designed to provide insight in potential links between the performance of artificial reefs on coral growth and fish attraction and their construction variables. Furthermore, it provides insight on forms of management and associated effects of fisheries on artificial reefs. With the results of this study, advises can be formulated, that can help conservation organizations to increase their chance of implementing artificial reef projects that are successful in terms of coral reef ecosystem restoration.

1.9 Research questions

Main question 1:

Which combination of artificial reef construction variables can be beneficial for the settlement and growth of coral and for the attraction of fish?

Sub-questions:

The sub-questions associated with the first main question are related to the different construction variables and their impact on the settlement and growth of coral and the attraction of fish. The variables are:

a) Artificial reef structure type
b) Artificial reef structure material
c) Habitat of artificial reef
d) Depth of artificial reef
e) Number of artificial reef structures
f) Size of artificial reef structures

Main question 2:

What is the impact of potential fisheries management and enforcement on the abundance of fish on artificial reefs?

Sub-questions:

Is fishing on artificial reefs in the Caribbean Sea and the Gulf of Mexico associated with management and enforcement?

Are there differences in fish abundance between artificial reefs where fishing is being practiced and unfished artificial reefs?

2. Materials and Methods

2.1 Research Area

The research area of the present study compounds of the Caribbean Sea and the Gulf of Mexico. During this research, all islands, countries and states in the research area are considered for data collection and none have been excluded (*Figure 1, 2*). The archipelago of the Caribbean islands consists of 25 countries and more than 35 islands. The area is bordered by the countries of Venezuela, Columbia, Panama, Costa Rica, Nicaragua, Honduras, Guatemala and Belize. The Caribbean Sea covers 2,754,000 km² and is divided into 5 ocean basins separated by submarine ridges (Agard, et al., 2007). The geographic characteristics of the Caribbean Sea make it the perfect place for coral growth. Nevertheless, are the coral reef ecosystems, which used to flourish in this area under considerable threat in recent times (Meesters, et al., 2015) (Bryant, 1998).

Countries in the Caribbean Sea

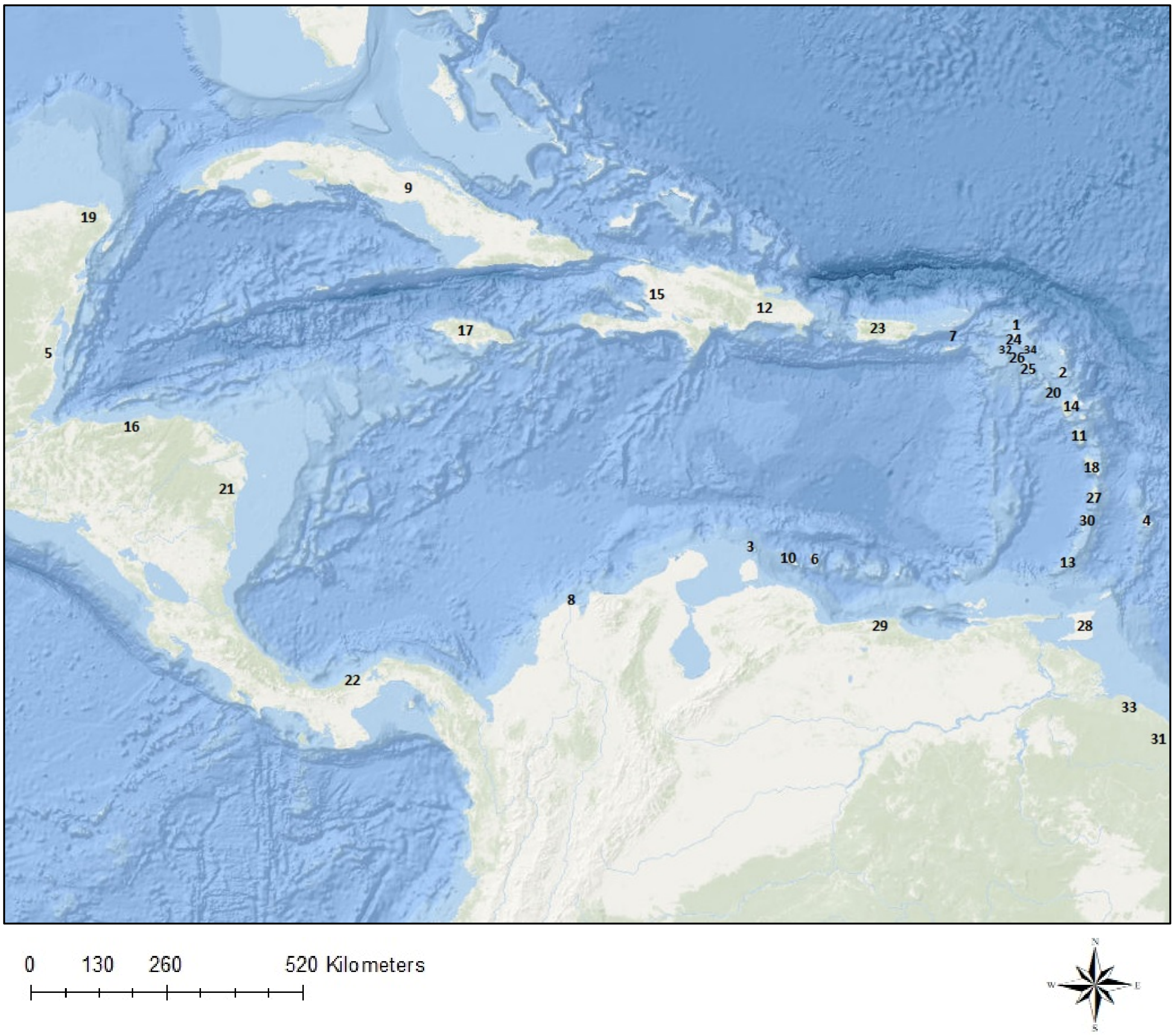

Figure 1: Countries in the Caribbean Sea. 1: Anguilla, 2: Antigua, 3:Aruba, 4: Barbados, 5:Belize, 6: Bonaire, 7:British &Virgin Islands, 8:Columbia, 9: Cuba, 10: Curaçao, 11: Dominica, 12: Dominican Republic, 13:Guadeloupe, 14: Haiti, 15: Honduras, 16: Jamaica, 17: Martinique, 18: Mexico, 19: Montserrat, 20: Nicaragua, 21: Panama, 22: Puerto Rico, 23: St. Martin, 24: St Kitts & Nevis, 25: St. Eustatius, 26: St. Lucia, 27: Trinidad, 28: Venezuela, 29: St. Vincent, 30: Suriname, 31: Saba, 32: Guyana, 33: St. Barts

The Gulf of Mexico is bordered by Mexico and the USA with the states of Florida, Alabama, Mississippi, Louisiana and Texas, and the island of Cuba. This semi-enclosed sea located at the southeast shores of the USA, covers an area of almost 1.5 million km² and reaches depths of 3660m (Love, et al., 2013). The Gulf of Mexico is a key area for commercial fisheries and almost one third of the natural gas and a quarter of the crude oil production in the United States is located here (Hillegeist, et al., 2011).

Figure 2: Countries in the Gulf of Mexico. 1: Florida, 2: Alabama, 3: Mississippi, 4: Louisiana, 5: Texas, 6: Mexico

2.2 Data collection

For the data collection of this study, an artificial reef is defined as one single structure (for example a wreck) or a gathering of multiple structures which will be referred to as 'artificial reef units', with less than 50m space in-between the reef units. The data collection during this study is divided in two main activities: (1) a review on relevant literature that is available on the internet, and (2) contacting practitioners like researchers, scientists and dive industry professionals. Practitioners have been contacted via e-mail or Skype and interviewed with a digital (email) or verbal (Skype) survey that contains questions, designed to gather information on associated artificial reef usage. The reason for contacting stakeholders is the overall poor availability of in-depth information on the history, management and purpose of artificial reef cases on the internet, since most artificial reefs are deployed during small scale projects without public interest (Baine, 2001). Information on these cases can however be available, for example in unpublished project-intern documents or in the form of practitioner knowledge.

The focus during the data collection phase lies on two types of information. Firstly, on information concerning the construction variables of artificial reefs and their suitability for coral growth and fish aggregation (*'Type', 'Number', 'Habitat', 'Depth'*, '*Material', 'Size Dimension', 'Evaluation coral growth/recruitment', 'Evaluation fish abundance'*) and secondly, on information about the management and associated enforcement of potential fisheries on artificial reefs ('*Fishing', 'Fishing management', 'Fishing management enforcement'*). These two types of information parameters have both been used for the data analysis with the goal to answer the research questions of this study. Next to these main objectives, global information parameters have been gathered for the synthesis of an overview figure of all artificial reef cases found during this study *('Country', 'Name Location', 'Purpose'*). Additionally, information parameters have been collected to announce the reliability of the information source *('Language', 'Monitoring', 'Contact person', Report available', 'Source'*). Furthermore, data on financial aspects of the artificial reef cases found during this study has been collected (*'Who & How Funded', 'Budget Costs'*). This information is not relevant for the data analysis of this study. However, this information has the potential to contribute to the AROSSTA project, by indicating financial aspects, which is a crucial factor for the implementation of artificial reef projects. All mentioned information parameters are explicated in *Appendix 2*.

During the minor 'Sustainable fisheries and Aquaculture', which forms a section of the bachelor study 'Coastal and Marine management' on the Van Hall Larenstein university of applied science in the Netherlands, an inventory on the use of artificial reefs in the Caribbean Sea has been executed in 2017. The aim of this study was the synthesis of an overview on the global use of artificial reefs in the area and a total of 109 cases were found. These results have been reviewed, corrected in terms of source validity and supplemented with additional information during the present study. 21 cases have been dismissed due to source limitations.

2.2.1 Literature review

The literature review was conducted by searching the web and reviewing sites, reports, articles and other grey literature. This has been done in a country wise approach. *Table 1* lists the search-terms that were used during the literature review to find cases of artificial reef usage and to collect specific data on artificial reef cases. These terms were combined with 'Caribbean Sea', 'Gulf of Mexico' and the names of countries, islands and states in the research area. All search-term combinations have been used in 'Google' and 'Google-Scholar'. The literature review aims on collecting as many information variables as possible and on gathering contact data of practitioners. In cases of missing information parameters on the literature source and available contact data, practitioners have been contacted.

