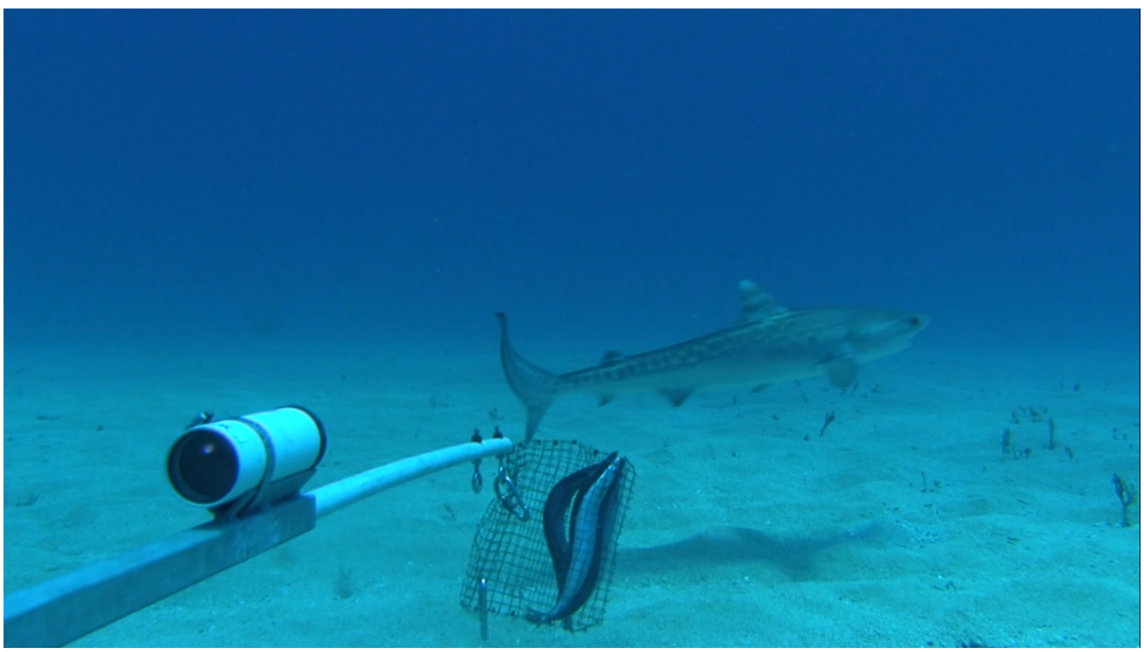
Baited Remote Underwater stereo-Video (stereo-BRUV) survey as a basis for elasmobranch conservation and management on Sint Maarten, Dutch Caribbean

Olivier Kramer & Jens Odinga



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Research report commissioned by the Institute for Marine Resources and Ecosystem Studies (IMARES) and the Nature Foundation Sint Maarten (NAFSXM)

Graduation thesis for the Bachelor of Science (BSc) Integrated Coastal Zone Management (ICZM) at Van Hall Larenstein University of Applied Sciences

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Cover photo: Juvenile tiger shark recorded during this stereo-BRUV survey

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Olivier Kramer & Jens Odinga
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Image 1: From left to right, Jens Odinga, Tadzio Bervoets, Olivier Kramer

Abstract

Elasmobranch populations (sharks, rays and skates) worldwide have declined drastically over the past decades and the situation in the Dutch Caribbean is no different. In Sint Maarten waters a shark sanctuary was established in 2011 and will remain in effect until 2021. In this period the Nature Foundation Sint Maarten is required to compile data on the status of elasmobranch populations to demonstrate the effects of these regulations. A stereo-BRUV survey conducted from March till May 2015 has successfully provided baseline information to enable a future assessment of the effectiveness of the shark sanctuary. The results from this baseline study can be compared with other surveys in the Caribbean to provide further insights into the status of elasmobranchs in the region and compare effects of legislation and management measures. The immediate results from this study have given insights into the relative abundance, species composition and distribution of elasmobranchs across different management zones around Sint Maarten. The widely used sampling technique Baited Remote Underwater stereo-Video (stereo-BRUV) has been used to collect data over 113 deployments. Three different shark species were identified, *Carcharhinus perezii* (Caribbean reef shark), *Ginglymostoma cirratum* (nurse shark) and *Galeocerdo cuvier* (tiger shark) and two different ray species, *Dasyatis americana* (southern stingray) and *Aetobatus narinari* (spotted eagle ray). Relative abundance of *D. americana* was highest of all elasmobranch species in this survey and was found widely distributed across management zones and habitat types. All sharks measured in this study were juveniles, of which *C. perezii* and *G. cirratum* have been observed in relatively higher abundances inside the marine park compared to the area outside the marine park. Especially the Conservation Zone within the marine park has shown significant differences in the presence of these species compared to other management zones. This should however be treated with caution as the majority of deployments in the Conservation Zone consisted of reef habitat, for which both species have a preference. Furthermore, previous tourist-driven shark-feeding excursions around Sint Maarten may have an influence on their distribution. This survey on its own is not elaborate enough to provide supporting evidence towards an expansion of the existing marine park. However, the significant numbers of juvenile *C. perezii* and *G. cirratum* inside the marine park provide an indication that the shallow coastal waters with high coral reef cover inside the marine park provide an important and protective habitat for these species. These findings, coupled with the effects of Marine Protected Areas (MPAs) on shark populations, provide grounds for a continued protection and conservation of sharks through additional management measures in the marine park. For the juvenile *C. perezii*, an endemic species to the Caribbean, these grounds are even more solid by providing a spillover effect to adjacent areas around Sint Maarten.

Keywords: Stereo-BRUV, elasmobranch, shark conservation, shark sanctuary, Marine Protected Area (MPA), Sint Maarten

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1 Introduction

1.1 Elasmobranchs

Elasmobranchs (sharks, skates and rays (*Elasmobranchii)*) are of critical importance to our oceans and seas. As apex predators they consume dead and weaker organisms in the food chain from the same or lower trophic levels (Techera and Klein, 2010) and contribute to an ecological balance in the marine environment. Their importance in the organisation, stability, and biodiversity in the Caribbean has been highlighted in a study by Rezende *et al.* (2009). Elasmobranchs are considered natural regulators of piscivore biomass on Caribbean reefs (Chapman *et al.*, 2006) and potentially provide a biological control against the invasive *Pterois volitans* (Lionfish) (Albins and Hixon, 2008; Arias-Gonzalez *et al.*, 2011).

Elasmobranch populations are vulnerable to increased fishing mortality rates since they grow slowly, have a late age at maturity and produce a limited number of offspring during their life (Musick, 1999). Over the past decades they have declined drastically worldwide due to their depleting food sources through overfishing and bycatch in commercial fisheries (Aires-da-Silva and Gallucci, 2007; Myers *et al.*, 2007; Herndon, 2010; Branch *et al.*, 2010; Cosandey-Godin and Morgan, 2011). Based on reports by the Western Central Atlantic Fishery Commission (WECAFC) supported by local diver and anecdotal accounts, the situation in the Dutch Caribbean is no different (Debrot and Criens, 2005). It appears that throughout the wider Caribbean, elasmobranch populations decline when human population density increases (Stallings, 2009). This is mainly through the deterioration and decline of important elasmobranch habitats including habitats of juvenile elasmobranchs in coastal waters (Fowler *et al.*, 2005).

Of the 33 elasmobranch species present in the Dutch Caribbean the IUCN Red List displays that 10 are threatened with extinction (Critically Endangered=1, Endangered=2, Vulnerable=7), 8 are near threatened and for 9 species data is deficient, which does not imply these species are not threatened, on the contrary it might be indicative they are (van Overzee *et al.*, 2013). Deficient data and lack of enforcement capacity are the major obstacles for protection and conservation of elasmobranch populations (Fowler *et al.*, 2005). Appendix I lists the commonly found and potentially present elasmobranch species in Sint Maarten waters including the ones observed in this study.

Besides their ecological importance to marine ecosystems, elasmobranchs are a major attraction for scuba divers on Sint Maarten and have substantial economic value (Maljkovic and Cote, 2011; Bervoets, 2012). According to a recent study by the Nature Foundation Sint Maarten (NAFSXM), coral reefs and their associated biota provide important goods and services to Sint Maarten's economy. Approximately 80% of Sint Maarten's visitors conduct reef-associated activities. Therefore, safeguarding the provided goods and services by the reefs is of major importance to the island's economy. The revenue generated from associated tourism (which includes diving and accommodation) and fisheries is estimated at USD$57.743.000 (€51.283.000) annually, with the main contributor of this amount being tourism (USD$55.743.000 (€49.509.000) and fisheries USD$1.844.000 (€1.637.000)) (Nature Foundation Sint Maarten, 2010). However, the total value of reef-associated benefits is thought to be underestimated in this case, as coastal protection and other non-use values are not included. The economic value of elasmobranchs for Sint Maarten through (dive) tourism together with their ecological role as apex predators can potentially raise the need for their protection and conservation.

Sint Maarten is situated on the Anguilla bank, a submarine plateau with a maximum depth of 36 meters. This plateau is shared with the neighbouring islands St. Barthélemy and Anguilla. Typical marine habitats surrounding the island are coral reefs, seagrass beds and mangroves, which have all been severely degraded over the past decades. (Nature Foundation Sint Maarten, 2011)

Coral reefs on Sint Maarten are mainly patch reefs divided by spur and groove formations (coral ridges divided by sand channels) and include boulders. Their complex structure hosts a high species diversity and coral reefs are considered a major contributor to fish biomass and hence provide an important habitat for several elasmobranch species. Mainly *Carcharhinus perezii* (Caribbean reef shark), which is endemic to the Western Atlantic from Bermuda to southern Brazil (Garrick, 1982; Compagno, 1984; Jensen *et al*., 1995), and *Ginglymostoma cirratum* (nurse sharks) inhabit Sint Maarten's reefs. Occasionally *Carcharhinus limbatus* (blacktip shark) and *Galeocerdo cuvier* (tiger shark) are seen. Other sightings include *Manta birostris* (manta ray), *Himantura schmardae* (chupare stingray), *Dasyatis say* (bluntnose stingray), *Dasyatis americana* (southern stingray) and *Aetobatus narinari* (spotted eagle ray). (Nature Foundation Sint Maarten, 2011)

Seagrass beds provide highly productive ecosystems for a diversity of marine life and mainly form in shallow coastal lagoon areas. Seagrass beds on Sint Maarten are located around the southern and southwestern shores, but have been severely degraded by unsustainable fisheries and coastal development over the past decades (Nature Foundation Sint Maarten, 2011). A study by DeAngelis *et al.* (2008) suggests that seagrass beds may be utilised as *G. cirratum* mating ground and Heithaus *et al.* (2002) propose that seagrass beds are a foraging area for *G. cuvier*.

Mangroves are productive feeding grounds for a variety of marine life and offer a protective habitat for juvenile fish as well as juvenile elasmobranchs (Kaiser *et al.,* 2005). Mangroves around the world are in steep decline (>60%) mainly due to coastal development, which is no different on Sint Maarten. Species previously identified in the few mangroves left on Sint Maarten are *A. narinari* and various species of juvenile elasmobranchs (Nature Foundation Sint Maarten, 2007). Other studies have found that mangroves provide an important habitat for juvenile *Negaprion brevirostris* (lemon shark) and juvenile *C. limbatus* (Cortés and Gruber, 1990; Heupel and Hueter, 2002; Hoffmayer and Parsons, 2003).

This study provides the first baseline survey on the relative abundance, species composition and distribution of elasmobranch populations around Sint Maarten, including the investigation of potential habitats for juvenile elasmobranchs. The elasmobranch abundance in this study is relative, as absolute numbers cannot be determined by the method used. An attempt to identify habitats for juvenile elasmobranchs is aimed to increase the protection and conservation potential for certain elasmobranch species and their marine habitats. This elaborates on the ongoing Negara project in the northern (French) part of the island, which investigates the abundance and distribution of juvenile *N. brevirostris*. Other juvenile species identified during the pilot stage in the French research are *G. cirratum*, *C. limbatus* and *A. narinari* (Chalifour and Beaufort, 2015).

In this study, data was collected through fisheries independent surveys, using a Baited Remote Underwater stereo-Video technique, from here on referred to as stereo-BRUV. This method is increasingly used to sample both tropical and temperate fish assemblages, as well as elasmobranchs. Over 2012 and 2013 the first structured and standardised reef fish surveys using stereo-BRUV have been conducted in the Dutch Caribbean on Saba, Saba bank and St. Eustatius (Stoffers, 2014; Van Looijengoed, 2013; Van Kuijk, 2013).

1.2 Policy and legislations for elasmobranch protection and conservation

Sint Maarten is one of the six islands that make up the Dutch Caribbean that can be divided into the Leeward Islands (Aruba, Bonaire and Curaçao), just off the coast of Venezuela and the Windward islands (Saba, St. Eustatius and Sint Maarten), in the northeastern Caribbean (Nature Foundation St. Maarten, 2011). Bonaire, Saba and St. Eustatius make up the Caribbean Netherlands and are under Dutch jurisdiction through the Ministry of Economic Affairs, whereas Aruba, Curaçao and Sint Maarten are autonomous countries within the Kingdom of the Netherlands (Ministry of Economic Affairs, 2013). The Dutch Ministry of Economic Affairs is directly responsible for the policy and management of areas within the Exclusive Economic Zone (EEZ) of the Dutch Caribbean, whereas Sint Maarten's local government is responsible for the implementation of management within its own national jurisdiction, i.e. its Territorial Waters (TW) (Overzee *et al.,* 2012). The international jurisdictional borders of Sint Maarten with surrounding countries are determined based on equidistance lines (i.e. legal concept that a nation's maritime boundaries conform to a median line equidistant from the shores of neighbouring nation-states (Dallmeyer *et al*., 1989)) (Meesters *et al*., 2010).

The island of Sint Maarten is shared by two sovereign governments, the Dutch Sint Maarten, and the French Saint-Martin (collectively they are known as St. Martin) (Nature Foundation St. Maarten, 2011). This study focuses on the Dutch part of the island, Sint Maarten.