Table 1: List of search-terms

Terms for finding artificial reef cases	**Terms for specific data on artificial reef cases**
Artificial reef structure	Average depth of the reef site
Bio rock	Average size of the reef unit(s)
Casitas (*)	Habitat type of the reef site
Coral reef restoration	Legislation on artificial reefs
Coral Gardening	Material of the reef unit(s)
Coral conservation	Number of reef unit(s) on the site
Coral reef restoration	Purpose of the reef site
Coral restoration foundation	Type of reef unit (s)
Diving	
Fish aggregation	
Lobster aggregation	
Reef balls	
Sunken structures	
Nature conservation organization	
Wreck	

(*) structure for lobster aggregation (Spanish)

2.2.2 Digital survey and interviews

The first communications were conducted in the form of emails, which are written in English. The email can be found under *Appendix 3*. Multiple stakeholders have been contacted simultaneously for the same artificial reef case. The link to a purpose made online survey has been attached to the emails, which contained questions about the information parameters that have been collected during this study ('*Name Location, 'Year', 'Type', 'Number', 'Habitat', 'Depth', 'Material', 'Size Dimension', 'Purpose', 'Who & How Funded', 'Fishing', 'Fishing management', 'Fishing management enforcement', 'Budget Costs', 'Monitoring', 'Evaluation coral growth/recruitment', 'Evaluation fish abundance', 'Contact person', 'Report available')*. The survey can be found under *Appendix 4*.

In cases of no response within a timeframe of five workdays, the identical email was sent anew. If another five workdays went by without any contact being made and a phone number was available, practitioners have been contacted and interviewed on the phone, using Skype. Interviews contained the same questions as the surveys. If still no contact could be announced, every effort was made for the sake of this study and the missing information parameters have been marked as 'not available' (N/A) in the data matrix. In cases of missing information parameters during the stakeholder communication process, this has been noted as 'not available' as well. The detailed data collection procedure is visualized in *Figure 3.*

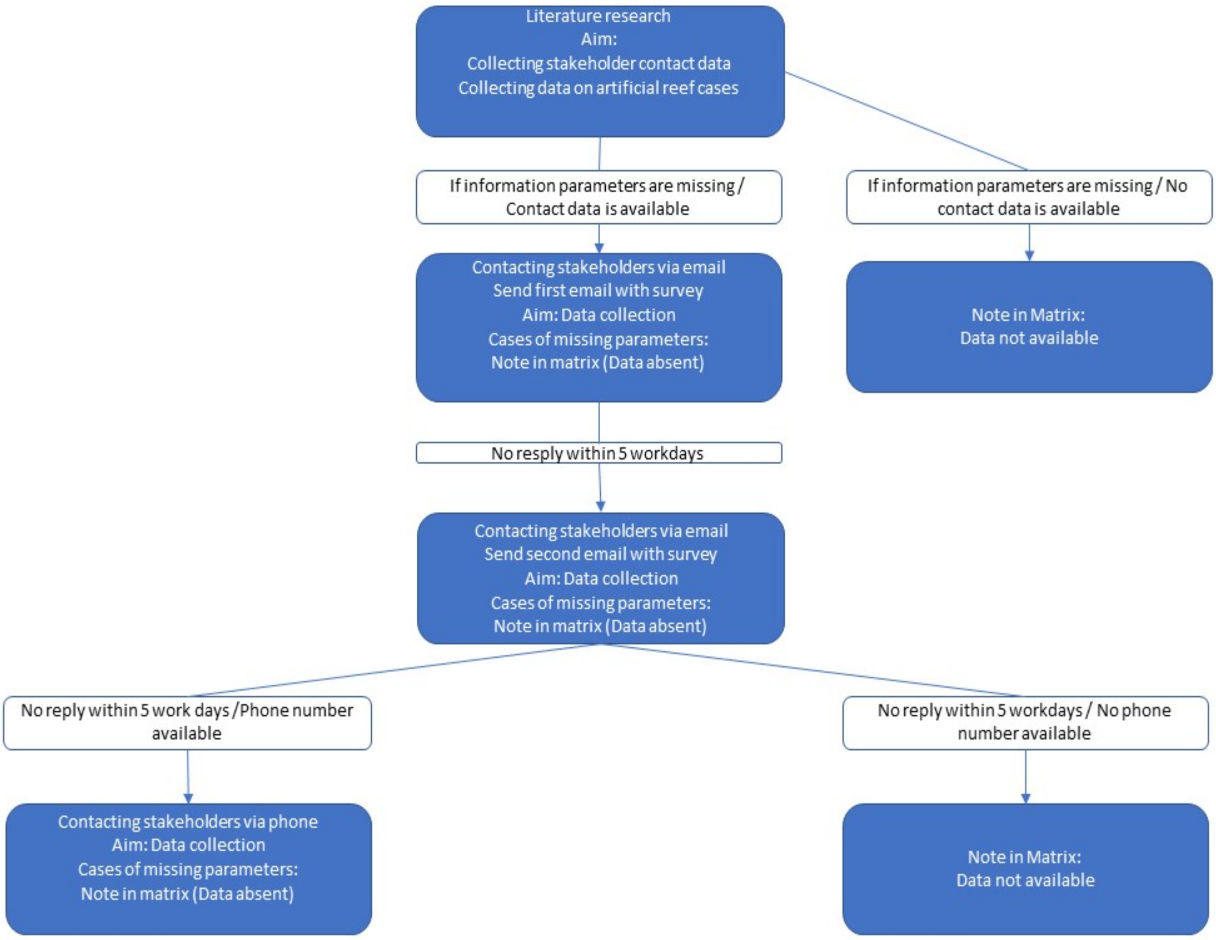

Figure 3: Flow-chart of data collection process

2.3 Data analysis

The data found during both parts of this study has been transferred into a data matrix, which holds the information parameters that are relevant for this study. This list eased the process of both data collection and analysis since it visualizes findings for every case in a clear and uniform way. Data has only been collected in cases that meet the present study's definition of an artificial reef (*one single structure, for example a wreck, or a gathering of multiple structures which will be referred to as 'artificial reef units', with less than 50m space in-between the reef units*).

Key variables of the present study (*'Fishing', 'Fishing management enforcement', 'Evaluation coral growth/recruitment', 'Evaluation fish abundance')* that were found during literature review have been assessed using an evaluation scale. Scores were given based on results and statements or on video material and photographs, that were found in different forms of literature (articles, websites, blogs, fora). For the variables *'Coral growth/recruitment'* and *'Fish abundance',* the five evaluation scores range from *'no growth/recruit/ fish abundance'* to *'better growth/recruitment/ fish abundance than natural reef'.* For the variables *'Fishing'* and *'Fishing management enforcement'* the four evaluation scores ranged from *'no fishing/ fishing management enforcement'* to *'regular fishing/ fishing management enforcement'*. A detailed description of the rating of *'coral growth/recruitment'* and *'fish abundance'* can be found under *Appendix 7.* During the collection of data in literature cases 'F*ishing' and 'Fishing management enforcement'* has exclusively been assessed on the basis of available documents of legal laws and regulations (E-CFR, 2018) (Gulf of Mexico Fishery Management Council, 2018) (McManus, 2012). During online surveys, participants were asked to assess the same key variables mentioned above, using the same evaluation scale for the assessment of these variables.

To achieve the goal of giving insight in potential links between the performance of artificial reefs on coral growth and fish attraction and their construction variables, the associated data (*'Type', 'Number', 'Habitat', 'Depth', 'Material', 'Size Dimension', 'Evaluation coral growth/recruitment', 'Evaluation fish abundance'*) has been analyzed. Analysis steps have been conducted using data that has been collected in literature cases and survey results. The information parameters of construction variables (*'Type', 'Number', 'Habitat', 'Depth', 'Material', 'Size Dimension')* were linked to the associated evaluation of key variables (*'Coral growth/recruitment' and 'Fish abundance'*). This was done separately for the evaluation for '*coral growth/recruitment' and 'fish attraction*'. The results are visualized using 'grouped bar-charts' and 'pie charts'. In this way, the evaluation scores of every construction variable used for artificial reefs that were found during this study was visualized separately for both purposes. Based on this information, advises for favorable artificial reef construction variables (construction variables with highest evaluation scores) have been formulated for the purposes of coral growth and fish attraction.

To achieve the goal of giving insight in potential impact of fisheries management on the fish abundance of artificial reefs, the associated data *('Fishing pressure', 'Fishing management', 'Fishing management enforcement'*) has been be analyzed. Therefore, these information parameters have been linked to the evaluation of the variable '*fish abundance'*. This has been done using the same approach as described for investigating the impact of construction variables on coral growth/recruitment and fish abundance. Based on the results of this analysis, advises for favorable aspects of fishing management on artificial reefs have been formulated. The software that has been used for the analysis and visualization of the data described above is SPSS, which is specially designed for the purpose of statistical analysis (Chandler, 2018). Additional to the specific data analysis, all cases of artificial reef usage that were identified during this research have been visualized in figures, that provide an overview of the different types and purposes.

3. Results

3.1 General use of artificial reefs

During the data collection phase of this study 223 cases of artificial reef usage have been identified of which 108 are located in the Caribbean Sea and 115 in the Gulf of Mexico. Various different types of artificial reef structures are established and have been summarized in 8 different categories of designs. A visual specification of the different artificial reef structure types can be found under *Appendix 8.* Man-made structures are employed for the different purposes of attracting scuba diving tourism, aggregating fish, ecosystem enhancement, scientific research and shoreline protection. The captured structures are variable in terms of material, complexity, volume and habitat consistency of deployment areas.

Caribbean Sea

In the Caribbean Sea the largest part of the located artificial reefs are scuttled ship wrecks (45%), followed by diverse concrete structures (reef balls, blocks, layered cakes, pyramids). Metal structures, limestone reefs and 'biorocks' form the rest of the identified structures that are used in artificial reef projects in this area. There was a single case found where car tires have been used to add structure to the ocean floor. Five different purposes of artificial reef usage have been identified in this part of the research area, of which the promotion of SCUBA diving tourism was the most common (35%). The restoration of degraded ecosystems was the second most common aim followed by research purposes, increasing fishing yields, and shoreline protection projects.

Gulf of Mexico

In the Gulf of Mexico, the largest part of the located artificial reefs consists of diverse concrete structures (Reef balls, blocks, layered cakes, pyramids, casitas), followed by limestone rocks, wrecks and other metal structures. Four cases of tires that were sunken for fish aggregation purposes form the rest of the identified structures that are used in this area. 75% of the artificial reef projects that were found in the coastal areas of Mexico and the USA had the purpose of fish aggregation, followed by ecosystem enhancement purposes. Nine projects have been identified where artificial reef structures were scuttled for research purposes and four concrete lobster aggregation reefs ('casitas') were found. The *Figures 4* and *5* visualize the differences in artificial reef structure types and purposes between the Caribbean Sea and the Gulf of Mexico with associated numbers.

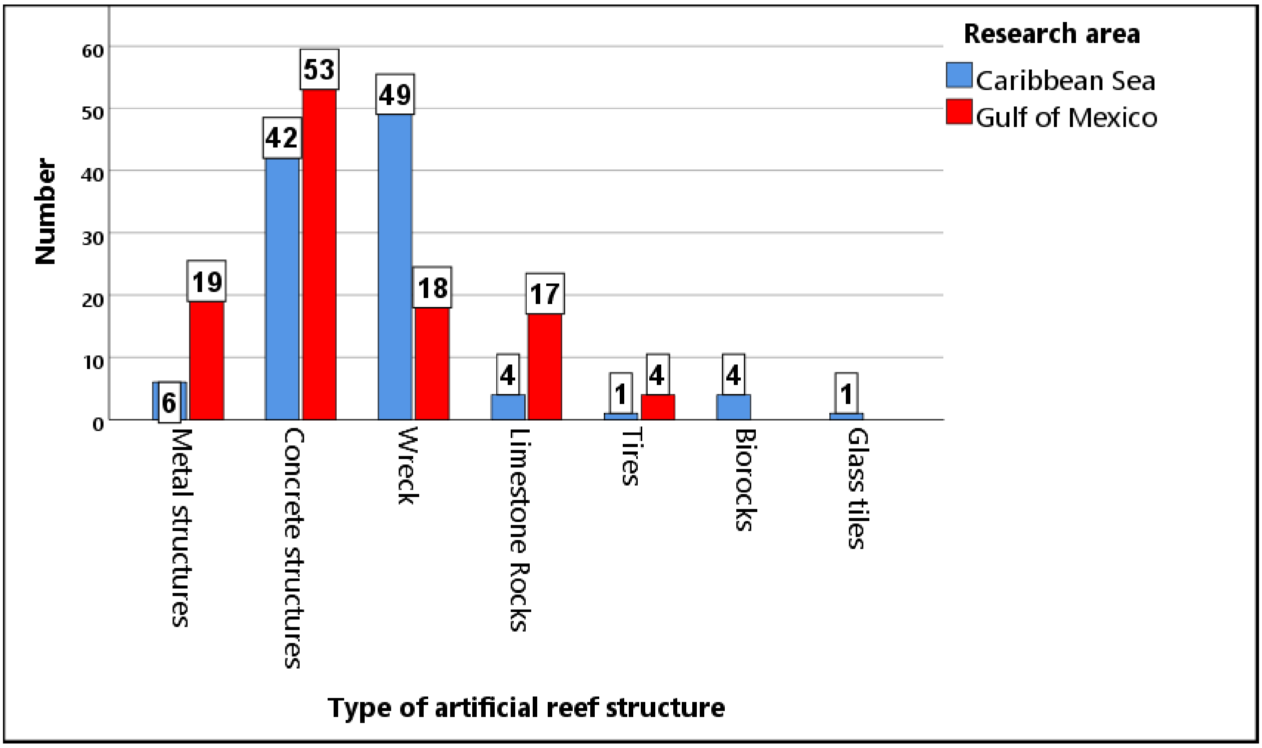

Figure 4: Different artificial reef types in the Caribbean Sea and the Gulf of Mexico with associated numbers

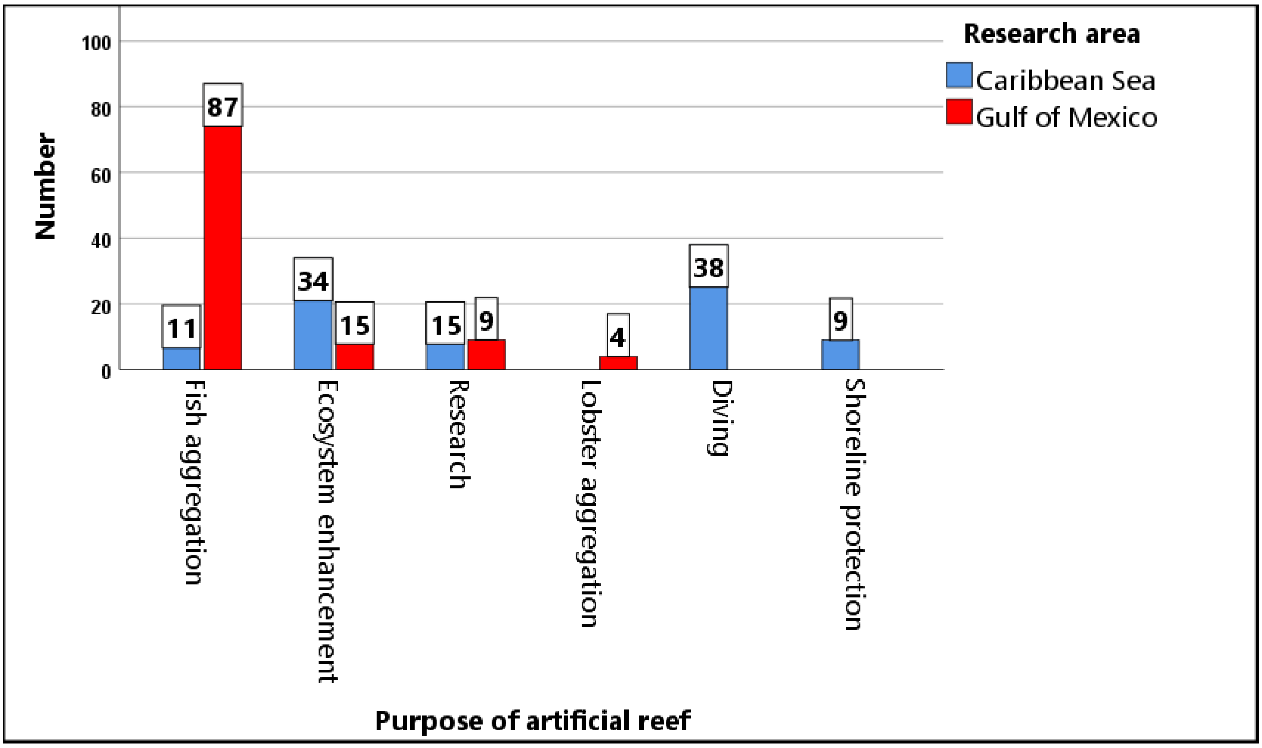

Figure 5: Different artificial reef purposes in the Caribbean Sea and the Gulf of Mexico with associated numbers

3.2 Coral growth/recruitment and fish abundance on artificial reefs

The first main goal of this study is the investigation of potential impacts of artificial reef construction variables on coral growth/settlement and fish attraction. To achieve this goal, data of survey respondents and literature review has been analyzed. Of the 223 cases, 92 personal contact data have been identified. These practitioners have been contacted. 11 people were willing to fill in the survey and provided detailed information on testing variables for 25 different artificial reef sites. An overview of respondents can be found under *Appendix 5*. All of the projects for which surveys have been completed are located in the Caribbean Sea. Contacting practitioners in the Gulf of Mexico (n=18) did not result in any responses. Only limited amounts of contact data for artificial reef practitioners in this area were available.

Figures 6-10 show the combined scores of variables given by practitioners and literature cases (Caribbean Sea [n=49], Gulf of Mexico [n=31]) for which coral growth/recruitment and fish abundance has been rated. Since there were only negligible amounts of data available on coral growth/recruitment in the Gulf of Mexico, cases that have been identified in this area have been excluded from the analysis of this variable. Associated figures (*Figure 7, 8*) visualize the combined data of survey results and data extracted from literature on projects, situated in the Caribbean Sea. Cases of missing data have been excluded from analysis.

Artificial reef structure types

The evaluation of all artificial reef structure types that were used by interviewed practitioners in the present study showed at least distinct fish abundances. Concrete 'reef balls' and 'pyramids' showed the highest abundance scores. Artificial reefs that consist of concrete 'blocks' or 'layered cakes', 'limestone rocks' and 'biorock' structures where evaluated with overall good fish abundances. Cases that were identified during literature research conform with these observations to some degree. In multiple cases, artificial reefs with high structural complexity such as wrecks, reef balls and other purpose made structures (pyramids, blocks, metal structures) were reported to show good fish abundances.

Due to the limited amounts of data, substantiated statements could however only be made for the fish abundance on 'concrete blocks' (n=25), 'reef balls' (n=14) and 'wrecks' (n=16). Analysis displays that the evaluations of 'reef balls' show the most favorable results (64% good abundance / 36% better abundance than natural reef), followed by 'concrete blocks' (72% good abundance / 20% better abundance than natural reef). Wrecks display the lowest fish abundance evaluations (37,5% good abundance / 62,5% distinct abundance). *Figure 6* visually displays combined fish abundance ratings of survey and literature cases.

Due to limited data availability and discrepancy of results that was identified during survey result assessment and literature review concerning the impact of artificial reef structure types on coral growth and recruitment, no contributing results could be asserted for this variable based on present findings.