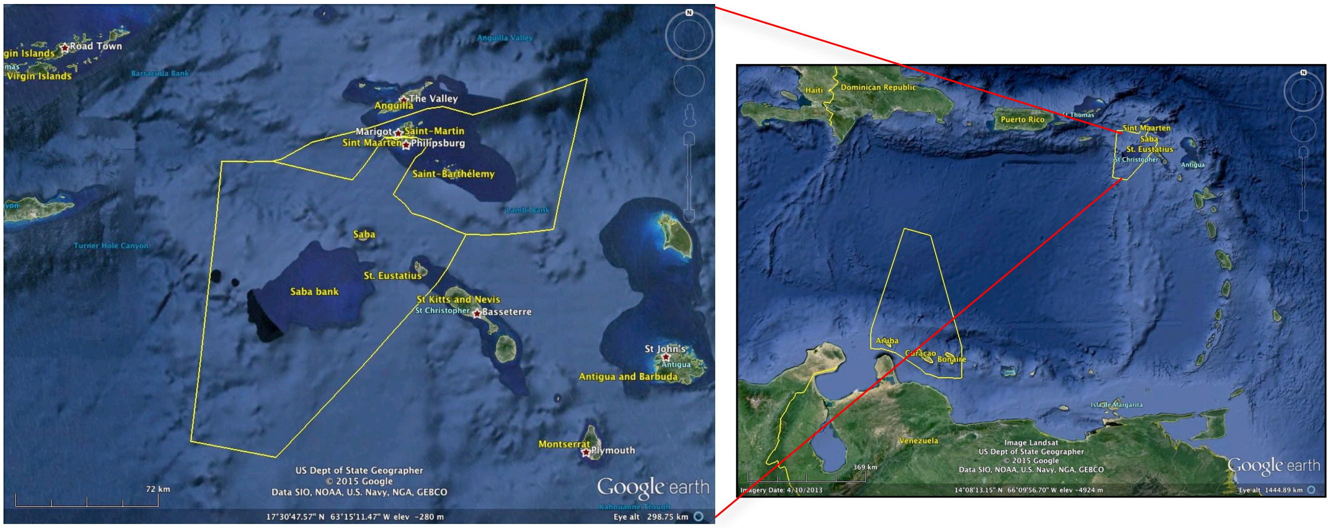


Figure 1: Left: Dutch Windward Islands and surrounding countries including Dutch and French EEZ. Right: Caribbean region and West Indies including EEZ of Dutch Caribbean. (Google Earth, 2105)

The Kingdom of The Netherlands and Sint Maarten have ratified a number of international and regional treaties and conventions by which elasmobranchs are directly or indirectly protected (van Beek *et al.,* 2012). The most important ones are:

- CBD: Convention On Biological Diversity
- CITES: Convention on International Trade in Endangered Species of Wild Flora and Fauna
- CMS: Convention On The Conservation Of Migratory Species Of Wild Animals
- SPAW: Special Protected Area protocol of the Cartagena Convention for the Protection and Development of the Marine Environment of the Wider Caribbean

Appendix I lists the commonly found and potentially present elasmobranch species in Sint Maarten waters including their protective status according these international treaties and conventions.

Within the framework of the above ratifications the Dutch Ministry of Economic Affairs has developed the Nature Policy Plan Caribbean Netherlands (Natuurbeleidsplan Caribisch Nederland). This plan provides the framework for nature conservation in the Caribbean Netherlands and strives to align conservation measures with the other islands of the Dutch Caribbean including Sint Maarten. It also strives to form partnerships with other countries in the Caribbean to perform research on elasmobranchs and align elasmobranch conservation measures. For the management of natural resources in Territorial Waters and the EEZ of the Dutch Caribbean a management plan has been developed to which Sint Maarten has also committed itself. Goals have been set in this management plan to establish international partnerships to designate shark sanctuaries and develop National Plans of Action for the Protection of Sharks (NPOA-Sharks) throughout the Dutch Caribbean, as also advised by the WECAFC (Meesters *et al*., 2010). (Ministry of Economic Affairs, 2013)

This study is in line with plans as set out by the Dutch Caribbean Nature Alliance (DCNA). DCNA is a non-profit organisation offering a regional network and assistance to nature conservation organisations to benefit the protection of the natural environment and improve sustainable natural resource management in the Dutch Caribbean (Ministry of Economic Affairs, 2013). DCNA manages a fund that receives annual contributions from the Ministry of the Interior and Kingdom Relations to support nature conservation throughout the Dutch Caribbean (Ministry of Economic Affairs, 2013). Their conservation project 'Save our sharks' aims to build awareness and capacity for elasmobranch conservation throughout the Dutch Caribbean (DCNA, 2015b) for which financial support from the Dutch Postcode Lottery was received in February 2015 (Nationale Postcode Loterij, 2015). Part of this project is to conduct extensive elasmobranch surveys including the support of IMARES in their stereo-BRUV surveys throughout the Dutch Caribbean (DCNA, 2015d).

On 4 October 2011 the Ministry of Tourism, Economic Affairs, Telecommunication and Transportation on Sint Maarten declared a shark sanctuary for all national waters including its EEZ. This regulation applies a ban on fishing, chasing, injuring or killing elasmobranchs and when accidentally caught they need to be released without inflicting any harm. The shark sanctuary applies to sharks, skates and rays (*Elasmobranchii*) and includes meaningful sanctions as outlined in Appendix II (Ministry of Tourism, Economic Affairs, Telecommunication and Transportation, 2011). Enforcement of regulations is mainly done through patrolling by NAFSXM and reporting by dive operators. However, there are reports of illegal elasmobranch fishing and in 2012 a fisherman was arrested and sentenced for illegally catching a *C. perezii* (T. Bervoets, pers. comm., 2015).

The shark sanctuary came into effect after a reduction in elasmobranch sightings was detected by NAFSXM staff and dive operators (T. Bervoets, pers. comm., 2015). There are no directed elasmobranch fisheries in the Dutch Caribbean, yet elasmobranch bycatch is very common in the Caribbean (Fowler *et al*., 2005). Many foreign fishing fleets operate in Sint Maarten waters and so called 'trophy fishing' (act of display to catch the largest fish) including shark catches were often reported. After intensive lobbying by the NAFSXM with the small artisanal fishing fleet, tourism operators and Sint Maarten government, acceptance for the protection of elasmobranchs grew and eventually led to the designation of the current shark sanctuary (T. Bervoets, pers. comm., 2015). The shark sanctuary will remain in effect until 4 October 2021 and in this period the NAFSXM is required to compile data on the status of elasmobranch populations and will attempt to demonstrate the effect of these regulations (T. Bervoets, pers. comm., 2015).

This study supports the NAFSXM by enabling an assessment of the effectiveness of the shark sanctuary over time by providing baseline information for future comparison studies. Additionally, it will support IMARES in a comparison of relative abundance, species composition and distribution of elasmobranch populations with previous studies performed on Saba, the Saba bank and St. Eustatius. Both the assessment of the shark sanctuary and the comparison of elasmobranch information across the Dutch Caribbean form the foundations from which this study is conducted. The information gathered in this study is of further relevance to support international elasmobranch conservation and protection measures in the Dutch Caribbean by DCNA and the Dutch Ministry of Economic Affairs.

1.3 Management measures through the Man of War Shoal Marine Park

On 30 December 2011 the Man of War Shoal Marine Park was established and covers 31 km^2 (3,100 hectares) of some of the islands' ecologically and economically most important marine habitats (DCNA, 2015c). It is located on the southeastern side of the island in an area known as the 'Proselyte Reef Complex' (Figure 2) and includes extensive coral reef areas and seagrass beds. It is a home, migratory stopover and breeding site for three IUCN Red List Species, 10 CITES Appendix I species and 89 Appendix II species and numerous species of elasmobranchs (Nature Foundation Sint Maarten, 2011). Studies have shown that biodiversity and coral reef cover is high compared to outside the marine park and fish populations have increased in size by 10% since its establishment (Nature Foundation Sint Maarten, 2011). Entrance fees to the marine park go directly towards management of the park (DCNA, 2015a) and together with its attraction for tourism (10-15,000 divers and 50-100,000 snorkelers each year) its economic value is estimated at around USD$55 (€48 million annually (Nature Foundation Sint Maarten, 2011). On 9 December 2014 the marine park was formally listed under the Special Protected Areas and Wildlife (SPAW) Protocol of the Cartagena Convention (Sint Maarten Island Time, 2014).

The Man of War Shoal Marine Park (hereafter referred to as marine park) legally restricts the area for exploitation and use and consists of a Conservation Zone and Traffic Zone. In the Conservation Zone there is entire prohibition of water scooter use, fishing of any kind, sailing with vessels exceeding an average draft of six meters, removal of dead or alive organisms and introducing invasive species. Within the Traffic Zone shipping is allowed at all times to allow entry and access for around 650 cruise ships to Great Bay and Phillipsburg on an annual basis.

The NAFSXM aims to expand the marine park with a proposed Conservation Zone extension. This area covers extensive coral reef areas across the Anguilla bank on the eastern side of the island. This extension will improve ecological connectivity with the Réserve Naturelle Marine, a French marine park located on the northeastern side of the island. The location of the proposed extension has only roughly been determined, as illustrated in Figure 2. (Nature Foundation Sint Maarten, 2011; T. Bervoets, pers. comm., 2015)

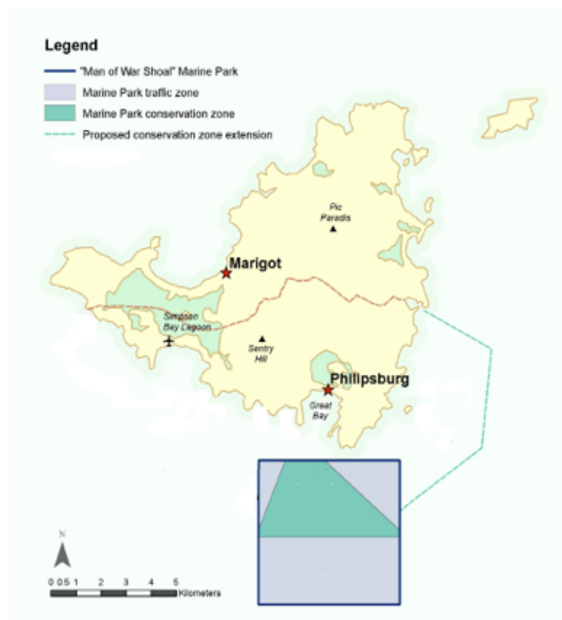


Figure 2: Marine park management zones around Sint Maarten.

The baseline survey in this study will be conducted throughout Sint Maarten waters inside- and outside the marine park, including the proposed Conservation Zone extension. The results from this study can contribute to an assessment of the effect of different management zones on relative abundance, species composition and distribution of elasmobranch populations when similar surveys are conducted in the future. Furthermore, it can provide information in support of the NAFSXM in its plans for an extension of the existing marine park.

1.4 Research aim and questions

The main aim in this study is to provide an initial assessment of elasmobranch populations around Sint Maarten in support of existing and future elasmobranch conservation measures for Sint Maarten and the rest of the Dutch Caribbean.

The objectives of this study are the following:

- Provide an initial assessment on relative abundance, species composition and distribution of elasmobranch populations across different management zones around Sint Maarten
- Identify potential habitats for juvenile elasmobranchs around Sint Maarten based on their presence
- Provide information in support of an expansion of the existing marine park on Sint Maarten
- Provide information to support the review of the shark sanctuary for Sint Maarten.

This research aim and objectives lead to the following research questions:

1. What is the relative abundance, species composition and distribution of elasmobranchs across different management zones* around Sint Maarten?

2. Can habitats for juvenile elasmobranchs be identified around Sint Maarten based on their presence?

3. Do differences in results among different management zones* and identified juvenile habitats provide supporting information towards an expansion of the existing marine park on Sint Maarten?

4. How can this study support the review of the shark sanctuary for Sint Maarten?

* Throughout this document, management zones refer to:

- Conservation Zone and Traffic Zone inside the Man of War Shoal marine park
- Proposed Conservation Zone extension
- Area outside the Man of War Shoal marine park (within TW of Sint Maarten)

2 Material and methods

2.1 Study area

This stereo-BRUV elasmobranch survey was conducted between 1 March and 3 May 2015 on (Dutch) Sint Maarten. Stereo-BRUV samples were collected throughout Territorial Waters (12 nautical mile zone), designated as shark sanctuary, marked by the yellow boundary lines in Figure 3 below. The study area is partly situated on the Anguilla bank, with a maximum depth of 36 meters and harbours a variety of marine habitats for elasmobranchs, including sand, seagrass, coral reef and mangroves. In addition to an ecological differentiation in this study, a management zone distinction is made, i.e. inside and outside the marine park with a further distinction between Conservation Zone, Traffic Zone, proposed Conservation Zone extension and the area outside the Marine Park within Territorial Waters (see 1.3 Management measures through the Man of War Shoal Shoal marine park).

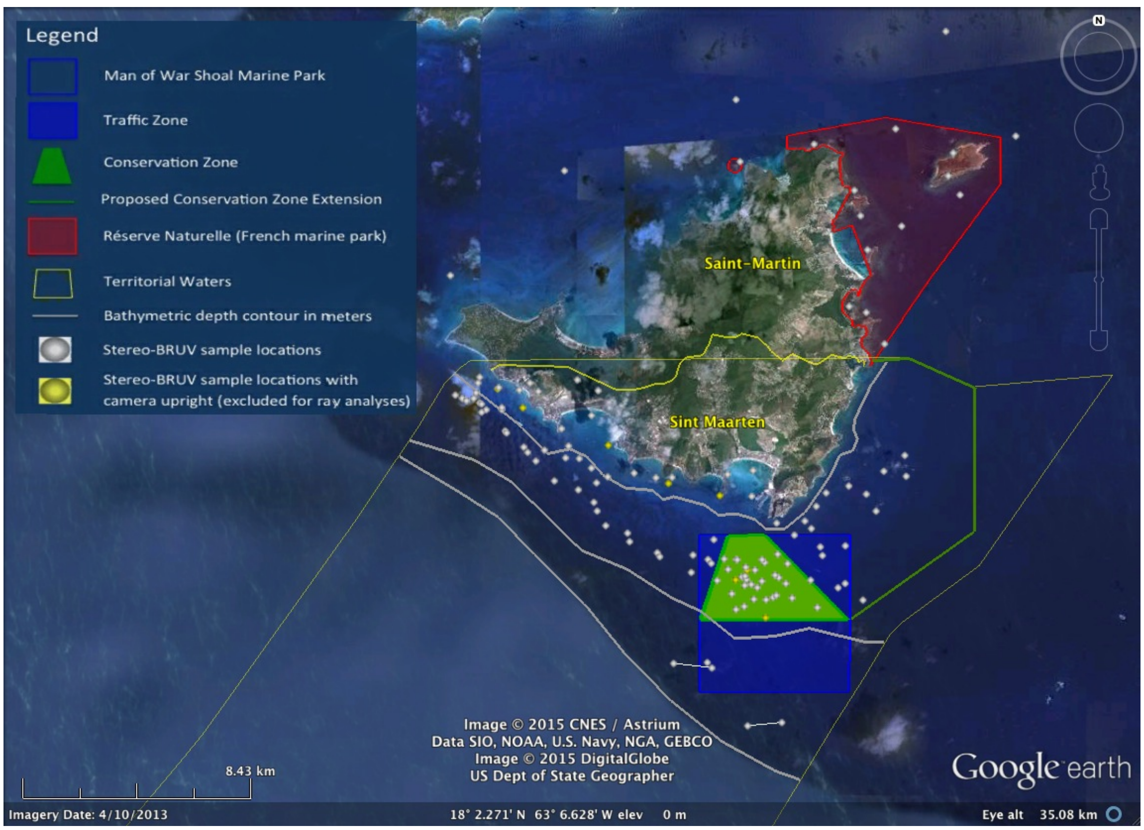


Figure 3: Stereo-BRUV deployments on Sint Maarten

2.2 Sampling technique

This baseline survey was conducted by a Baited Remote Underwater stereo-Video (stereo-BRUV) sampling method. This method is increasingly used to sample both tropical and temperate fish assemblages, as well as elasmobranchs. The camera setup and operation is derived from successful studies from the past, Harman *et al.* (2003), Watson *et al.* (2005) and Langlois *et al.* (2010) and comprises of 2 Canon Legria HFG10 video cameras assembled to a steel frame, 70 cm apart and inwardly converged at 8