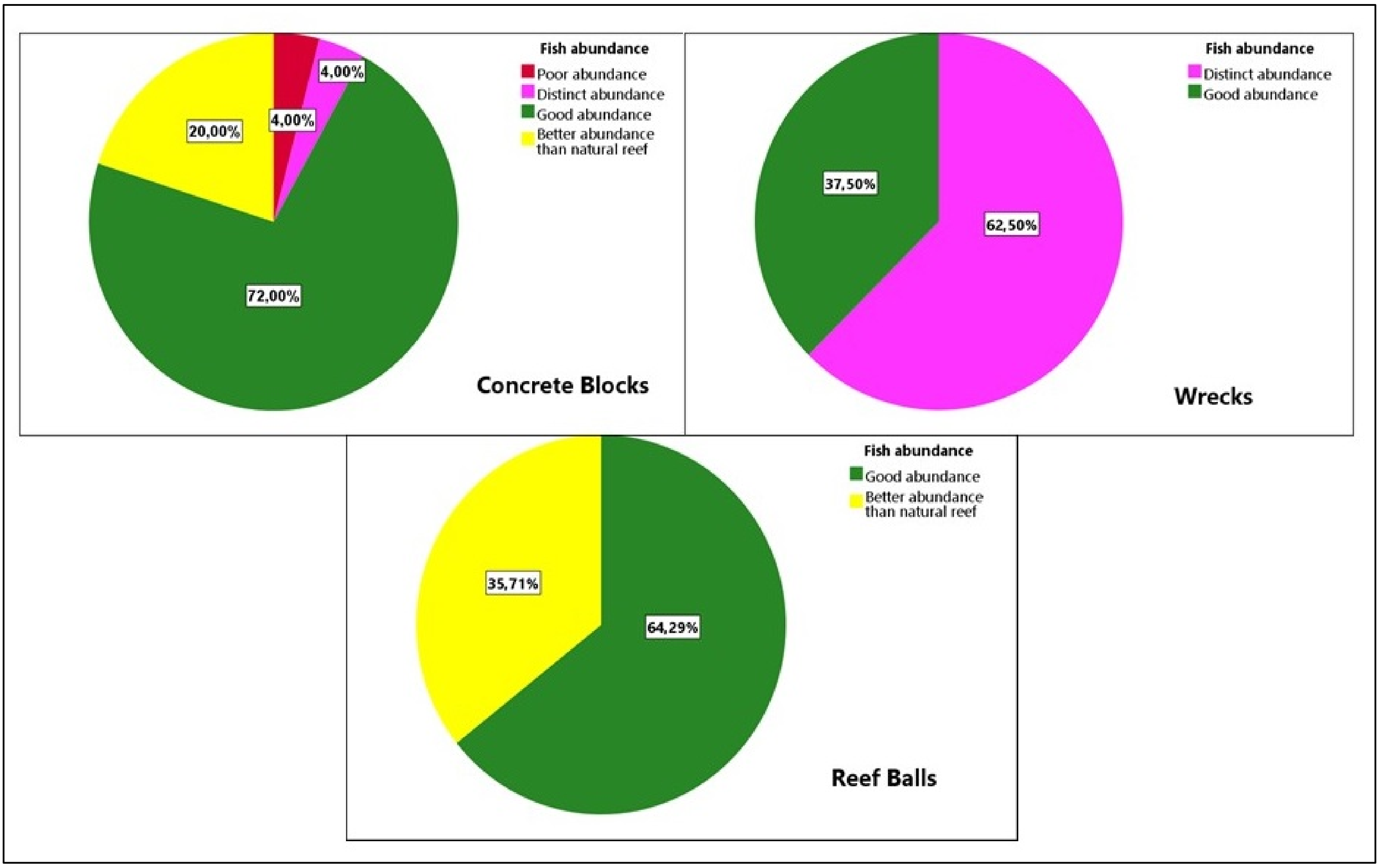

Figure 6: Evaluation of fish abundance on different artificial structure types

Artificial reef material

Materials that are used for artificial reefs by survey respondents are concrete, limestone and metal. The coral growth and recruitment on concrete and limestone structures was evaluated to be generally good with better results than observed on natural reefs in single cases. On both metal structures that were used by practitioners who filled in the survey, only distinct coral growth/recruitment has been observed.

Literature cases provide comparable findings. Metal has been reported to show no- or poor coral growth/recruitment in most of the identified cases while concrete and limestone were evaluated to support good results. In a single literature case of available information on coral growth/recruitment, rubber was used but did not contribute to any coral growth or settlement.

Due to limited n-values, analysis steps have only been executed for metal (n=15) and concrete (n=27) structures. Results display that metal structures are evaluated to show significantly less favourable coral growth/recruitment (40% no growth/recruitment / 40% poor growth/recruitment) than concrete structures (61,54% good growth/settlement, 4% better growth/recruitment than natural reef). *Figure 8* visualises associated findings.

Limited data availability hindered the investigation of potential impacts of artificial reef structure material on fish abundance.

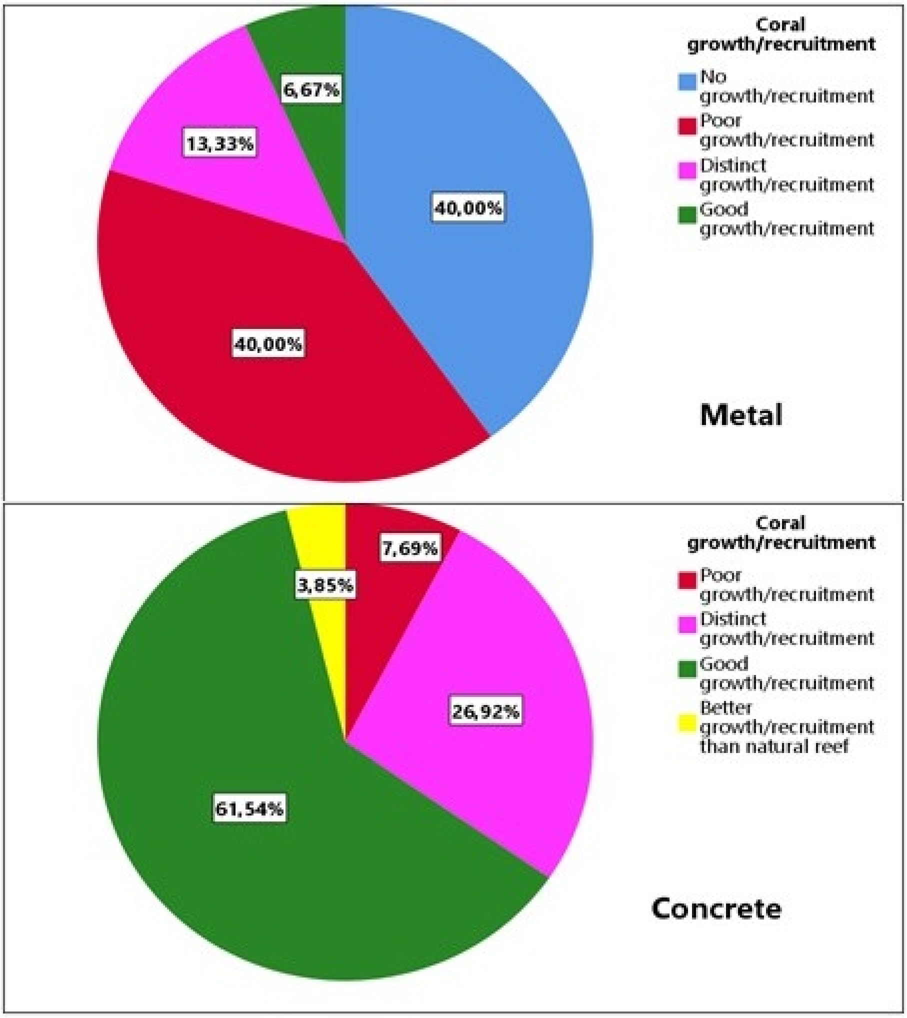

Figure 7: Evaluation of coral growth/recruitment on different artificial reef materials

Artificial reef habitat types

Artificial reef projects of contacted practitioners are located in four different types of marine habitats. Most of them are established in sand and rubble areas where natural structure has been depleted. The highest scores of coral growth and recruitment are achieved on structures that are placed in coral reef areas. Rubble, sand and seagrass habitats scored comparable evaluations with overall good growth and recruitment of corals.

Practitioners observations are comparable with literature cases. For most of the identified cases favorable coral growth and settlement has been reported in areas where natural reefs are situated or used to be situated. Structures that are located in marine habitats that lack natural, three-dimensional structure (sand, rubble) are also reported to show good coral growth and recruitment.

Based on evaluations of practitioners and literature results it can furthermore be suggested that the habitat type of artificial reef deployment areas is affecting fish abundance. Completed survey results show the highest fish abundance scores in sand and rubble habitats. Additionally, multiple literature cases indicate, that areas with little natural structure yield high abundances.

Due to insufficient representation of other habitat types in the present study, analysis has only been executed for coral growth/recruitment (n=34) and fish abundance (n=64) on artificial reefs in sandy habitat types. Both variables are evaluated to show generally good results (47,06% good coral growth/recruitment, 67,69% good fish abundance). *Figure 8* visually displays the results of the survey analysis and data provided by literature evaluation.

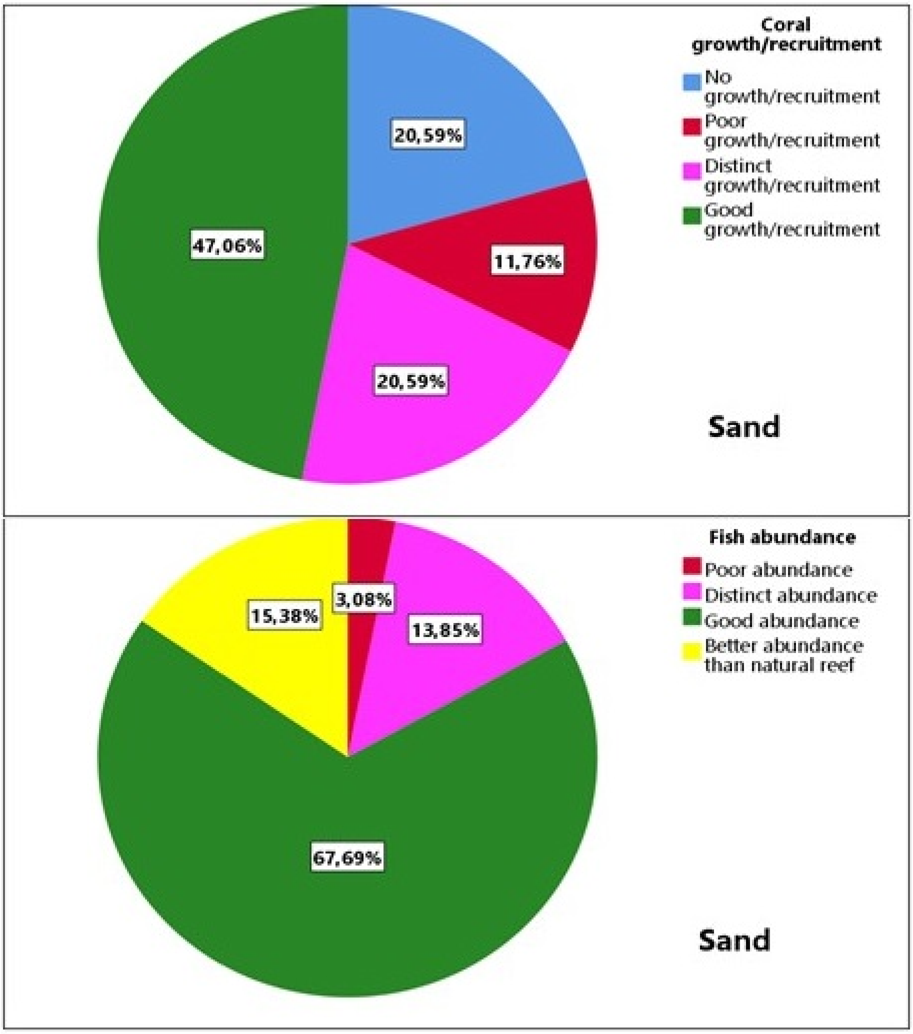

Figure 8: Evaluation of coral growth/recruitment and fish abundance on artificial reefs in sandy habitat types

Depth

Survey respondents reported their artificial reefs to be situated in depth between 2 and 15 meters with no apparent differences of coral growth/recruitment. Cases of artificial reefs in the Caribbean Sea that were identified during literature review also provided only limited information on coral growth/recruitment in different depth. No trend or correlation between depth and coral growth/recruitment could be asserted based on the available data.

Evaluation of survey results and literature cases on the impact of depth on fish abundance of artificial reefs revealed an indication of increased fish abundance on deep reefs (*Table 2*).

Table 2: Different fish abundances in mean depth of artificial reefs

Poor abundance (n=3)	**Distinct abundance (n=3)**	**Good abundance (n=62)**	**Better abundance than natural reef (n=11)**
Mean=14,33 ± SD 18,23	Mean=10,77 ± SD 2,54	Mean=13,37 ± SD 7,22	Mean=25,55 SD ± 3,57

Number of structures/structure sizes
The analysis of respondent and reviewed data on the impact of artificial reef structure sizes and numbers on coral growth/recruitment was due to the limited amounts not suitable for substantiated statements. Practitioners reported to use a variety of structure sizes (0,03m^3 - 10m^3) and numbers (2 – 5000 units) on their artificial reefs. Nevertheless, hinders the low number of completed surveys an explicit analysis of these variables. Literature that was found for artificial reefs in the research area reported comparable varieties of both structure sizes and numbers. However, the impact of both variables on coral growth/recruitment has not been tested in any of these cases, which makes it impossible to assert. Comparable limitations complicated the analysis of the impact of both variables on fish abundance on artificial reefs. Although extensive research that has been executed in the northern and north-eastern part of the Gulf of Mexico indicates that these variables affect fish populations on artificial reefs, detailed information on structure sizes and numbers are lacking.

3.3 Impact of fisheries on artificial reefs

The second main goal of this study is to investigate the potential impact of fisheries management and enforcement on the fish abundance of artificial reefs. To achieve this goal, scientific papers and other forms of online literature have been reviewed and analyzed together with the results of completed surveys. Cases of missing data have been excluded from the associated analysis.

Fisheries management and enforcement
Survey respondents reported that more than half of the artificial reef projects that participated in the present research are situated in areas, where fishing is prohibited. In all remaining cases, completed surveys indicate that there is no fishing management in place. Additional literature data on fishing management, in particular in the Gulf of Mexico, indicates that most of the artificial reefs here are placed in areas where fishing is managed in some way. *Figure 10* visualizes the evaluations of fish abundance on artificial reefs that are situated in areas where fishing is either managed or not managed. It indicates that artificial reefs in areas where fishing is managed are reported to show better fish abundances. Detailed information on specific management components is however not available in most of these cases.
Although practitioners reported that there are shortfalls of management enforcement with no- or rare enforcement being practised in almost all cases, limited data availability in literature cases did not allow a substantiated analysis of this variable.

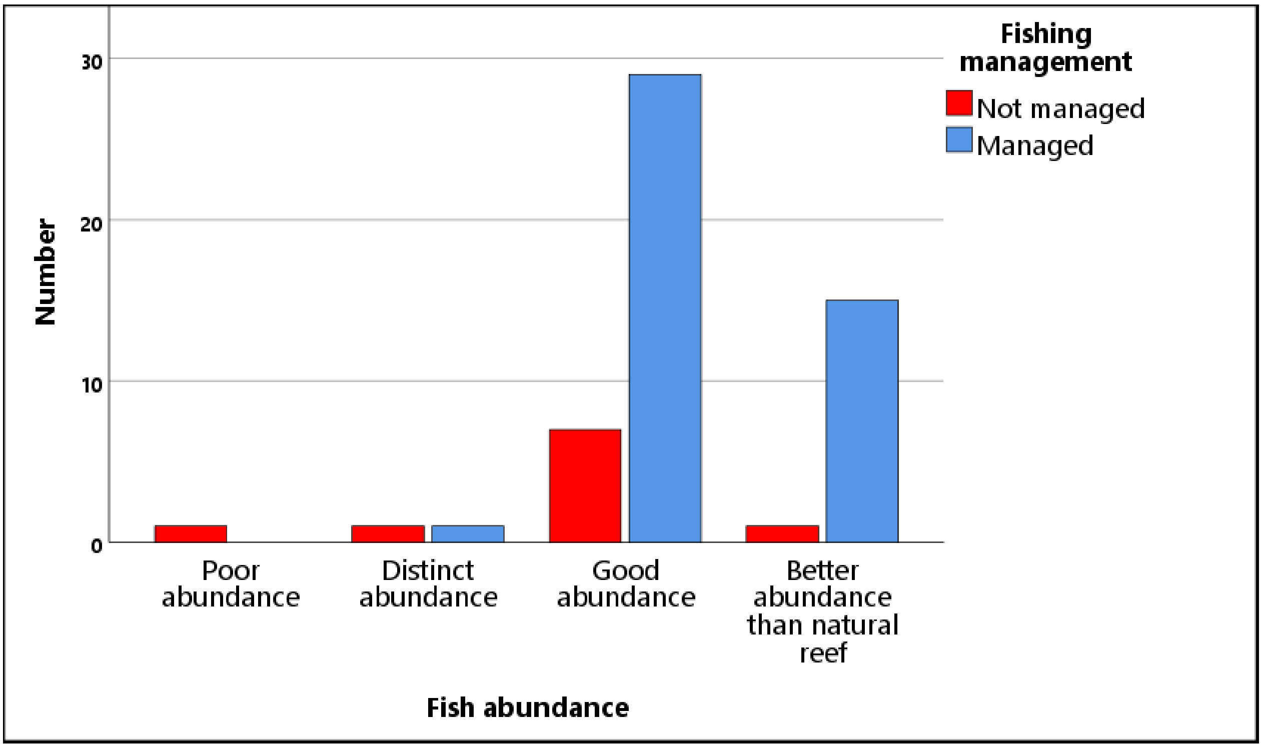

Figure 9: Fishing management on artificial reef sites

Fishing pressure

A discrepancy of practitioner's evaluations and literature findings has been identified for the impact of fishing pressure on fish abundance of artificial reefs. Survey respondents generally evaluated fish abundance to be higher on artificial reefs that experienced no- or little fishing pressure compared to reefs that are occasionally or regularly fished. One particular respondent stated changes in fishing management during the monitoring phase of an artificial reef in Antigua. Fishing used to be prohibited and the area has recently been announced as public fishing ground with no active fishing management in place. The respondent stated that species abundance and richness of reef inhabitants has declined ever since. Contrawise, results of literature cases indicate better fish abundance on artificial reefs that are regulary fished. *Figure 11* displays these disagreeing findings.

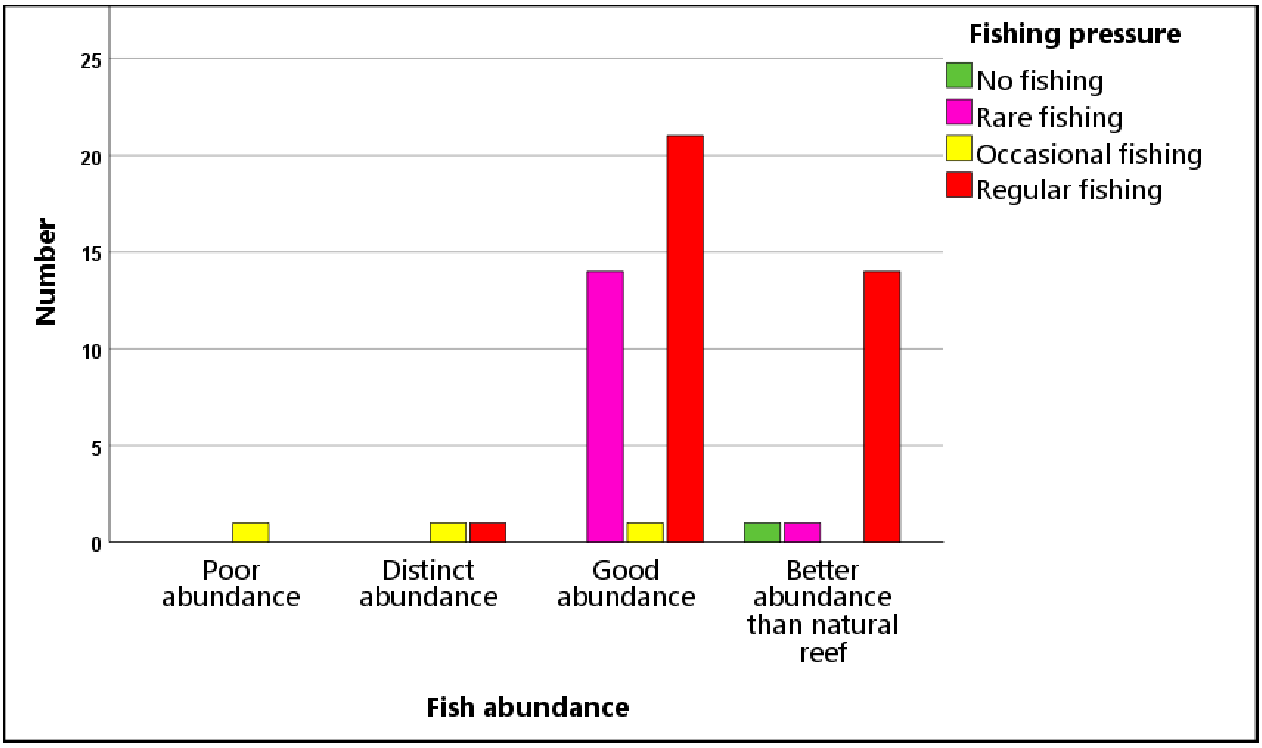

Figure 10: Evaluation of fish abundance on artificial reefs with different impacts of fishing pressure