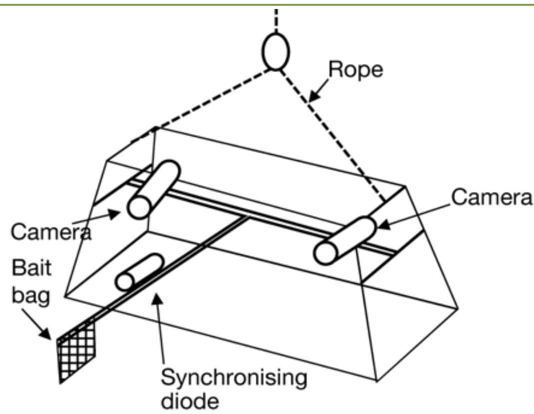


Figure 4: Stereo-BRUV setup

degrees (Figure 4). The frame is equipped with a synchronising diode and bait bag containing approximately 800 grams of pilchards (*Sardinops sp.*) positioned at 1.5 meters distance in front of the cameras. More details on materials can be found in Appendix III: Equipment list.

Once the camera frame was dropped off the boat, the buoy line adapted to the depth profile and frame checked for horizontal position on seabed, the boat steered away from the sampling location to minimise disturbance. One stereo-BRUV deployment obtained approximately 60 minutes of continuous video footage. In total, three camera systems were available during this study and could be operated concurrently provided that sample locations were at least 500 meters apart to reduce overlap of bait odour plumes (Willis and Babcock, 2000; Harvey *et al*., 2007; Heagney *et al*., 2007). For concurrent deployments not within this accepted minimum range, observed individuals were tracked in video analysis and only observations of unique individuals were accepted and included in data analysis. The cameras can be deployed to a maximum depth of 100 meters, hence deep sea elasmobranch species have been excluded from this survey. Appendix IV describes the detailed stereo-BRUV deployment procedures.

2.3 Sampling design

For the baseline survey a total of 115 stereo-BRUV deployments were performed in Sint Maarten waters and were divided over different management zones and habitat types (Figure 5). Habitat types were largely unknown prior to executing this survey and hence the spread of deployments between habitat types was unequal. Deployments across management zones were also unequally distributed through limited sampling effort in the Conservation Zone and proposed Conservation Zone extension. Their exposed location and persistent strong winds coupled with bathymetric relief caused swells pulling the frames upright. Four deployments were performed near mangroves targeted on identifying habitats for juvenile elasmobranchs. Two deployments were performed in the pelagic zone as a pilot study in which no sharks were observed. Both mangrove and pelagic deployments have been

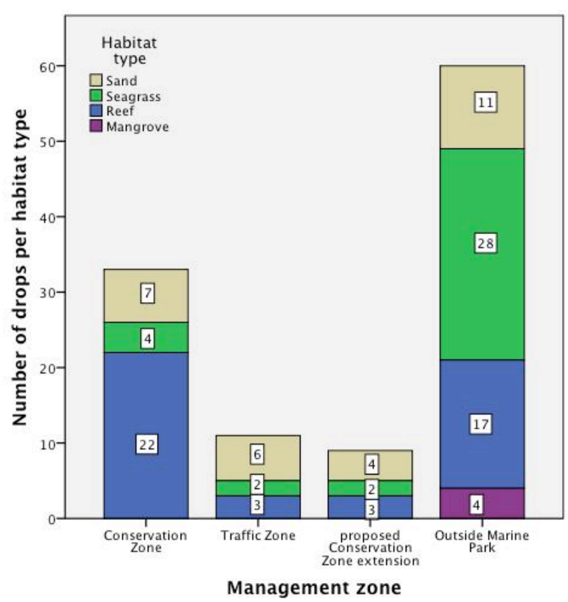


Figure 5: Number of deployments per management zone and habitat type. Mangroves have been included for completeness.

excluded from data analysis of relative abundance of elasmobranchs. Besides a low n-value these variables created a dependency with the variable management zone, thereby interfering with statistical analysis. Eleven deployments were unsuccessful for ray analysis as the frame pointed upright in which case their abundance is likely to be underestimated as most ray species have a strictly benthic lifestyle. For shark analysis, these deployments were included, as sharks tend to come very close while being attracted by the bait bag and are therefore likely to be recorded on camera. In conclusion, respectively 109 and 98 deployments are accepted for analysis of relative abundance of sharks and rays. Another 18 deployments were performed in French waters (Saint Martin) including the marine park Réserve Naturelle, but have not been included in data analysis as the shark sanctuary covers Dutch waters only. This effort has strengthened the relationship between the French and Dutch in support of elasmobranch conservation.

2.4 Video analysis

Prior to video analysis of the data, the camera setup was calibrated with SeaGIS CAL V2.10 software (www.seagis.com.au) in order to take accurate length measurements. Further information and details on the calibration can be found in Harvey and Shortis (1995; 1998). A practical note not included in the manual, but necessary for accurate results: Video footage for calibration was collected on a clear day (no clouds) in clear water in a swimming pool.

Elasmobranch size and relative abundance datasets were obtained from the video analysis software EventMeasure (www.seagis.com.au). See Appendix V for images of the video analysis software CAL and EventMeasure. Maximum number (MaxN) is a common relative abundance index for studying reef fish assemblage, yet is less suitable for larger, less abundant species such as sharks. Instead, Catch per Unit of Effort (CpUE), i.e. number of elasmobranch per hour, was used as a relative abundance index during video analysis (Brooks *et al.*, 2011; Cappo *et al.*, 2006). Lengths of sharks and disc widths of rays were obtained when possible. The cameras are mounted on steel frames on a slight inward angle, enabling EventMeasure to calculate both the distance of an individual from the camera (range) and its length, provided that the individual is fully visible on both cameras (Cappo *et al.,* 2006). Length measurements were accepted if the precision of measurements, calculated by the ratio standard deviation/length, was below 0.10 (e.g. <10cm on 1m elasmobranch). In addition, the RMS intersection for measurement quality control was set to ≤10 mm in line with other stereo-BRUV surveys around the world (pers. comm. M. de Graaf). Relative abundance and length data was obtained from EventMeasure and then further processed into categorical data including time on seabed, management zone, habitat type, species, gender and length. Gender was not analysed, as it was observed in just 18% of all elasmobranchs. When individuals with a similar length, within the precision range, or distinctive morphological characteristics like scars or ray tail length were observed in one video they were not counted to ensure unique observations. Identification of individuals was applied within one deployment, i.e. one hour of video, and not across deployments.

Habitat data was derived from an image of the video, once the cameras were at the bottom. This study distinguishes the following habitats: sand, seagrass, mangroves and (coral) reefs including a structure complexity index of 0-4 (Figure 6; Polunin and Roberts, 1993). All habitat images including habitat classification are included in Appendix VIII.

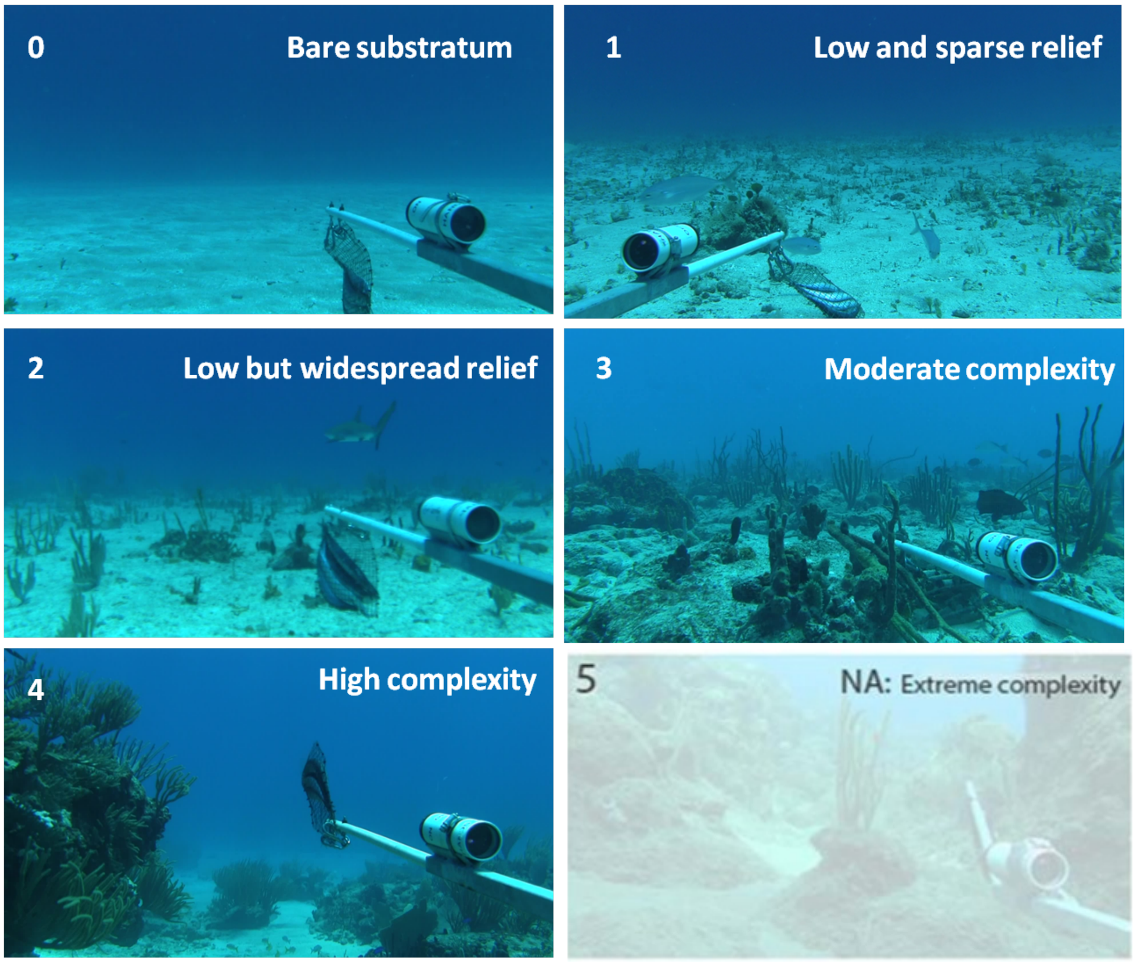


Figure 6: The 6-point scale (0-5) of Polunin and Roberts (1993) used in this study to quantify habitat by the complexity scale of the reef. It is divided into the categories: (0) bare substratum, (1) low and sparse relief, (2) low but widespread relief, (3) moderate complexity, (4) high complexity and (5) extreme complexity. The latter category (5) was not found in the sampling data of Sint Maarten and is therefore left out in this study.

Habitat complexity was further normalized to a three-point scale (Low, Medium, High) to increase n-values of individual categories and to include seagrass. Habitat complexity Low includes sand, seagrass cover 0-10% (Figure 7) and reef complexity 0-1 (Polunin), Medium includes seagrass cover 10-100% (Figure 7) and reef complexity 2-3 (Polunin) and High includes reef complexity 4-5 (Polunin). Mangroves were excluded in the habitat complexity index, as images could not be classified due to poor visibility.

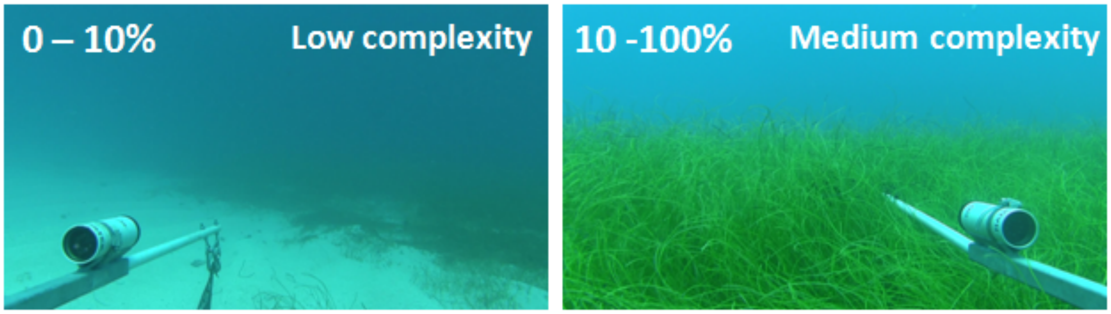


Figure 7: Classification of seagrass within the normalised habitat complexity index.

2.5 Data analysis

Elasmobranch abundance was analysed using binary logistic regression in SPSS (IBM SPSS Statistics version 21). First the relative abundance data was transformed into an indirect index, in this case presence/absence of elasmobranchs instead of using Catch per Unit of Effort (number of elasmobranchs per hour) as direct measure for relative abundance. This was done since the dataset was not normally distributed, not homogeneous, contained many 0-values (no elasmobranchs observed) and a low n-value of deployments with elasmobranchs was observed. Elasmobranch abundance was tested for the explanatory factors marine park, management zone, habitat type and habitat complexity. The factors marine park and management zone are dependent upon each other, as well as habitat type and habitat complexity and have been tested in separate models. The interactions marine park * habitat type, management zone * habitat type, marine park * habitat complexity and management zone * habitat complexity were also tested as they can influence relative abundance, species composition and distribution of elasmobranch populations. Since CpUE is a common measure of expressing relative abundance in other stereo-BRUV surveys (Brooks *et al.*, 2011; Bond *et al.*, 2012) this method has been applied for completeness and can be found in Appendix VII.

3 Results

During this survey a total of 133 stereo-BRUV deployments were performed in St. Martin waters of which 109 and 98 are accepted for shark and ray analysis respectively. In 18 deployments 37 sharks were observed consisting of three different species. *Carcharhinus perezii (*Caribbean reef shark) was the most abundant shark species in this study in absolute numbers (n=21, 57%). *Ginglymostoma cirratum* (nurse shark) was the second most abundant species (n=15, 40%) and one *Galeocerdo cuvier* (tiger shark) (3%) was observed. *G. cuvier* is excluded from statistical analyses due to its low n-value. Also excluded from data analysis are one *C. perezii* inside and two *C. perezii* outside the French Réserve Naturelle and two *G. cirratum* inside the Réserve Naturelle. Over 26 deployments 37 rays were observed consisting of two species. *Dasyatis americana* (southern stingray) was the predominant species (n=35, 95%) and *Aetobatus narinari* (spotted eagle ray) was observed twice (5%) and was excluded from statistical analyses due to its low n-value. Also excluded from data analysis are five *D. americana* inside and three *D. americana* outside the French Réserve Naturelle. Number of deployments (%) with elasmobranchs is displayed in Figure 8. Species composition (in numbers) is displayed in Figure 9. Spatial distribution of sharks and rays is illustrated in Figure 10 and 11 respectively (next page).

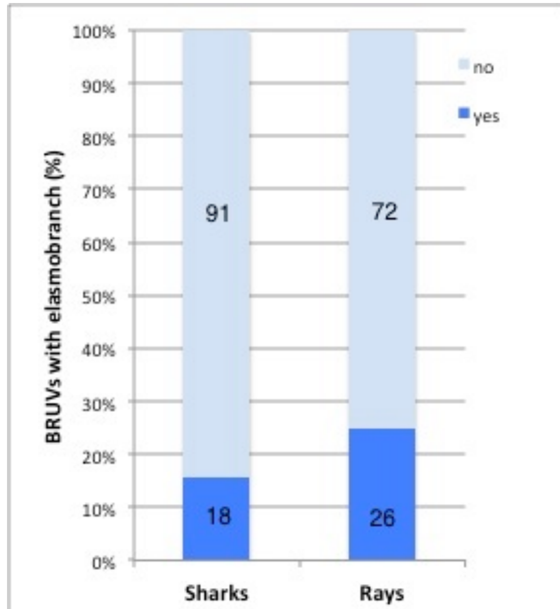
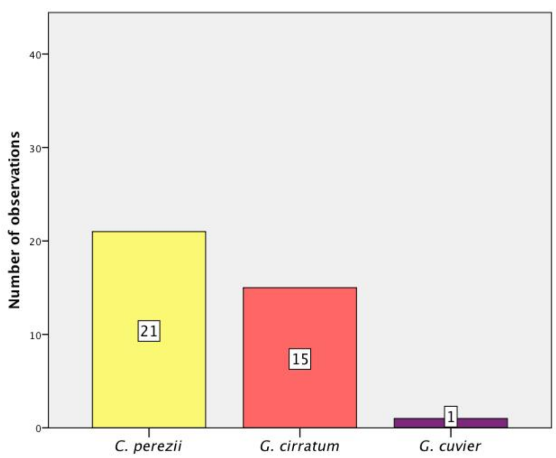


Figure 8: Stereo-BRUV deployments with elasmobranchs. Data labels display absolute numbers.



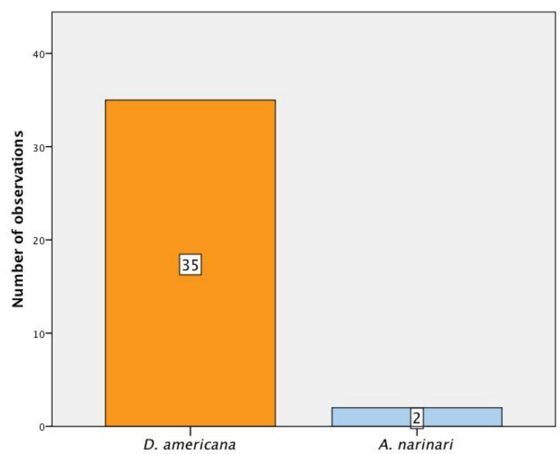


Figure 9: Elasmobranchs species composition in numbers per species. Data labels display absolute numbers.

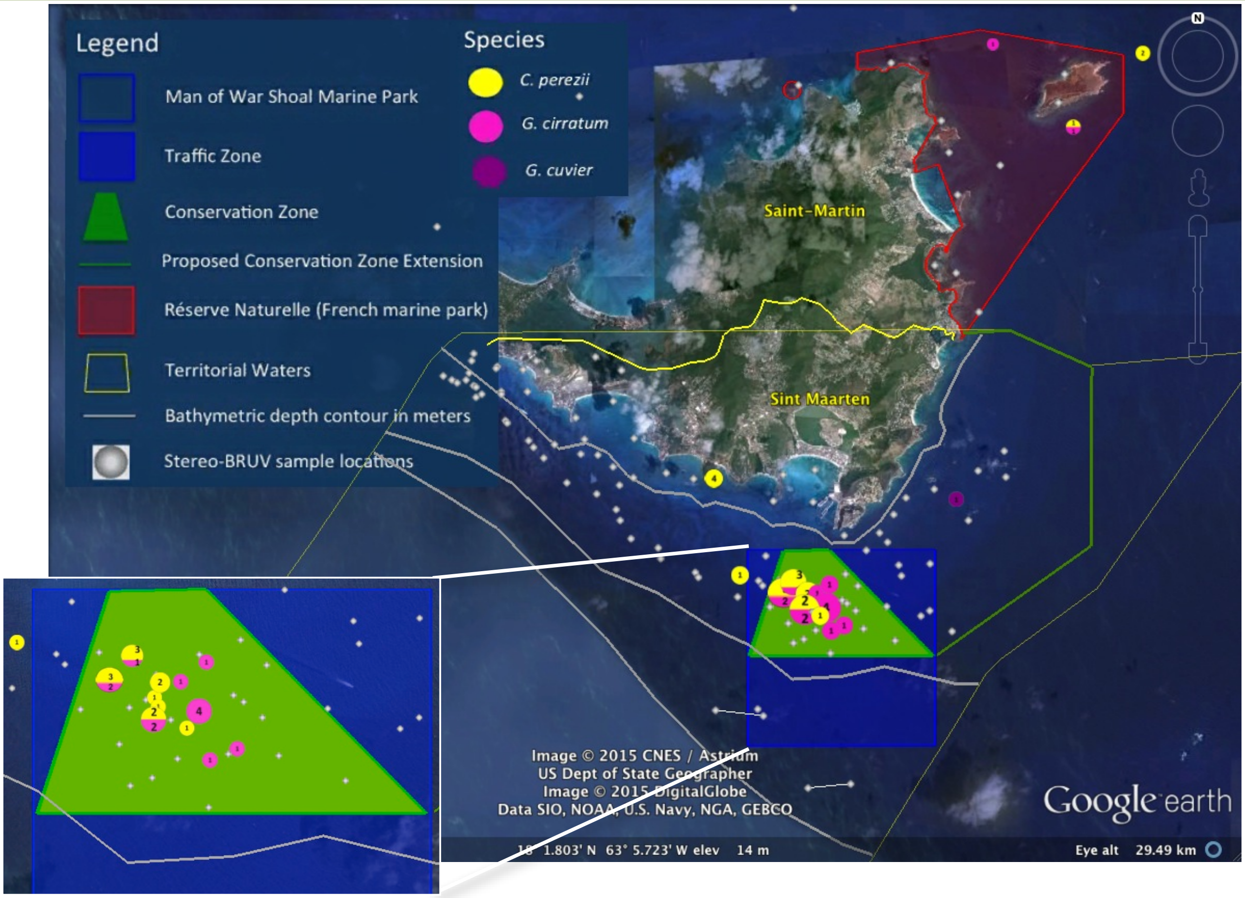


Figure 10: Spatial distribution of sharks around Sint Maarten and Saint Martin. The inset displays details within the Conservation Zone. Shark abundance is illustrated by (absolute) numbers and size of dots.

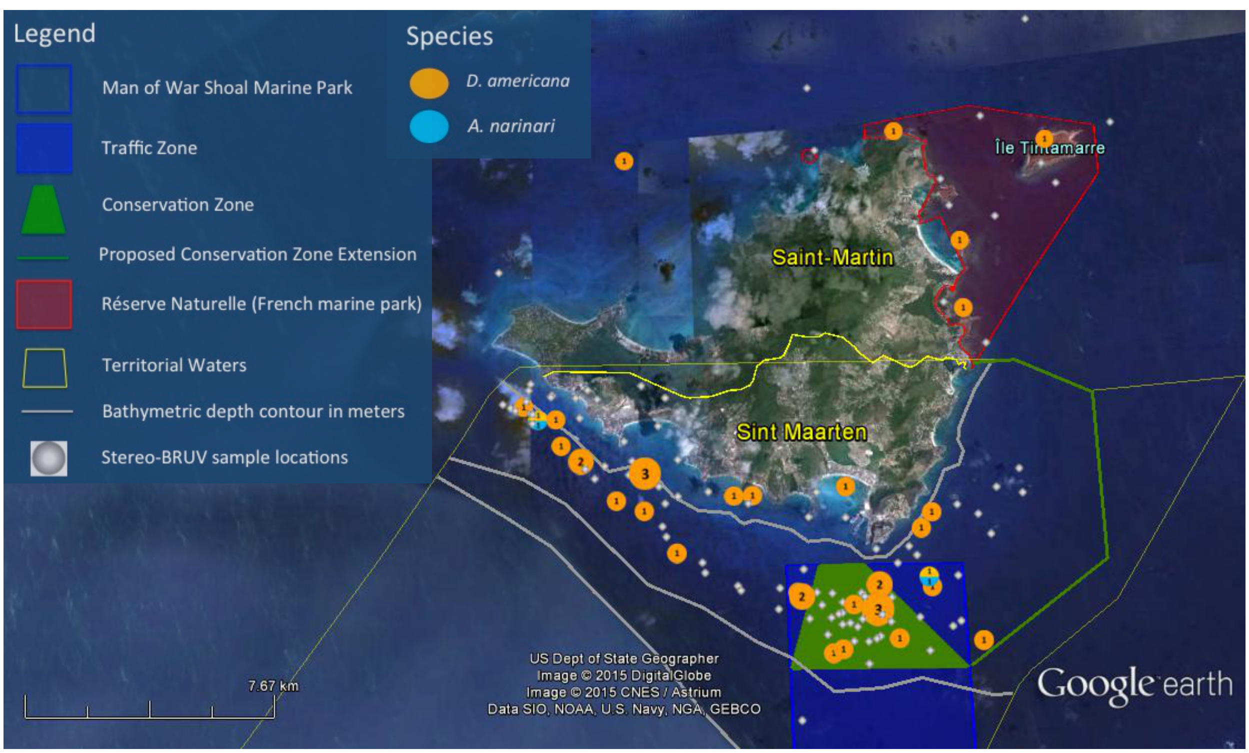


Figure 11: Spatial distribution of rays around Sint Maarten and Saint Martin. Ray abundance is illustrated by (absolute) numbers and size of dots.

In terms of presence/absence of sharks during stereo-BRUV deployments *G. cirratum* was observed in most deployments (n=9) followed by *C. perezii* (n=8). For rays *D. americana* was observed over most deployments (n=26) and two *A. narinari* were observed over two separate deployments (Figure 12A). In terms of number of sharks per hour (CpUE) *C. perezii* was most abundant at 0.19 and *G. cirratum* at 0.12 per hour. For rays *D. americana* was observed 0.31 and *A. narinari* 0.02 times per hour (Figure 12B).

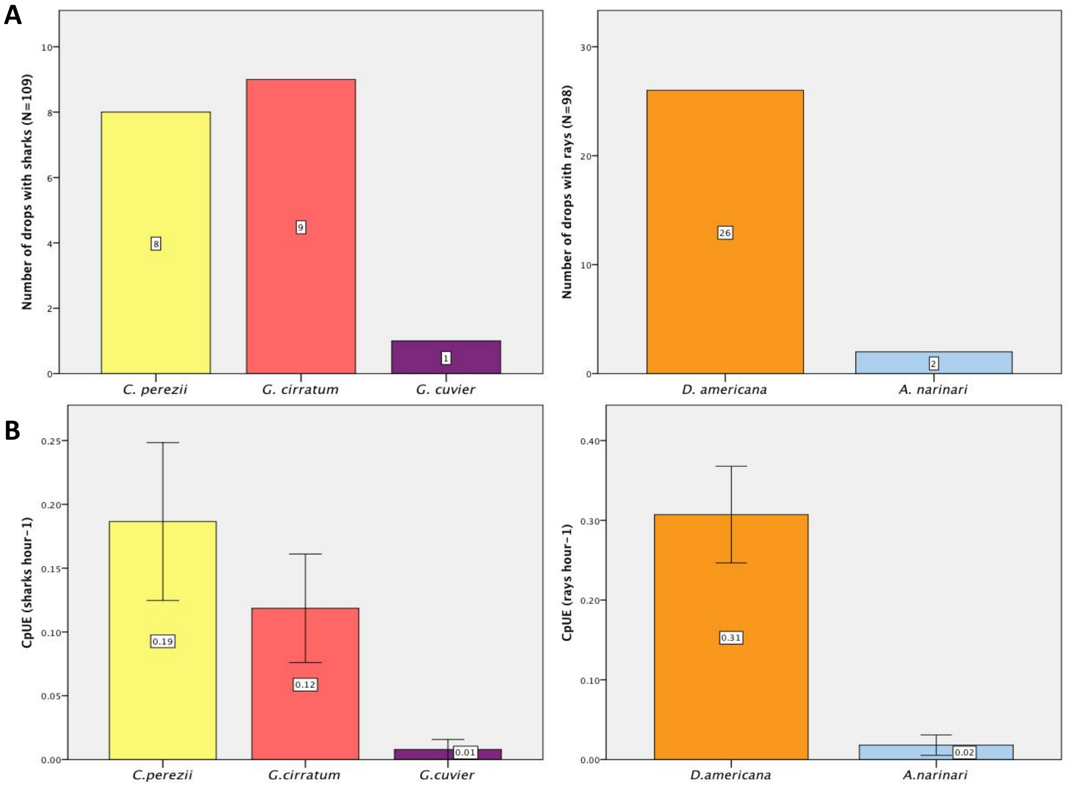


Figure 12: Relative elasmobranch abundance per species expressed in presence/absence (A) and Catch per Unit of Effort (CpUE) (B), which accounts for the variation in actual effort (i.e. actual time on seabed).