4 Discussion

Caribbean Sea

The background of the composition of artificial reef types and purposes in the Caribbean Sea originates from multiple factors. Recreational scuba diving in this area started to increase drastically during the 1980s and is ever since considered to be one of the most popular tourist activities in the Caribbean (Meesters, 2014) (Tabata, 1992). The use of artificial structures, particularly ship wrecks, to stimulate scuba diving in the Caribbean has been identified as a common practice in prior studies (Stolk, 2009) (Tabata, 1992). Furthermore, a region wide decline of coral reefs occurred contemporaneous and forms one of the biggest ecological disasters of this area to date (Gardner, 2003). The associated loss of critical habitat and biodiversity has led to an increase in reef enhancement and conservation projects in the Caribbean and the use of artificial reefs is one of the most common approaches (Lirman & Schopmeyer, 2016) (Young, et al., 2012). These projects initially concentrated on vessel sinking's with the aim of fast restoration of three-dimensional hard structure for coral reef recovery (Lirman & Schopmeyer, 2016) (Precht, 2006). Most of the wrecks (68%), which were captured in conspicuously high numbers during the present study originate from that time (*Appendix 1*). The limited rate of prosperity in terms of effective coral reef restoration, using wrecks to simply replace lost natural structure, stimulated new coral restoration approaches (Lirman & Schopmeyer, 2016) (Young, et al., 2012). Currently, the most popular and widespread technique in the Caribbean is 'coral gardening' (Lirman & Schopmeyer, 2016) (Young, et al., 2012). This method implies the grow-out of coral fragments from natural reefs in artificial nursery structures and their out planting onto degraded coral reef areas (Precht, 2006). This is either done onto natural or artificial reef structures (Meesters, et al., 2015). Frequently used man-made structures for this approach are concrete 'Reef Balls', 'Layered Cakes' and 'Pyramids' (Young, et al., 2012) (Spieler, et al., 2002). Next to the loss of biodiversity that can be associated with the massive coral reef decline, the disappearing hard structure in the shallows of the countries and islands in the Caribbean Sea leaves shorelines vulnerable to the impact of storms and currents (Wells, et al., 2006). Many extended artificial reef projects are launched to antagonize this problem with increasing popularity for the use of reef balls and comparable structures (Barber, 2007). High numbers of mainly concrete structures with the purpose of ecosystem enhancement and shoreline protection found in the Caribbean Sea during this study can be substantiated by the widespread loss of coral reefs and associated degradation of ecosystems in this area.

Gulf of Mexico

The Gulf of Mexico has connotatively less natural reef structures than the Caribbean Sea. Especially the U.S. coast of this area is dominated by monotonous sandy and muddy habitats (Szedlmayer & Shipp, 1994). This habitat composition makes the area unsuitable for extensive growth of coral reefs, which is why data on coral growth/recruitment was negligibly scare (Rabalais, et al., 2002). The fish population of this semi enclosed sea is appreciable decreasing in the last decades due to downgrading water quality and overfishing (Rabalais, et al., 2002) (Shipp & Bortone, 2009). Particularly in the northern part of the Gulf, numerous artificial reef projects have been established to ad critical habitat to the monotonous sea floor for fish population enhancement. Various massive concrete constructions like bridges, pillars and purpose made reef structures are scuttled amongst wrecks, oilrigs and platforms to support fish species of commercial interest (Outdooralabama, 2018) (Sneath, 2018). Extensive research on fish populations and behavior has been conducted on these structures (Bohnsack, et al., 1994) (Pickering & Whitmarsh, 1996) (Szedlmayer & Shipp, 1994).

According to all accounts, the artificial reefs in the Gulf of Mexico with the purpose of aggregating fish, can be considered successful. Gallaway, et al. (2009) assumed that fishing yields of certain species in this area increased since the proliferation of artificial reefs. They even suppose that the harvest of some fisheries in the Gulf is meanwhile dependent on sunken man-made structures. These findings can be supported by the results of comparable studies (Bohnsack, et al., 1994) (Pickering & Whitmarsh, 1996). These findings can explain the high numbers of artificial reefs with the purpose of aggregating fish that have been revealed in this area during the present study.

Structure types and material

Literature research revealed general discrepancy concerning the question 'which type of artificial reef structures are suitable for coral growth and settlement', in particular with view on long-term data. During a research, carried out by Salinas-de-Leon, et al (2011), results of coral recruitment showed similar settlement rates between limestone rocks and concrete blocks. Bachtiar & Prayogo (2010) found significant differences of coral settlement on different 'reef balls' on the same artificial reef site ranging from 1 to 76 coral colonies per structure, while other sources suggest that concrete blocks and similar structures are rather unsuitable for natural coral settlement (Thomas, 2009) (Ortiz-Prosper, et al., 2001). Present findings and the inconsistency of literature results contribute to the suggestion that structure material is more significant in terms of coral growth and settlement than structure types and shapes (Reefball Foundation, 2018) (Baine, 2001).

Specialist consider concrete to be a suitable material for coral growth. However, a conspicuous inconsistency of results for coral growth and recruitment on concrete artificial reef materials has been asserted during present observations and literature findings (Edwards & Clark, 1998) (Munoz-Chagin, 1997) (Raymundo, et al., 1999). This phenomenon could be generated by differences in composition of the used materials. Normal concrete, which is commonly used for land-based constructions contains binder additives that release calcium hydroxide when getting in contact with sea water. This compound is toxic and makes regular concrete unsuitable for the settlement of fouling communities and corals. Additionally, is the PH value of this material different from values observed in marine environments and makes natural settlement unlikely. In 'marine grade' concrete however natural binder ingredients are used, and PH values of this material are adapted to marine environments which makes this material more practical for coral restoration (Spieler, et al., 2001). Present results indicate that metal is an unsuitable material for coral growth and recruitment. These findings can be confirmed by literature. Especially metals with iron content stimulate macro algal growth which blocks both settlement and growth of corals (Fitzhardinge & Bailey-Brock, 1889) (Birrell, et al., 2005). Furthermore, are metal materials rapidly broken apart in marine environments due to high pH values of ocean water and therefore not suitable in terms of providing permanent supporting structure which is needed for coral growth (Reefball Foundation, 2018) (Fitzhardinge & Bailey-Brock, 1889).

In terms of fish aggregation however contra wise significance of reef type and material are found. Of the artificial reef structure types that were identified in the present study, those who have the highest structural complexity (wrecks, purpose made structures) are reported to support high fish abundances. During prior researches Sherman, et al (2002) and Brickhill, et al (2005) found that the structural complexity of artificial reefs is a key factor in terms of fish aggregation, which affirms present observations. It should however be noted that potential structure shape inconsistency between cases that were identified during the present study can compromise results.
Although single literature cases, executed in fresh water, suggest that hard materials are more suitable for fish aggregation than soft materials, the impact of this variable in marine environments is insufficiently examined to formulate substantiated statements (Santos, et al., 2011) (Bohnsack, et al., 1994). Therefore, the structure type of artificial reef units is considered to be of more significance for fish aggregation in the present study than artificial reef material.

Habitat types and depth

During the present study, generally good results on structures in sandy areas have been reported. These findings can be supported by the fact that adding stable, three-dimensional structure to marine environments that lack natural hard structure provides corals with critical habitat (Edmunds, 2000) (Meesters, et al., 2015).
Although practitioners and single literature cases reported favourable coral growth on artificial reefs in coral reef areas, this habitat was due to insufficient data representation excluded from the analysis of the present study. It should however be noted that studies on habitat adaptation of various coral species, revealed that favourable growth on man-made structures can best be achieved in habitat types and depth of former or present natural reefs under consideration of species specific predilections (Bowden-Kerby, 2008) (Meesters, et al., 2015).
Results of the present study indicate a high suitability of sandy habitat types for the placement of artificial reefs for fish aggregation at which increasing depth contributes to increasing fish abundance. This can be confirmed by numerous scientific papers that report significantly higher fish abundance on artificial reef structures in deep sea bottom environments that lack natural structure (Bohnsack, et al., 1994) (Gallaway, et al., 2009) (Brickhill, et al., 2005). Brickhill, et al (2005) reported differences in fish abundance on introduced structures in areas with more natural structure availability, where significantly less fish individuals, biomass and species richness were observed. The results of a study executed by Thomas (2009), furthermore suggest that artificial reefs in sandy habitats contribute to the production of certain fish species. Sherman, et al (1999) compared artificial reef sites consisting of reef ball structures in two different depth. Their results show highly significant differences in fish abundance between sites. There were conspicuously more fish species and individuals observed near the deep artificial reef site.

Number and size of structures

The impacts of artificial reef structure numbers and sizes on coral growth/recruitment and fish abundance could not be analysed in the present study due to limited amounts of data. Although practitioners reported both variables, the low number of completed surveys hindered an explicit analysis of these variables. Literature that was found for artificial reefs in the research area reported comparable varieties of both structure sizes and numbers. However, the impact of both variables on coral growth/recruitment has not been tested in any of these cases, which makes it impossible to assert. Comparable limitations complicated the analysis of the impact of both variables on fish abundance on artificial reefs. Although extensive research that has been executed in the northern and north-eastern part of the Gulf of Mexico indicates that these variables have the potential to affect fish populations on artificial reefs, detailed information on structure sizes and numbers are lacking. Further research on these variables has been recommended in the past (Ajemian, 2015).