47% of *C. perezii* and *G. cirratum* could be measured where mean fork length of *C. perezii* was 84cm (±6SE) with the smallest observed individual being 60cm and the largest 115cm. Mean fork length of *G. cirratum* was 71cm (±8SE) with the smallest observed individual being 54cm and largest 111cm. The tiger shark was a female measuring 82cm fork length (Figure 13). The length frequency diagram (Figure 14A) displays that most observations of *C. perezii* were in between 65-95cm with a few individuals measuring over one meter in fork length. Most *G. cirratum* were in between 60-90cm with a few other individuals measuring a little over 1 meter. All sharks measured during this study were juveniles based on life history information (Fowler *et al*., 2005; Froese and Pauly, 2011). 89% of *D. americana* could be measured with a mean disc width of 87cm (±6SE) with the smallest observed individual being 30cm and the largest 204cm. Of *A. narinari* no lengths were measured. The length frequency diagram for *D. americana* (Figure 14B) displays that a number of smaller individuals in between 30-50cms were observed with a relatively large peak in between 100-120cm disc width. Of the measured individuals of *D. americana* 10 were juveniles and 21 were adults based on life history information (Froese and Pauly, 2011). No significant differences in shark or ray sizes were detected across different management zones.

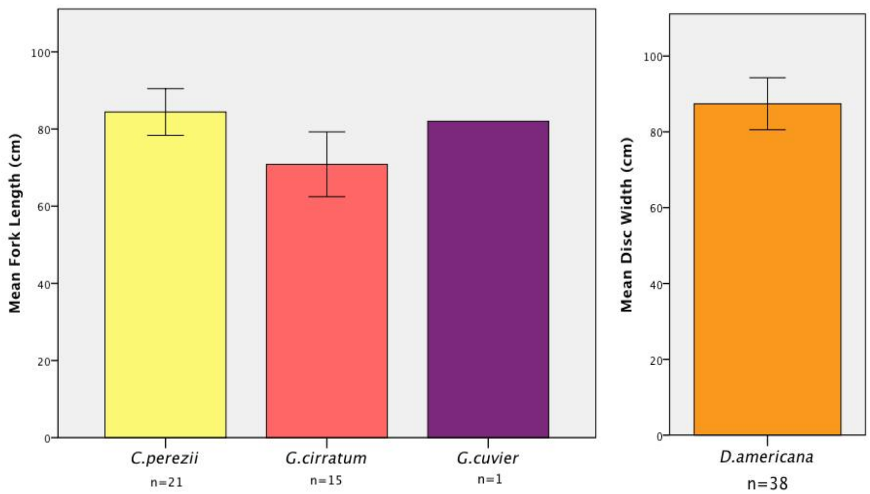


Figure 13: Mean fork length (FL) of *C. perezii* and *G. cirratum* and mean disc width (DW) of *D. americana*. Measurements are shown in centimeters. Error bars indicate the standard error (SE). Of *G. cuvier* only one individual was observed. *A. narinari* is excluded as no accurate length measurements are available.

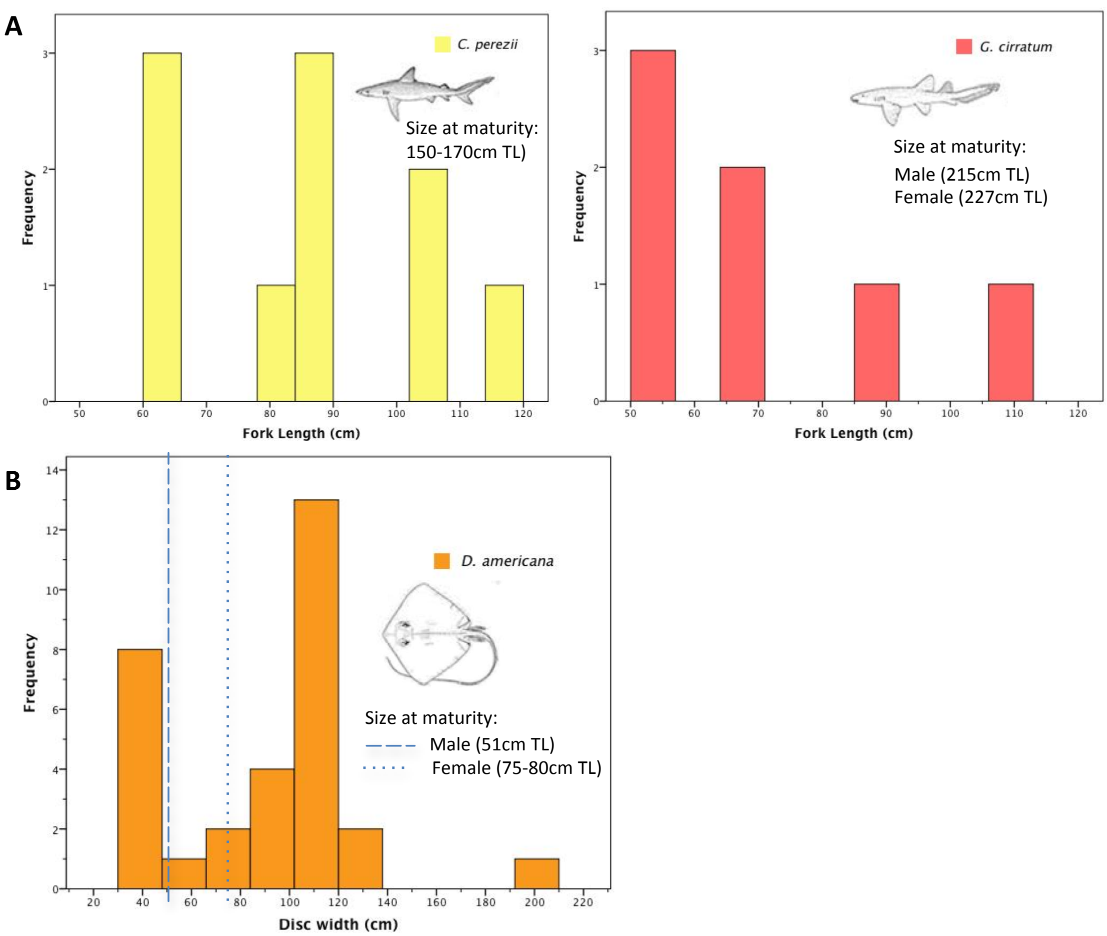


Figure 14: Frequency diagrams of shark fork length (A) and ray disc width (B). *D. americana* size at maturity is indicated by dotted lines. Shark sizes at maturity are outside measured length ranges. *G. Cuvier* is not included as only one observation was made. *A. narinari* is excluded, as no accurate length measurements were available.

The majority of all *D. americana* observations was on seagrass (46%), 35% on reef and 19% on sand. Figure 15 displays a further distinction of maturity over habitat types. No statistical significance was derived from this data.

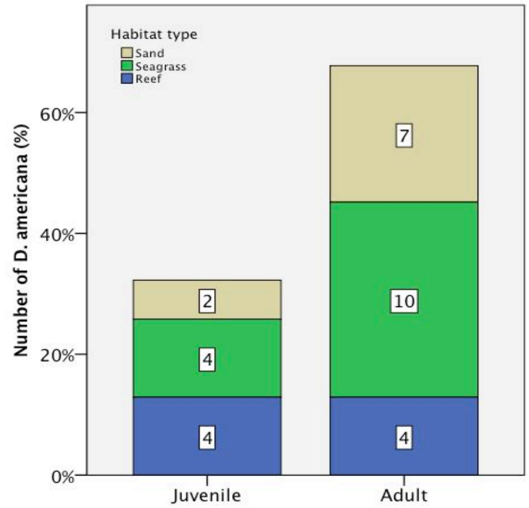


Figure 15: Maturity of *D. americana* per habitat type

Binary logistic regression revealed that the variables marine park and management zone had Wald chi-square statistic P-values <0.05 for the relative abundance of all shark species pooled (Table 1). Individual tests of relative abundance for both *C. perezii* and *G. cirratum* also proved to be significantly different inside compared to outside the marine park (*C. perezii* P=0.031 and *G. cirratum* P=0.024) and for Conservation Zone compared to the other management zones (*C. perezii* P=0.016 and *G. cirratum* P=0.022). Table 1 displays the last step of backward stepwise logistic regression models with all variables that tested significant for predicting presence of *C. perezii, G. cirratum* and all shark species pooled. No significant differences were found for the other explanatory factors, habitat type and habitat complexity nor for interactions between factors. On the relative abundance of *D. Americana,* none of the variables had Wald chi-square statistic P-values <0.05 as tested by binary logistic regression. Appendix VI displays the results from complete models stepwise, including non-significant values. Figure 16 displays an analysis of all observed species across the explanatory factors.

Table 1 (continued on next page): Estimated regression coefficients (B) from the last step of backward stepwise logistic regression models predicting presence of *C. perezii, G. cirratum* and for all shark species pooled, across different habitat types, levels of habitat complexity, management zones and in- or outside the marine park. Sample sizes were 8 for *C. perezii* and 9 for *G. cirratum*. The last model step retained variables with P-values <0.05. For each variable considered, the Wald statistic, degrees of freedom (df), significance, odds ratio (Exp(B) including 95% confidence interval (95% CI) are given.

Sharks

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B) Lower	95% C.I.for EXP(B) Upper
Step 2a	Outside MP			12,266	3	,007			
	Conservation Zone	2,134	,629	11,497	1	,001	8,450	2,461	29,014
	Traffic Zone	-18,638	12118,636	,000	1	,999	,000	,000	.
	Proposed	,486	1,181	,169	1	,681	1,625	,161	16,441
	Constant	-2,565	,519	24,436	1	,000	,077		

a. Variable(s) entered on step 1: Habitat Type, Management Zone.

Sharks

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B) Lower	95% C.I.for EXP(B) Upper
Step 2a	Inside Marine Park	1,616	,571	8,013	1	,005	5,032	1,644	15,405
	Constant	-2,485	,465	28,499	1	,000	,083		

a. Variable(s) entered on step 1: Habitat Type, Marine Park.

C. perezii **presence last step**

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B) Lower	Upper
Step 2[a]	Outside MP			5,802	3	,122			
	Conservation Zone	1,732	,719	5,802	1	,016	5,653	1,381	23,145
	Traffic Zone	-18,331	12118,636	,000	1	,999	,000	,000	.
	Proposed	-18,331	13397,657	,000	1	,999	,000	,000	.
	Constant	-2,872	,593	23,414	1	,000	,057		

a. Variable(s) entered on step 1: Habitat Type, Management Zone.

C. perezii **presence last step**

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B) Lower	Upper
Step 2[a]	Inside Marine Park	1.524	.709	4.627	1	.031	4.593	1.145	18.420
	Constant	-3.029	.591	26.246	1	.000	.048		

a. Variable(s) entered on step 1: Habitat Type, Marine Park.

G. cirratum **presence last step**

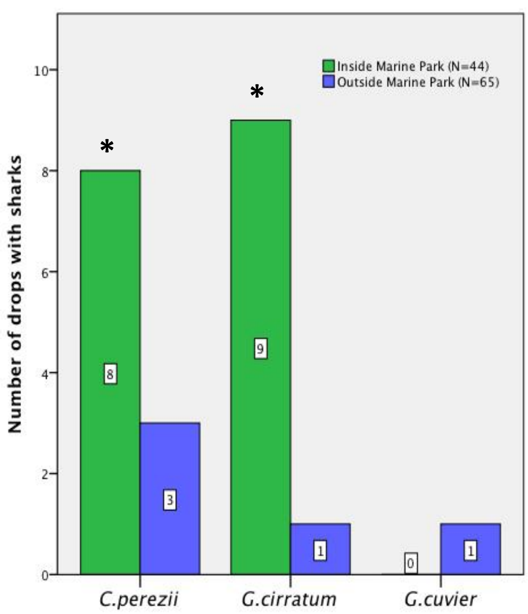
		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B) Lower	Upper
Step 2[a]	Outside MP			7,822	3	,050			
	Conservation Zone	3,027	1,082	7,822	1	,005	20,625	2,473	171,983
	Traffic Zone	-17,196	12118,636	,000	1	,999	,000	,000	.
	Proposed	-17,196	13397,657	,000	1	,999	,000	,000	.
	Constant	-4,007	1,009	15,772	1	,000	,018		

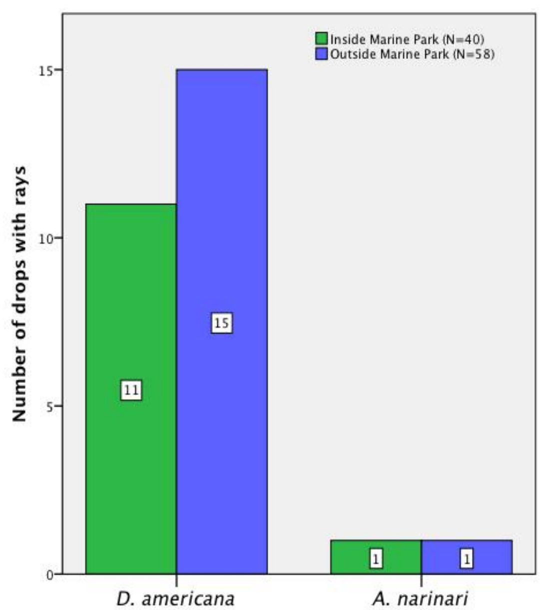
a. Variable(s) entered on step 1: Habitat Type, Management Zone.

G. cirratum **presence last step**

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B) Lower	Upper
Step 2[a]	Inside Marine Park	2,801	1,075	6,790	1	,009	16,457	2,002	135,291
	Constant	-4,159	1,008	17,030	1	,000	,016		

a. Variable(s) entered on step 1: Habitat Type, Marine Park.





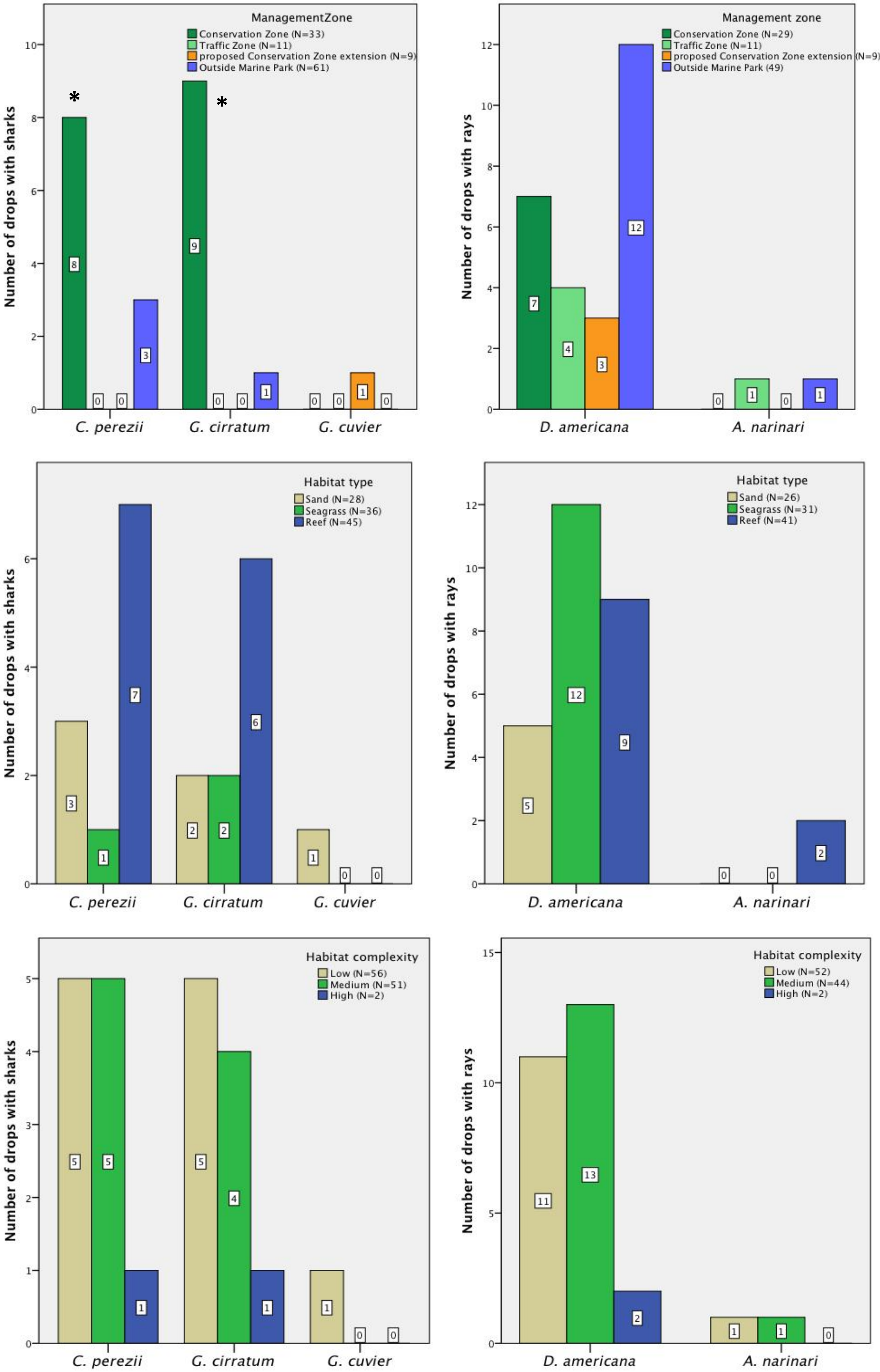


Figure 16: Relative elasmobranch abundance expressed in presence/absence for the variables marine park, management zone, habitat type and habitat complexity. Significant differences are indicated by asterisks (*)

4 Discussion

4.1 Factors influencing relative abundance

This study found relatively higher abundances of *C. perezii* and *G. cirratum* inside the marine park compared to outside the marine park. In particular the Conservation Zone within the marine park showed significantly higher abundances of both species compared to other management zones. This should however be treated with caution as the majority of deployments in the Conservation Zone consisted of reef habitat (67%) for which *C. perezii* has a preference. For *G. cirratum* habitat utilisation is largely unknown (Carrier *et al*., 1998). Other studies in Belize (Bond *et al*., 2012; Chapman *et al*., 2007) and Brazil (Garla *et al*., 2006) demonstrated that Marine Protected Areas (MPAs) have a significant positive effect on relative abundance of *C. perezii* and provide spillover to adjacent areas. These studies also suggest that *C. perezii* prefer coastal waters and coral reef ecosystems in depths up to 30 meters, which is in line with results in this study. Statistical analysis on relative abundance between habitat types and management zones in this survey showed no significant difference. Therefore it is unknown if the higher abundance of *C. perezii* and *G. cirratum* in the Conservation Zone can be contributed to management measures or habitat preference.

Since 1998 regular tourist-driven shark-feeding excursions took place in Sint Maarten waters. These activities have been banned from the marine park since 2010 and this ban was further extended in October 2014 to all Territorial Waters of Sint Maarten after a dive shop employee was bitten by a shark during shark-feeding activities (T. Bervoets, pers. comm., 2015). The shark-feeding excursions attracted a number of different sharks, most commonly *C. perezii* and occasionally *G. cirratum* and *C. limbatus,* and may still have an effect on their abundance and distribution and thereby the results in this study (T. Bervoets, pers. comm., 2015). The impacts of wildlife provisioning are generally poorly known, especially for marine species like sharks (Orams, 2002). A study by Malcović *et al.* (2010), specifically focused on *C. Perezii*, suggests that the (long-term) effects of regular provisioning may be limited with regards to variation in the extent of spatial movement, as well as shifting home ranges.

Habitat types were largely unknown prior to executing this survey and hence the spread of deployments across habitat types and habitat complexities was unequal. Deployments across management zones were also unequally distributed through limited sampling effort in the Conservation Zone and proposed Conservation Zone extension. Their exposed location and persistent strong winds coupled with bathymetric relief caused large swells pulling the frames upright. This non-equal spread of deployments across management zones and habitat types may have affected the results in this study as comparisons of elasmobranch presence are inadequate.

Lastly, this survey was conducted in a short timeframe and temporal aspects were not accounted for in the sampling design. Within and between day variability of reef fish assemblages that may be of influence on the abundance of elasmobranchs (Birt *et al*., 2012), can have affected spatial and abundance patterns in this survey.

4.2 Elasmobranchs maturity and gender

Mangroves were not identified as habitat for juvenile elasmobranchs in this study though they were investigated to minimal extent. This was due to a focus on completing a comprehensive baseline survey in the time available, but also due to a minimal amount of mangroves left on Sint Maarten. In addition, the remaining mangroves are surrounded by marinas and other coastal development, which has an effect on their suitability as a habitat for juvenile elasmobranchs. The (northern) French part of the island contains more 'unspoilt' mangroves in which juvenile *N. brevirostris* are found and investigated through the ongoing Negara project. Seagrass was also not identified as a habitat for juvenile elasmobranchs, although this habitat displayed a relatively high abundance of *D. americana*, including both adults and juveniles. Statistical analyses showed these numbers were close to significant and more deployments could potentially be more conclusive.

Not all observed individuals could be measured, due to not being fully visible in both cameras or being too distant for accurate measurements. This may mean some adult sharks have been observed, but its effect on the results in this study can be neglected. Lastly, elasmobranch gender was not analysed in this study as only 23% of all individuals observed were sexed, which was insufficient to gather meaningful results.

4.3 Methodology

4.3.1 Stereo-BRUV method

Data in this survey was collected using the stereo-BRUV method, which has increasingly been used to sample both tropical and temperate fish assemblages, as well as elasmobranchs. Advantages of the chosen method are high measuring accuracy and the provision of a permanent record of the assemblages that can be validated when required or independently reanalysed (Langlois *et al.,* 2010). In addition, sampling by stereo-BRUV surveys is non-invasive, causes minimal damage to the benthic environment, and is not size-selective like traditional capture methods where hook or mesh size are influential (Cappo *et al*., 2006). Furthermore, as stereo-BRUV surveys have already been performed throughout the Dutch Caribbean, reference data is available at IMARES, providing the ability to compare results with nearby regions. Lastly, fisheries dependent research methods, alternative to the stereo-BRUV technique, are inadequate for this study due to a limited amount of local fisheries efforts (T. Bervoets, pers. comm., 2015) and the inability to use capture methods to sample in the Sint Maarten shark sanctuary.

4.3.2 Index for relative abundance

Several ways of generating relative abundance indices have been used in different studies, where maximum number of individuals of the same species in one frame (MaxN) is the most common index for studies on reef fish assemblages (Cappo *et al.,* 2006). MaxN is considered a conservative method and for species where individuals can be identified as unique observations by size or morphological characteristics, CpUE is a more appropriate and a widely used measure (Meekan and Cappo, 2004; Cappo *et al.,* 2006). Initially, CpUE was measured for all samples in this study but a data quality check showed that the relative abundance dataset was not normally distributed, not homogeneous, contained many 0-values (no elasmobranchs observed) and a low n-value of deployments with elasmobranchs was observed. Therefore, an indirect index, i.e. a model for relative probability of occurrence, instead of using Catch per Unit of Effort (CpUE) was chosen as a more appropriate relative abundance measure. Furthermore, predicting presence/absence of elasmobranchs with this dataset is more acceptable as it is difficult to predict elasmobranch abundance in numbers solely based on variables derived from habitat and management zone.

4.3.3 Identification of individuals

For efficiency, stereo-BRUV deployments were performed concurrently during this survey. Three camera systems could be deployed concurrently with a minimum distance range of 500 meters between sample locations to reduce overlap of bait odour plumes. It could however be possible that individuals have moved from one stereo-BRUV station to the other and were counted twice, since identification of individuals was applied within one deployment, i.e. one hour of video, and not across deployments. Other variables can also be of influence such as the direction of currents and feeding behaviour. These factors have not been taken into account, in line with other previously mentioned stereo-BRUV surveys.

4.4 Comparison of relative abundance in region

Catch per Unit of Effort (CpUE) is used as a method for comparison with other stereo-BRUV surveys in the region on relative abundance of elasmobranchs. In terms of number of sharks per hour (CpUE) in this study around Sint Maarten (n=109), the most abundant species was *C. perezii* (0.19 sharks hour^{-1}) and thereafter *G. cirratum* (0.12 sharks hour^{-1}). Compared to a survey on reef fish assemblages on the Saba bank in 2014 (n=165) (Stoffers, 2014), CpUE of *C. perezii* (0.22 sharks hour^{-1}) was similar and *G. cirratum* (0.25 sharks hour^{-1}) was lower on Sint Maarten. On the Saba bank, both species were most abundant in depths between 15 and 25 meters compared to deeper waters (40m), which is in line with results on Sint Maarten. On Saba (N=108) (Van Looijengoed, 2013), *C. perezii* abundance was also similar (0.11-0.20 sharks hour^{-1}) and *G. cirratum* (0.20-0.22 hour^{-1}) was also observed less frequent on Sint Maarten. On St. Eustatius (n=101) (Van Kuijk, 2014), *C. perezii* (0.26-0.44 sharks^{-1}) was observed in higher abundances than on Sint Maarten. CpUE of *G. cirratum* was not analysed in the study on St. Eustatius. A study on *C. perezii* in Belize (N=200) found considerably lower abundance ranging from 0.04-0.13 observations per hour (Bond *et al.,* 2012). For rays, *D. americana* around Sint Maarten (0.31 hour^{-1}) was most abundant in comparison to results on the Saba bank (0.17 hour^{-1}) and St. Eustatius (0.11-0.13 hour^{-1}). CpUE for *D. americana* was not analysed on Saba.

Species diversity was more limited around Sint Maarten compared to stereo-BRUV surveys on Saba, Saba bank and St. Eustatius. Additional species were observed on Saba, though in limited numbers, i.e. *Carcharhinus falciformis* (silky shark), *Carcharhinus limbatus* (blacktip shark), *Sphyrna lewini* (scalloped hammerhead). On the Saba bank and St. Eustatius *C. limbatus* was also observed in addition to the shark species on Sint Maarten. With regards to rays, additional species observed on the Saba bank were *Dasyatis centroura* (roughtail stingray) and *Manta birostris* (manta ray). Rays were not specifically analysed during the stereo-BRUV reef fish assemblage studies on Saba and St. Eustatius, hence no species comparisons are available for those areas.

A comparison between the abovementioned studies has to be treated with caution as the index of relative abundance (see paragraph 4.3.2), focus of studies (i.e. reef fish assemblage survey vs. elasmobranch survey) as well as temporal and environmental variables (e.g. sampling period, habitat types) are different.

5 Conclusion

5.1 Relative abundance, species composition and distribution

This stereo-BRUV survey has identified three different shark species, *Carcharhinus perezii* (Caribbean reef shark), *Ginglymostoma cirratum* (nurse shark) and *Galeocerdo cuvier* (tiger shark) and two different ray species, *Dasyatis americana* (southern stingray) and *Aetobatus narinari* (spotted eagle ray). Relative abundance of *D. americana* was highest of all elasmobranch species in this survey and was found widely distributed across management zones and habitat types. An influence of management measures was not detected for this species. Inside the marine park relatively higher abundances of *C. perezii* and *G. cirratum* have been observed compared to the area outside the marine park. Especially the Conservation Zone has shown significant differences in the presence of these species compared to other management zones.

5.2 Habitats for juvenile elasmobranchs

No specific habitats for juvenile elasmobranchs have been identified. However, all sharks measured in this study were juveniles of which most appear to concentrate in shallow coastal areas with extensive coral reef cover. For *C. perezii* these results are supported by literature and give an indication that the shallow coastal areas with coral reef cover provide an important habitat for juvenile *C. perezii* around Sint Maarten.

5.3 Marine park extension

This survey on its own is not elaborate enough to provide supporting evidence towards an expansion of the existing marine park. However, the significant numbers of juvenile *C. perezii* and *G. cirratum* inside the Man of War Shoal marine park provide an indication that the marine park provides a protective habitat for these species. In addition, Marine Protected Areas (MPAs) appear to have a significant positive effect on populations of *C. perezii*. The results from this study coupled with the effects of MPAs provide grounds for at least a continued protection and conservation of sharks through additional management measures in the marine park. For the juvenile *C. perezii*, an endemic species to the Caribbean, these grounds are even more solid by providing a spillover effect to adjacent areas around Sint Maarten.

5.4 Review of shark sanctuary

This stereo-BRUV survey has been successful in providing baseline information of elasmobranch populations around Sint Maarten. It supports the Nature Foundation Sint Maarten by enabling an assessment of shark sanctuary legislation and marine park management measures over time. The results from this baseline study can be compared with other surveys in the Caribbean and provide further insights into the status of elasmobranchs in the region and compare effects of legislation and management measures. Future surveys will provide information on relative trends in elasmobranch populations around Sint Maarten separate from general trends throughout the Caribbean.

6 Recommendations

6.1 Conservation management

The information from this study is particularly useful for the Dutch Caribbean Nature Alliance (DCNA) in support of its ‘Save our sharks’ project. Previous stereo-BRUV surveys throughout the Dutch Caribbean (Saba, Saba bank and St. Eustatius) and future surveys provide the ability to compare results on relative abundance and distribution of elasmobranchs across the region. Moreover, by combining the results from different elasmobranch surveys, quantifiable indicators and reference points can be defined to provide a robust monitoring framework of elasmobranchs throughout the (Dutch) Caribbean.