Fishing management and enforcement

Although the availability of detailed information on fishing management in artificial reef areas was found to be poor during the present study, literature states that fishing in the Caribbean Sea and the Gulf of Mexico is associated with a wide range of different management tools. Various types of fisheries are managed by required permits or licenses, size limits and closed seasons for target species, no-take zones and special regulations for employed fishing gear (Salas, et al., 2007). However, numerous regulations that are associated with fisheries in the research area have only been established in single countries while in many areas fishing remains under open access conditions (Chuenpagdee, 2006). Furthermore, is the efficiency of these regulations for small-scale fisheries questionable due to limited possibilities of enforcement. Additionally, are management approaches of fisheries in this area considered to be insufficiently adapted to small scale fisheries (Salas, et al., 2007) (Anon., 2008). Although general awareness about the problem of overfishing in fishermen has been reported, the lack of economic opportunities gives them little chance of comparable lucrative sources of income (Nez-Badillo, 2008). Most of the artificial reef cases that were found in the present study are located in close-to-shore areas, where essentially small-scale fisheries operate. Therefore, these limitations are of special interest and can be affirmed by contacted practitioners, who consistently reported that especially enforcement of fishing management and regulations is poor. Cooperative fisheries management in the Caribbean, in which authority and responsibility is shared amongst stakeholders and governments has proven to be an effective way to adapt regulations for small scale fisheries in single cases but region wide implementation is a distant prospect (Pomeroya, et al., 2004).

Fishing pressure

Interviewed practitioners observed in general more fish abundance on artificial reefs that experienced no- or little fishing pressure. Contrariwise, collected literature data on identified cases of artificial reef usage indicates, that fish abundance is higher on artificial reefs that are situated in areas were regular fishing is being practiced. This contradiction can be explained by the fact that most of the artificial reefs of which information on fish abundance has been extracted from available literature are situated in the Gulf of Mexico. Regular fishing is being practiced in the better part of this area (Rabalais, et al., 2002). Here, almost all artificial reefs have the purpose to aggregate fish. Executed research on man-made structures concentrates on the abundance of fish (Bohnsack, et al., 1994) (Brickhill, et al., 2005) (Gallaway, et al., 2009). During the present study there was no case found in which the impact of fishing on these reefs was tested.

Structures in this area are deployed in sandy areas where limited natural structure is available. Fish in these habitats are attracted by scuttled structures (Pickering & Whitmarsh, 1996). Therefore, studies that compare abundance between natural habitat and artificial reefs indicate higher abundance on artificial reefs.

Fishing pressure is known to have a fundamental impact on the composition and therefore on the functionality of marine ecosystems (Jennings & Kaiser, 1998). Studies on this subject revealed drastical changes in species compositions and fish abundance of natural reefs that had increased fishing pressure compared to control reefs where no fishing was executed. These changes are reported to have far wider impact on the ecosystems than just the decrease of targeted fish species (Anon., 1989). Koek, et al. (2014) investigated potential differences in fish assemblages between heavily fished natural reefs and artificial reefs in proximate areas. The results revealed a significantly higher fish abundance on artificial reefs. Next to the higher structural complexity of artificial reefs, this phenomenon is explained by the fact that fishing pressure on artificial reefs was lower. The exact locations of artificial reef sites were relatively unknown to commercial fishermen and short distances between reef structures made big-scale fishing with the use of nets impossible. They also recorded that especially fish species of commercial interest were attracted by the artificial reefs, most likely due to lower fishing pressure. These results can give an indication on the negative impact that high fishing pressure has on the fish abundance of ecosystems and makes present findings questionable. Furthermore, are artificial contributing to simplification of fishing effort and increasing potential yields which rises the chance of overfishing in cases of high fishing pressure(Whitmarsh, 2008) (Pickering & Whitmarsh, 1996).

Compromising factors

The results of this study are based on data originating from online sources and the results of an online survey that was shared amongst practitioners. This approach showed some compromising factors during conduction. The most deciding factor that compromised the significance of results was the low rate of response amongst contacted practitioners, in particular regarding completed surveys. Only 12% of invited practitioners actually filled in the survey and all of them are situated in the Caribbean Sea. No replies from the Gulf of Mexico can be announced. This can be explained by the fact that especially in the northern and north-eastern part of the gulf, artificial reef projects are extremely extensive. These projects are financed and executed by big companies like BP and Shell or institutions like Marine Patrol Divisions, Coastguard and even the US Army' (Outdooralabama, 2018) (Sneath, 2018). Personal contact data is not available for most of these projects. Combined with the poor online availability of specific data on testing variables of identified cases, this limitation leads to an incomplete representation of identified cases during the data analysis.
Furthermore, does the limited amount of specific data in online sources and survey responses hinder a contributing analysis for some of the variables tested during this study (structure size, number of structures), which is why the impact of these factors on tested variables can only be evaluated on the basis of general findings in scientific literature. Some of the literature cited however, presents results that were found outside the scope of the present research area. It should be noted that findings have the potential to vary in different parts of the world.
The data availability for coral growth and recruitment in the Gulf of Mexico was very limited. Therefore, associated analysis have been executed exclusively using data that has been found for the Caribbean Sea. This leads to less representative results for coral growth and recruitment analysis compared to fish abundance analysis.

5 Conclusion

Of the variables that were tested during the present study, structure material and habitat type were found to be of particularly importance in terms of coral growth and recruitment. According to present findings, favourable results can be achieved on marine-grade concrete structures. Based on the results of this study it can furthermore be stated, that marine habitats with limited natural hard structure can be considered preferential for coral restoration with the use of artificial reefs. Although scientific literature provides points of references, the potential impact of structure types, sizes and numbers of artificial reefs on coral growth and settlement cannot be indicated on the basis of present findings.

In terms of fish aggregation on artificial reefs, present findings indicate that the structure type of reef units and the consistency of deployment areas are the most important factors. Reef units with high structural complexity are suggested to contribute to high rates of fish occupation. Furthermore, are marine habitats with limited availability of natural structure considered to be predestined for favourable fish aggregation on artificial reefs. In connection to habitat composition is depth another important aspect to consider. Artificial reefs in deep marine environments (>20m) are reported to contribute to the occupation of more fish by present findings. Due to limited data availability, the impact of materials, numbers and sizes of artificial reefs structures on fish abundance cannot be assessed on present findings.

Although present findings on the impact of fishing management on fish abundance of artificial reefs show weak points in terms of representativeness it can be stated that fishing management is an exceedingly important factor to consider. Artificial reefs have been proven to attract fish by present findings and are therefore contributing to simplification of fishing effort and increasing potential yields. These characteristics could contribute to the risk of overfishing. Therefore, fishing management on artificial reefs can be considered necessary.

6 Recommendations

It is recommended to implement marine grade concrete structures with high structural complexity in marine habitats that lack natural structure to achieve favourable results in terms of coral growth/recruitment and fish abundance on artificial reefs. In this connection increasing depth can contribute to high fish abundance. It should however be noted that favourable coral growth/recruitment is indicated to be dependent on species specific depth preferences.

It is furthermore recommended to implement artificial reef structures in marine habitats where fishing is prohibited or at least strictly managed since the attraction impact of man-made structures on fish communities can lead to overfishing in cases of high fishing pressure.

Present limitations of survey respond lead to the recommendation that personal face-to-face communication with practitioners should be applied in comparable future research to achieve favourable amounts of completed surveys.

Due to the limited availability of information on the impact of present tested construction variables on coral growth/recruitment and fish abundance, further research is recommended. In particular research on the impact of structure sizes and numbers has the potential to reveal interesting results.

Present limitations of coral growth/recruitment data representativeness lead to the recommendation that comparable future research should be executed in research areas with consistent coral reef occurrence.

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Appendix

Appendix 1

Wrecks in the Caribbean Sea. Marked cases were scuttled during the 1980's and -90's (68%). 14 cases have been dismissed in conjunction with missing information.

Country	Specification	Sinking
Anguilla	Wreck of Sarah	1990
Anguilla	Wreck of Lady Vie	1990
Anguilla	Wreck of Hilda	1990
Anguilla	Wreck of Commerce	1986
Anguilla	Wreck of Marie	1985
Anguilla	Wreck of Oosterdiep	1990
Anguilla	Wreck of Catheley H.	1993
Aruba	Wreck of Antillia	1940
Barbados	Wreck of Berwyn	1919
Barbados	Wreck of Friara Cag	1984
Barbados	Wreck of Eillon	1996
Barbados	Wreck of SS Stavronikita	1976
Belize	Wreck of Sayonara	1985
Belize	Wreck of Amigos	1996
Bonaire	Wreck of Hilma Hooker	1984
British and US Virgin Islands	Wreck of Green Cay	1945
Dominican Republic	Playa Caleta	1984
Grenada	Grand Mal Bay	2007
Grenada	Sister Rocks	2018
Honduras	Wreck of Prince Albert	1987
Honduras	Wreck of El Aguila	1997
Jamaica	Runaway Bay	1991
Jamaica	Negril	1988
Jamaica	Negril	2013
Martinique	Wreck of Nahoon	1993
Sint Maarten	Wreck of Le Renee	1997
Sint Maarten	Wreck of The Porpoise	2000
Sint Maarten	Wreck of Charlie	2012
St Lucia	Wreck of Wawina Atlantic	1980
St Lucia	Wreck of Daini Koymaru	1996
St Lucia	Wreck of Lesleen M'	1985
St. Eustasius	STENAPA Reef	1997
St. Eustasius	Wreck of Charls L. Brown	2003
Venezuela	Golfo de Cariaco, Araya	2009
Venezuela	Wreck of Carmen Fabiana	2000

Appendix 2

Specification of variables

Parameter	**Description**
'Country'	Country of the reef site location
'Language'	Language spoken in the country of the reef site location
'Name Location'	Name of the reef site location (Bay, dive site, etc.)
'Year'	Year of the first reef unit(s) placement on the reef site
'Type'	Type of reef unit(s) (wreck, tires, reef-ball, etc.)
'Number'	Number of reef unit(s) on the site
'Habitat'	Habitat type of the reef site
'Depth'	Average depth of the reef site
'Material'	Material of the reef unit(s)
'Size Dimension'	Average size of the reef unit(s) (Height and width)
'Purpose'	Purpose of the reef site (food production, habitat protection, habitat restoration, recreation.)
*'Who & How Funded'**	Who funded the project? / How is the project funded?
'Fishing pressure'	Is any form of fishing practiced on the artificial reef?
'Fishing management'	Is fishing on the artificial reef managed in any form?
'Fishing management enforcement'	Is fishing management of the artificial reef enforced in any way?
*'Budget Costs'**	Total costs of the artificial reef project
'Monitoring'	Is the reef site being monitored? / How is the reef site being monitored? (frequency / by whom? / how?)
'Evaluation coral growth/recruitment'	Does the artificial reef site have potential for coral ecosystem restoration?
'Evaluation fish abundance'	Does the artificial reef site have potential for fish aggregation?
'Contact person'	Name and contact data of the contact person
'Report Available'	Is there a report available on the case?
'Source'	Type of source (Website, article, report, etc.)