The results of this survey, supported by literature, indicate that the shallow coastal waters with high coral reef cover in the Conservation Zone, provide an important habitat for juvenile *C. perezii* and *G. cirratum* around Sint Maarten. It is therefore recommended to continue existing conservation measures in the marine park.

For *G. cirratum,* habitat utilization and mating behaviour in the Caribbean remains largely unknown. In several areas in the Caribbean, a closure of a certain area is implemented during mating season of *G. cirratum* (Carrier *et al.*, 1998) aimed to reduce disturbances such as boat traffic and diving. Such a closure is an attempt to increase occurrences of vulnerable mating activities of *G. cirratum* (Carrier *et al.*, 1998). In general, it is recommended to investigate the feasibility of such seasonal management measures in areas where juvenile elasmobranchs are present.

6.2 Methodology

As this stereo-BRUV survey is one of the few globally with a specific focus on elasmobranchs it can be exemplary for future studies and give insights into methods, procedures and obstacles when using the stereo-BRUV technique.

Similar datasets to the one in this study are likely to be common in other elasmobranch studies in the Caribbean with regards to normality, homogeneity and the relatively high amount of samples without elasmobranchs. Therefore it is recommended to analyse data with indirect indices for relative abundance such as presence/absence, instead of using CpUE (elasmobranch observations $hour^{-1}$). It is recommended for future surveys to align data analysis methods and procedures to ensure accurate and comparable results.

In addition to fork length (FL) measurements used in this survey and other stereo-BRUV surveys on reef fish assemblages, it can be useful to include tail length (TL) for shark measurements, as this is a commonly used measure in shark surveys (Garla *et al*., 2006).

6.3 Future research

Future stereo-BRUV surveys around Sint Maarten are required to elaborate on the results of this study and provide further information to support an assessment of legislation and management effectiveness of elasmobranch conservation through the shark sanctuary and marine park. The information from this study can be used to determine locations of habitat types and improve future studies by creating an equal spread of deployments across habitat types. This will give further insights into the effect of environmental factors on differences in relative abundance across management zones.

It is recommended to increase sample size in mangroves and the pelagic zone to provide more information on relative abundance, species composition and distribution of elasmobranchs across additional habitat types.

It is recommended to use the obtained video materials from this survey for a reef fish assemblage study around Sint Maarten. This will enable a further comparison of studies on reef fish assemblages across the Dutch Caribbean. It can also provide further information in support of the proposed Conservation Zone extension plans, i.e. marine park extension.

Future surveys can assess the effectiveness of legislation and management measures on relative trends in elasmobranch populations on Sint Maarten, separate from general trends in elasmobranch populations throughout the Caribbean.

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Appendices

Appendix I: Identified elasmobranch species in Sint Maarten

Table 1: Commonly found and potentially present elasmobranch species in Sint Maarten including their status according to international conventions. Species observed in this study are indicated by X. All other sightings by Nature Foundation Sint Maarten marine park manager at least once a year. Potentially present species according to IUCN are also indicated (van Beek *et al.*, 2012). Where habitat is *italic* it is based on physical characteristics.

Common name	Scientific name	Observed	Status	Habitat	Usual depth range[1]
Family: Whale sharks	***Rhincodontidae***				
Whale shark[2]	*Rhincodon typus*		CITES[3]: II CMS[4]: II SPAW[5]: (II) IUCN[6]: VU	Pelagic[7]	0-100
Family: Nurse sharks	***Ginglymostomatidae***				
Nurse shark	*Ginglymostoma cirratum*	X	IUCN: DD	Demersal	1-35
Family: Requiem sharks	***Carcharhinidae***				
Caribbean reef shark	*Carcharhinus perezii*	X	SPAW: (II) IUCN: NT	*Semi-pelagic*	1-35
Blacktip shark	*Carcharhinus limbatus*		IUCN: NT	Semi-pelagic	0-30
Lemon shark	*Negaprion brevirostris*		IUCN: NT	*Semi-pelagic*	1-30
Bull Shark	*Carcharhinus leucas*		IUCN: NT	Semi-pelagic	1-30
Tiger Shark	*Galeocerdo cuvier*	X	IUCN: NT	Semi-pelagic	3-60

[1] Depth range is derived from Fishbase.org and marks the usual range, not maximum. Underlined values indicate that 'usual depth' is unknown and total depth range is used.
[2] Unconfirmed whale shark sighting in October 2010.
[3] CITES Appendix II: Species that, although not threatened with extinction now, might become so unless trade in them is strictly regulated.
[4] CMS Appendix II: Migratory Species requiring international cooperation.
[5] SPAW Appendix II proposed species (currently no elasmobranch species on list).
[6] IUCN Red List category: EN = Endangered; VU = vulnerable; NT = Near Threatened; LC = Least Concern; DD = Data Deficient.
[7] Pelagic or semi-pelagic species indicate migratory species and more vulnerable as bycatch to pelagic fisheries.

Blacknose reef shark[8]	*Carcharhinus acronotus*		IUCN: NT	*Semi-pelagic*	18-60
Brazilian sharp-nose shark	*Rhizoprionodon lalandii*		IUCN: DD	*Semi-pelagic*	3-70
Caribbean sharp-nose shark	*Rhiziprionodon porosus*		IUCN: LC	*Semi-pelagic*	0-100
Family: Hammerhead sharks	***Sphyrnidae***				
Greater hammerhead	*Sphyrna mokarran*		SPAW: (II) IUCN: EN	Semi-pelagic	1-100
Family: Catsharks	***Scyliorhinidae***				
Hoary catshark	*Apristurus canutus*		IUCN: DD	*Demersal*	500-1000
Boa catshark	*Scyliorhinus boa*		IUCN: DD	*Demersal*	330-675
Family: Stingrays	***Dasyatidae***				
Chupare stingray	*Himantura schmardae*		IUCN: DD	*Demersal*	Unknown
Bluntnose stingray	*Dasyatis say*		IUCN: LC	*Demersal*	1-10
Spotted eagle ray	*Aetobatus narinari*	X	IUCN: DD	Semi-pelagic	1-80
Southern stingray	*Dasyatis americana*	X	IUCN: DD	*Demersal*	1-25
Family: Manta/devil rays	***Myliobatidae***				
Giant manta ray	*Manta birostris*		CMS: I, II SPAW: (II) IUCN: DD	Pelagic	0-120

[8] Potentially present elasmobranch species according to the IUCN Shark Specialist Group.

Appendix II: International, regional and national laws for the protection of elasmobranchs

	Internationale en regionale verdragen			Specifieke wetgeving haaien	
Rechtsgebied	**CITES**	**CMS**	**SPAW**	**Bescherming**	**Sancties**
Koninkrijk der Nederlanden	Ja	Ja	N.v.t.		
Caribisch Nederland • Wet grondslagen natuurbeheer- en bescherming BES	Ja Art.6	Ja Art.12	Ja Art.13		
Bonaire • Natuurverordening: AB 2008 No. 23 • Natuurbesluit: AB 2010 No. 15 • Marien: AB1991 No. 8	Bijlage I Art.11.1 AB2008	Bijlage I Art.11.1 AB2008	Bijlage I&II Art.11.1 AB2008 Bijlage III mogelijk	Ja alle haaien en drie roggensoorten (*Manta birostris*, *Aetobatus narinari*, *Dasyastis Americana)* Art.11.1 AB2010 Dit als toevoeging op CITES/CMS/SPAW cf. Art.11.2 AB2008	Nee
St. Eustatius • Natuur: AB 1996 No. 3	Nee	Nee	Nee	Nee Toevoeging op vangst wel mogelijk cf art. 8	N.v.t. voor haaien, wel bij overtreding AB1996 (max 1mnd/ 5.000 NAF)
Saba • Marien: AB 1987 No. 10	Nee	Nee	Nee	Nee Toevoeging op vangst wel mogelijk cf art. 7	N.v.t. voor haaien, wel bij overtreding AB1987 (max 1mnd/ 5.000 NAF)
Aruba • Natuur: AB 1995 No. 2 • Cites register: AB 1995 No. 69 • Visserij: AB 1992 No. 116, AB 1993 No. 15	Bijlage I&II &III Art. 11&12&13 AB1995#2 AB1995#69	Nee	Art. 11&13 AB1995	Nee	Nee
Curaçao • Natuur: PB 1998 No. 49 • Visserij: AB 2009 No. 48	Ja Art.6&7 PB2001	Ja Art.8c PB2001	Ja Art.8a&8b PB2001	Nee	Nee
St. Maarten • Natuur: AB 2003 No. 25 • Maritiem: PB 2007 No. 18 • Visserij: PB 1991 No. 74 • Tijdelijk verbod haaienvisserij dd 12 oktober 2011	Bijlage I Art.16.1 AB2003	Bijlage I Art.16.1 AB2003	Bijlage I&II Art.16.1 Bijlage III mogelijk Art.16.3 AB2003	Nee Toevoegingen op CITES/CMS/SPAW wel mogelijk cf. Art.16.2 AB2003	Niet voor overtreding op CITES/CMS/SPAW in AB2003 Wel op haaienvangst in tijdelijk verbod 2011 (max 3mnd/500,000 NAF)

Appendix III: Equipment list

Table 2: Equipment list for practical data collection

Item	Notes
Baited Remote Underwater Video frames (with camera housings and diode arms) **3x**	
Canon Legria HFG10 video cameras **6x** (plus spare camera)	
Diode **3x**	
Magnet to turn diode on/off	
Diode opening tool **1x**	
Toolset to tighten any loose bolts on frames	
Clips to attach diode bars	
Camera batteries **40x**	Should be charged to last at least 1hr
16 GB Memory cards **40x**	
Waterproof case or dry bag	For memory cards and other electronic equipment
Calibration cube	
USB multi SD card readers **4x**	
Spare O-rings	
Silica bags 6x	To prevent condensation in housings
Buoys **3x**	
Rope (length adjusted to sampling depth) **3x**	
Rope handling gloves	
GPS handheld	Sample location navigation and marking
Slate and pencils (at least 1 extra pencil)	
Bait bags: plasticized mesh (chicken wire) (mesh size 1cm)	Enough for 10 bags
Sardines as bait	Amount adjusted to drop plan
Tie rips (different sizes)	To create bait bags
Karabiners (thumb size) **6x**	To secure bait bag to frame
Silicon grease	To lubricate rubber camera gaskets
Hard disks 1Tb **6x**	To store and backup video footage
9V batteries **6x**	For diodes
Duct tape	To attach diodes to diode arm
Drop plan	Depth, bottom time, etc.
Fresh water for rinsing the camera systems after every drop	Approximately 1 litre to rinse once
Phone	In case of an emergency

Appendix IV: Stereo-BRUV deployment procedure

Preparation

- Choose drop locations and mark in GPS handheld
- Minimum distance between sample locations is 500m
- Charge batteries of the cameras
- Charge batteries of the GPS
- Check if SD cards are empty
- Place SD cards in cameras and write down SD numbers on datasheet
- One SD card per deployment (camera memory can function as backup)
- Check settings of camera (see SeaGIS user manuals)
- Lubricate O-rings with silicone grease
- Place cameras in the housing and check O-ring
- Check rope length – should be depth plus min. 30% extra (a drop at 50m requires a 75m rope)
- Check bait provisions and availability
- Each deployment requires approximately 800g of sardines as bait (around 4 sardines)

Dropping frames (benthic deployment)

- Attach a rope with big and small buoy to the frame using the shackle
- Attach the diode bar to the frame and turn on diode with a magnet (check diode before every drop, sometimes it turns off by itself)
- Check the battery power left for both cameras and replace them with full ones if necessary
- Check if empty SD cards are in both cameras, close the lid and check the amount of recording time available
- When out of empty SD cards, change the camera settings to record on camera memory
- Check if the camera focus is set to infinitive **∞** and the zoom is set to wide W
- Check the camera O-rings and housings to make sure they are clean (no dust, hair or particles) and the O-rings are lubricated with silicone grease
- Put a new silicon bag in each housing
- Start recording, put cameras inside housings and close clasps
- Check if the cameras are recording and if the O-ring is fitted correctly (replace any O-ring with a spare if it does not properly fit)
- Tap your hand quickly on the diode bar in view of both cameras a few times (for synchronisation later)
- Attach the bait bag with sardines to the diode bar using carabiners and punch ≥5 holes in every sardine using a screwdriver or knife
- Deploy and lower the frame on the seabed
- Make sure it is positioned horizontally on the bottom and without obstructions. If it is not, redeploy.
- Record GPS location on GPS handheld. Optionally write down GPS coordinates.
- Record deployment time on data sheet
- Deploy the next frame and wait a minimum of 60 minutes before retrieving each frame.

Dropping frames alteration for pelagic deployments

- Attach a 2nd rope to the upper side of the frame itself, not to the shackle
- The additional rope should be at least 20-30 meters longer
- Perform all steps as described above and tie the 2nd rope to the boat
- This is to prevent loosing the frame and cameras should one of the ropes break or tear
- Beware, concurrent deployments are not possible using this method.