Appendix 3

Email used to contact practitioners

Dear «Name»,

I hope this email finds you well. My name is Jan Koschorrek and I am working at the Dutch University of Applied Sciences Van Hall Larenstein. We are working on a reef restoration project in the Caribbean, named AROSSTA (Artificial Reefs on Saba and Statia). Details on this project can be found on: https://arossta.wordpress.com/. In AROSSTA we compare the habitat function of different types of artificial reefs for coral and fish.

Each year, thousands of artificial reefs are deployed in the Caribbean and the Gulf of Mexico, while it is unclear if, and to which degree, these artificial reefs function well. One of our aims is to make an overview of all these artificial reefs, including their construction variables, purpose and performance. This overview will be used to identify best practises and will be made available for the general public. In this way, our study can help nature conservationists and other organizations to determine which type of artificial reef fits their purpose best and can thereby contribute to more effective use of artificial reefs.

To do this, we need your help! During the search for relevant cases on the internet I read about your involvement in marine conservation and I concluded that you might know about artificial reef usage around «Island».

1. Are you involved in any artificial reef program yourself? Please contribute to our project by filling in the survey attached to this mail.

2. Do you know of any other person/organization involved in artificial reefs? Please let me know by responding to this email!

Your participation is completely voluntary, and all your responses will be kept confidential. If you are interested, we would also like to share our results with you. Should you have any comments or questions, please feel free to contact me.

Thank you very much for your time and cooperation,

Sincerely,

Jan Koschorrek

coralresearch@hvhl.nl

Appendix 4

Survey

Questions	**Answers**
What is the name of the artificial reef site location? (Bay, dive site, etc.)	
In which year have the first reef unit(s) been placed on the artificial reef site?	
Which type of reef unit(s) is used on the artificial reef site?	
How many reef unit(s) are deployed on the artificial reef site?	
What is the habitat type of the artificial reef site?	
What is the average depth of the artificial reef site?	
Which material is used for the reef unit(s) on the artificial reef site?	
What is the average size of the reef unit(s) on the artificial reef site? (Height and width)	
What is the purpose of the artificial reef site?	
Who funded the artificial reef project?	
How is the artificial reef project funded?	
What are the cost dimensions of the artificial reef project?	
Is the artificial reef site being monitored?	
How is the artificial reef site being monitored? (frequency / by whom? / how?)	
Is there any type of fishing being practiced on the artificial reef site? (Fishing pressure) 1= no fishing 2= rare fishing 3= occasional fishing 4= regular fishing	1 2 3 4
Is fishing on the artificial reef site managed in any form? 1= Yes 2= No	1 2
Is fishing management enforced in any form? 1= no enforcement 2= poor enforcement 3= occasional enforcement 4= regular enforcement	1 2 3 4
Does the artificial reef site have potential for coral ecosystem restoration (percentage of settlement and growth of corals, compared to nearby natural reef)? 1= no recruitment/growth 2= poor recruitment/growth (1-20%) 3= distinct recruitment/growth (20-40%) 4= good recruitment/growth (40-60%) 5= better recruitment/growth than natural reef (60-100%)	1 2 3 4 5
Does the artificial reef site have potential for coral ecosystem restoration (percentage of fish abundance compared to nearby natural reef)? 1= no abundance 2= poor abundance (1-20%) 3= distinct abundance (20-40%) 4= healthy abundance (40-60%) 5= better abundance than natural reef (60-100%)	1 2 3 4 5
Is there a report available on the artificial reef project?	

Appendix 5

List of survey participants

Country	Email address
Jamaica	ross.andrew@mac.com
Dominican Republic	lharris@fit.edu
Barbados	scubadivebarbados@gmail.com
Honduras	max.bodmer@opwall.ac.uk
Grenada	info@divegrenada.com
St. Eustatius	alwin.hylkema@hvhl.nl
Saba	alwin.hylkema@hvhl.nl
Bonaire	christine@harbouvillage.com
Florida (Miami-Dade County)	info@arcreef.com
Nicaragua	chjolem@gmail.com
Antigua	larry@reefinnovations.com
Curacao	carmabilog@gmail.com

Appendix 6

List of online sources used for data analysis

Country	Source
Anguilla	https://www.youtube.com/watch?v=B2CYcPgutus
Anguilla	https://www.scubashackaxa.com/portfolio-view/catheley-h/, https://www.youtube.com/watch?v=K
Antigua	https://www.youtube.com/watch?v=AcZ6RIuMdLE
Bahamas	http://deadmansreef.com/adopt-reef-ball/, https://www.youtube.com/watch?v=5rsJwMn85_8&t=5
Barbados	https://www.youtube.com/watch?v=NW5blLEKgGw
Barbados	https://www.youtube.com/watch?v=NW5blLEKgGw
Barbados	http://reefinnovations.com/projects/western-atlantic/caribbean-reef-balls/barbados
Belize	http://sci-hub.tw/10.1016/j.hal.2009.11.002
Bonaire	https://www.youtube.com/watch?v=7Q3P7TK_wqs
Bonaire	http://www.feelbonaire.com/listings/hilma-hooker/
British and US Virgin Islands	http://aquaticcommons.org/12470/1/gcfi_41-14.pdf
British and US Virgin Islands	http://aquaticcommons.org/12470/1/gcfi_41-14.pdf
Columbia	**http://moam.com.co/wp-content/uploads/2015/07/11-MoAm-2015-Arrecifes-artificiales-bah%C3**
Columbia	http://moam.com.co/wp-content/uploads/2015/03/9-Delgadillo-Garz%C3%B3n-et-al-2013-Artificial-
St. Lucia	http://scubastlucia.com/diving.html
Cuba	https://www.youtube.com/watch?v=yGNujGj0ymI
Jamaica	https://www.yardieconserve.com/discover-the-port-royal-cays
Jamaica	https://www.youtube.com/watch?v=EiDoNF7ztXQ
Cuba	http://docserver.ingentaconnect.com/deliver/connect/umrsmas/00074977/v44n2/s19.pdf?expires=
Bonaire	http://www.dcbd.nl/sites/www.dcbd.nl/files/documents/PHYSIS%20VOL%206.pdf
Florida	http://sci-hub.tw/10.2307/1447304
Alabama	http://docserver.ingentaconnect.com/deliver/connect/umrsmas/00074977/v55n2/s49.pdf?expires=
Florida	https://academic.oup.com/icesjms/article/59/suppl/S196/617933
British and US Virgin Islands	http://docserver.ingentaconnect.com/deliver/connect/umrsmas/00074977/v55n2/s19.pdf?expires=
Florida	**https://sci-hub.tw/10.1080/11250009809386830**
Alabama	https://www.youtube.com/watch?v=n5IMoQxCJ-Q
Alabama	https://www.youtube.com/watch?v=jq8WVfZS5oo
Louisiana	http://www.ingentaconnect.com/content/umrsmas/bullmar/1994/00000055/F0020002/art00065#
Alabama	https://link.springer.com/article/10.1007/s10641-006-9009-4
Alabama	https://www.youtube.com/watch?v=-TAdrLSAZWQ
Louisiana	http://www.nrcresearchpress.com/doi/abs/10.1139/f97-005#.Wyob_qczbIV
Alabama	http://www.ingentaconnect.com/content/umrsmas/bullmar/2005/00000077/00000003/art00007#
Texas	https://www.youtube.com/watch?v=3ofyD1gldbg
Texas	https://www.youtube.com/watch?v=srI8MbXmtT8

Appendix 7

Assessment approach of online sources

Coral growth/recruitment		**Fish abundance**	
No Coral growth/recruitment	0% of structure surface settled by coral (video material, photographs, tables), Source statements: "… *no coral growth and recruitment", "… inhibited settlement*", etc.	No fish abundance	No individuals observed (video material, photographs, tables) Source statements:" … *no fish abundance ", "…no marine life", "…an abundance of fish did not aggregate this site"*, etc.
Poor Coral growth/recruitment	1-20% of structure surface settled by coral (video material, photographs, tables), Source statements: *"little coral growth", low rates of settlement*", etc.	Poor fish abundance	<20 individuals observed (video material, photographs, tables); Source statements: "…*reefs harbour relatively poor fish assemblages", "… low abundance of marine life*", etc
Distinct Coral growth/recruitment	20-40% of structure surface settled by coral (video material, photographs, tables), Source statements: *"some coral growth/recruitment observed"*, etc.	Distinct fish abundance	> 20 individuals observed (video material, photographs, tables); Source statements: "…*decent number of fish", "…several fish"*, etc.
Good Coral growth/recruitment	40-60% of structure surface settled by coral (video material, photographs, tables); Source statements: *"Successful recruitment of corals", "… improved settlement and growth"*, etc.	Good fish abundance	>50 individuals observed; (video material, photographs, tables); Source statements: "*A variety of fish can be seen", "…artificial reefs are, used by large numbers of fish"," attract an abundance of marine life*", etc.
Better Coral growth/recruitment than natural reef	60-100% of structure surface settled by coral (video material, photographs, tables), Source statements: *"…better performance than observed on natural reef", etc.*	Better fish abundance than natural reef	*>100 individuals observed;* (video material, photographs, tables); *Source statements: "…teeming with life", "…supporting more life than natural reef", etc.*

Appendix 8

Different types of artificial reef structures found during the present study

Types of artificial reef structures found: A= Layered Cake, B= Metal structures (diverse), C= Biorock, D= Concrete pyramids, E= Concrete blocks, F= Tires, G= Wreck, H= Reef balls