Retrieving frames

- Grab the rope or buoy and put buoy inside the boat
- If a 2nd person is available this person can direct the boat captain towards the direction of the frame. The other person can pull in the rope. This will prevent having to pull the boat as well as the frame!
- Once positioned above the frame, both can pull up the frame or use a winch if available!
- Gently lift the frame onboard. Depending on the size of the boat, take of the diode bar and bait bag.
- Dry off your hands and the camera housings with the towel
- Take the cameras from the housings
- Stop recording and check the movies to see if it has recorded this deployment
- Store SD cards in waterproof case and replace with empty ones
- Check focus and zoom settings and put cameras back inside housings
- Replace sardines - do not throw used sardines overboard
- Navigate 500m away from all other drop locations for that day for the next drop

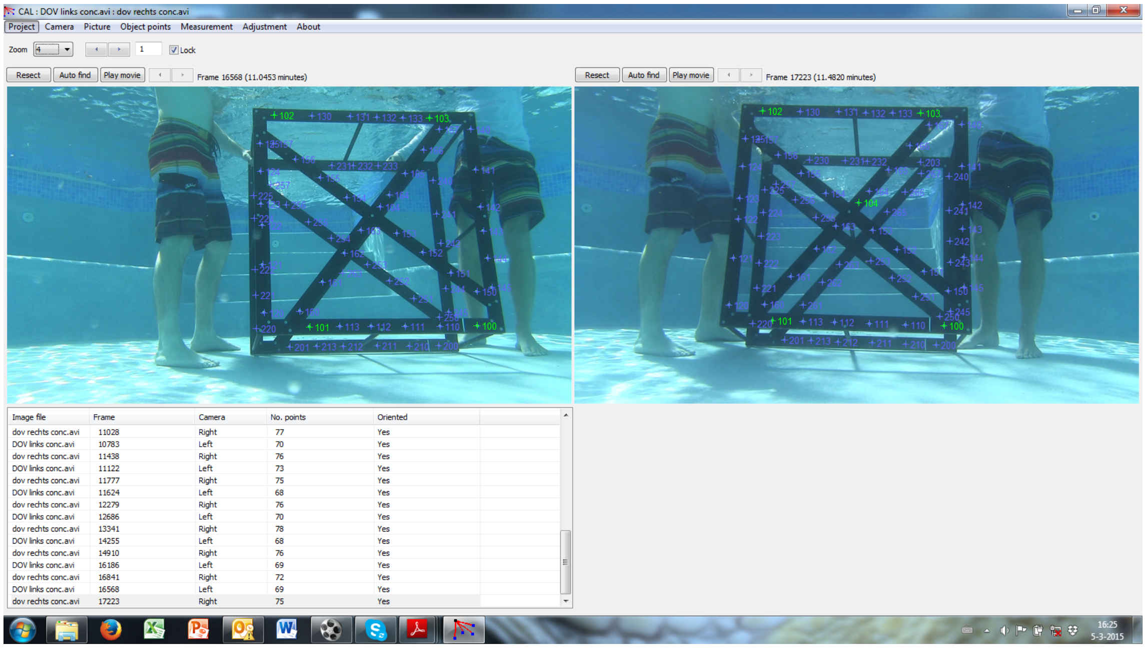
Image 2: Deploying frame

Image 4: Frame on seabed

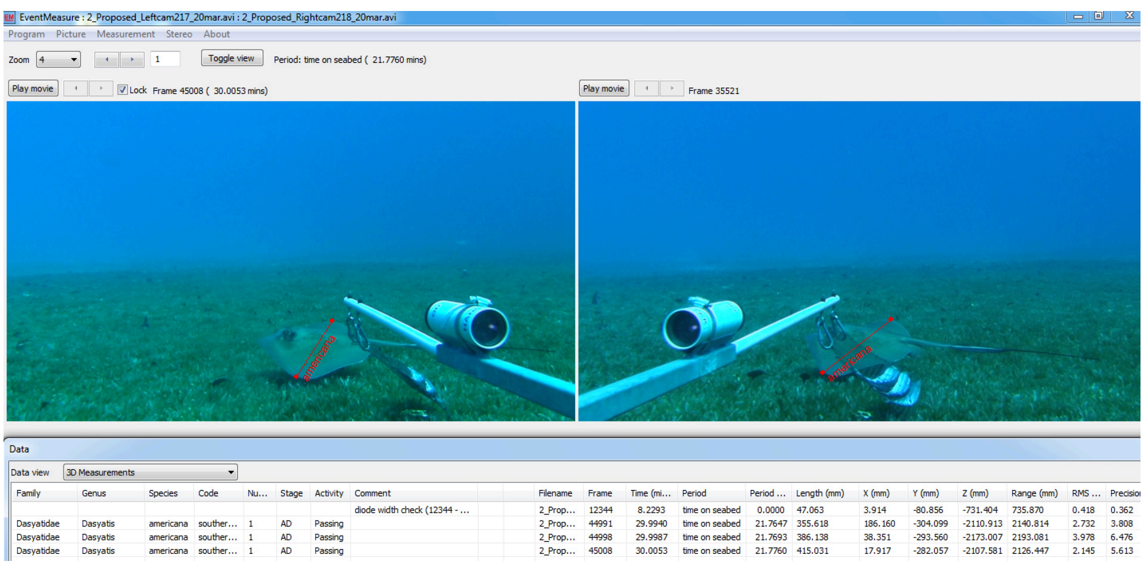
Image 3: Buoy floating on surface during deployment

Appendix V: Video analysis software screenshots

Calibration Software (CAL)



Video analysis software (EventMeasure)



Appendix VI: Results of statistical models

Categorical Variables Codings

		Frequency	Parameter coding (1)	(2)	(3)
ManagementZone	Conservation Zone	33	1,000	,000	,000
	Traffic Zone	11	,000	1,000	,000
	proposed Conservation Zone extension	9	,000	,000	1,000
	Outside Marine Park	56	,000	,000	,000
HabitatType	Sand	28	1,000	,000	
	Seagrass	36	,000	1,000	
	Reef	45	,000	,000	

C. perezii

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B) Lower	Upper
Step 1[a]	HabitatType			1,455	2	,483			
	HabitatType(1)	,147	,792	,034	1	,853	1,158	,246	5,465
	HabitatType(2)	-1,287	1,159	1,233	1	,267	,276	,029	2,677
	ManagementZone			3,327	3	,344			
	ManagementZone(1)	1,388	,761	3,327	1	,068	4,008	,902	17,814
	ManagementZone(2)	-18,683	11979,926	,000	1	,999	,000	,000	.
	ManagementZone(3)	-18,630	13216,987	,000	1	,999	,000	,000	.
	Constant	-2,451	,727	11,359	1	,001	,086		
Step 2[a]	ManagementZone			5,802	3	,122			
	ManagementZone(1)	1,732	,719	5,802	1	,016	5,653	1,381	23,145
	ManagementZone(2)	-18,331	12118,636	,000	1	,999	,000	,000	.
	ManagementZone(3)	-18,331	13397,657	,000	1	,999	,000	,000	.
	Constant	-2,872	,593	23,414	1	,000	,057		

a. Variable(s) entered on step 1: HabitatType, ManagementZone.

C. perezii **Pairwise Comparisons**

(I) ManagementZone	(J) ManagementZone	Mean Difference (I-J)	Std. Error	df	Sig.	95% Wald Confidence Interval for Difference	
						Lower	Upper
Conservation Zone	Traffic Zone	.24[a]	.075	1	.001	.10	.39
	proposed Conservation Zone extension	.24[a]	.075	1	.001	.10	.39
	Outside Marine Park	.19[a]	.080	1	.019	.03	.35
Traffic Zone	Conservation Zone	-.24[a]	.075	1	.001	-.39	-.10
	proposed Conservation Zone extension	.00	.000	1	1.000	.00	.00
	Outside Marine Park	-.05	.030	1	.075	-.11	.01
proposed Conservation Zone extension	Conservation Zone	-.24[a]	.075	1	.001	-.39	-.10
	Traffic Zone	.00	.000	1	1.000	.00	.00
	Outside Marine Park	-.05	.030	1	.075	-.11	.01
Outside Marine Park	Conservation Zone	-.19[a]	.080	1	.019	-.35	-.03
	Traffic Zone	.05	.030	1	.075	-.01	.11
	proposed Conservation Zone extension	.05	.030	1	.075	-.01	.11

Pairwise comparisons of estimated marginal means based on the original scale of dependent variable Perezii_presence

a. The mean difference is significant at the .05 level.

G. cirratum

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B)	
								Lower	Upper
Step 1[a]	HabitatType			,176	2	,916			
	HabitatType(1)	,008	,942	,000	1	,994	1,008	,159	6,383
	HabitatType(2)	,417	1,025	,166	1	,684	1,518	,204	11,311
	ManagementZone			7,401	3	,060			
	ManagementZone(1)	3,201	1,177	7,401	1	,007	24,561	2,447	246,505
	ManagementZone(2)	-17,055	12098,246	,000	1	,999	,000	,000	.
	ManagementZone(3)	-17,073	13371,838	,000	1	,999	,000	,000	.
	Constant	-4,238	1,210	12,268	1	,000	,014		
Step 2[a]	ManagementZone			7,822	3	,050			
	ManagementZone(1)	3,027	1,082	7,822	1	,005	20,625	2,473	171,983
	ManagementZone(2)	-17,196	12118,636	,000	1	,999	,000	,000	.
	ManagementZone(3)	-17,196	13397,657	,000	1	,999	,000	,000	.
	Constant	-4,007	1,009	15,772	1	,000	,018		

a. Variable(s) entered on step 1: HabitatType, ManagementZone.

G. cirratum **Pairwise Comparisons**

(I) ManagementZone	(J) ManagementZone	Mean Difference (I-J)	Std. Error	df	Sig.	95% Wald Confidence Interval for Difference	
						Lower	Upper
Conservation Zone	Traffic Zone	-,27[a]	,078	1	,000	-,42	-,12
	proposed Conservation Zone extension	-,27[a]	,078	1	,000	-,42	-,12
	Outside Marine Park	-,25[a]	,080	1	,001	-,41	-,10
Traffic Zone	Conservation Zone	,27[a]	,078	1	,000	,12	,42
	proposed Conservation Zone extension	,00	,000	1	1,000	,00	,00
	Outside Marine Park	,02	,018	1	,313	-,02	,05
proposed Conservation Zone extension	Conservation Zone	,27[a]	,078	1	,000	,12	,42
	Traffic Zone	,00	,000	1	1,000	,00	,00
	Outside Marine Park	,02	,018	1	,313	-,02	,05
Outside Marine Park	Conservation Zone	,25[a]	,080	1	,001	,10	,41
	Traffic Zone	-,02	,018	1	,313	-,05	,02
	proposed Conservation Zone extension	-,02	,018	1	,313	-,05	,02

Pairwise comparisons of estimated marginal means based on the original scale of dependent variable Cirratum_presence

Sharks

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B)	
								Lower	Upper
Step 1[a]	HabitatType			,363	2	,834			
	HabitatType(1)	-,131	,713	,034	1	,854	,877	,217	3,551
	HabitatType(2)	-,473	,785	,363	1	,547	,623	,134	2,901
	ManagementZone			9,255	3	,026			
	ManagementZone(1)	1,974	,674	8,577	1	,003	7,200	1,921	26,985
	ManagementZone(2)	-18,731	12099,366	,000	1	,999	,000	,000	.
	ManagementZone(3)	,395	1,201	,108	1	,742	1,484	,141	15,632
	Constant	-2,323	,653	12,639	1	,000	,098		
Step 2[a]	ManagementZone			12,266	3	,007			
	ManagementZone(1)	2,134	,629	11,497	1	,001	8,450	2,461	29,014
	ManagementZone(2)	-18,638	12118,636	,000	1	,999	,000	,000	.
	ManagementZone(3)	,486	1,181	,169	1	,681	1,625	,161	16,441
	Constant	-2,565	,519	24,436	1	,000	,077		

a. Variable(s) entered on step 1: HabitatType, ManagementZone.

Sharks Pairwise Comparisons

(I) ManagementZone	(J) ManagementZone	Mean Difference (I-J)	Std. Error	df	Sig.	95% Wald Confidence Interval for Difference Lower	Upper
Conservation Zone	Traffic Zone	-,39[a]	,085	1	,000	-,56	-,23
	proposed Conservation Zone extension	-,28[a]	,135	1	,036	-,55	-,02
	Outside Marine Park	-,32[a]	,092	1	,000	-,50	-,14
Traffic Zone	Conservation Zone	,39[a]	,085	1	,000	,23	,56
	proposed Conservation Zone extension	,11	,105	1	,289	-,09	,32
	Outside Marine Park	,07[a]	,034	1	,038	,00	,14
proposed Conservation Zone extension	Conservation Zone	,28[a]	,135	1	,036	,02	,55
	Traffic Zone	-,11	,105	1	,289	-,32	,09
	Outside Marine Park	-,04	,110	1	,719	-,26	,18
Outside Marine Park	Conservation Zone	,32[a]	,092	1	,000	,14	,50
	Traffic Zone	-,07[a]	,034	1	,038	-,14	,00
	proposed Conservation Zone extension	,04	,110	1	,719	-,18	,26

Pairwise comparisons of estimated marginal means based on the original scale of dependent variable shark_presence

a. The mean difference is significant at the ,05 level.

D. americana

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B) Lower	Upper
Step 1[a]	ManagementZone			2,281	3	,516			
	ManagementZone(1)	,446	,621	,515	1	,473	1,562	,462	5,278
	ManagementZone(2)	1,065	,786	1,837	1	,175	2,902	,622	13,542
	ManagementZone(3)	,842	,838	1,010	1	,315	2,322	,449	11,999
	HabitatType			4,579	2	,101			
	HabitatType(1)	-,341	,661	,266	1	,606	,711	,195	2,599
	HabitatType(2)	1,011	,593	2,906	1	,088	2,749	,859	8,791
	Constant	-1,644	,535	9,453	1	,002	,193		
Step 2[a]	HabitatType			3,413	2	,181			
	HabitatType(1)	-,167	,624	,071	1	,790	,847	,249	2,879
	HabitatType(2)	,809	,528	2,351	1	,125	2,246	,798	6,315
	Constant	-1,269	,377	11,303	1	,001	,281		
Step 3[a]	Constant	-1,019	,229	19,818	1	,000	,361		

a. Variable(s) entered on step 1: ManagementZone, HabitatType.

Categorical Variables Codings

		Frequency	Parameter coding (1)	(2)	(3)
ManagementZone	Conservation Zone	33	1,000	,000	,000
	Traffic Zone	11	,000	1,000	,000
	proposed Conservation Zone extension	9	,000	,000	1,000
	Outside Marine Park	56	,000	,000	,000
HabitatComplexity	Low	56	1,000	,000	
	Medium	51	,000	1,000	
	High	2	,000	,000	

C perezii

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B) Lower	Upper
Step 1[a]	HabitatComplexity			1,861	2	,394			
	HabitatComplexity(1)	-2,250	1,654	1,850	1	,174	,105	,004	2,697
	HabitatComplexity(2)	-1,944	1,640	1,405	1	,236	,143	,006	3,563
	ManagementZone			5,800	3	,122			
	ManagementZone(1)	1,816	,754	5,800	1	,016	6,147	1,402	26,948
	ManagementZone(2)	-18,136	12103,245	,000	1	,999	,000	,000	.
	ManagementZone(3)	-18,119	13382,638	,000	1	,999	,000	,000	.
	Constant	-,908	1,607	,319	1	,572	,403		
Step 2[a]	ManagementZone			5,802	3	,122			
	ManagementZone(1)	1,732	,719	5,802	1	,016	5,653	1,381	23,145
	ManagementZone(2)	-18,331	12118,636	,000	1	,999	,000	,000	.
	ManagementZone(3)	-18,331	13397,657	,000	1	,999	,000	,000	.
	Constant	-2,872	,593	23,414	1	,000	,057		

a. Variable(s) entered on step 1: HabitatComplexity, ManagementZone.

G. cirratum

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B) Lower	Upper
Step 1[a]	HabitatComplexity			1,883	2	,390			
	HabitatComplexity(1)	-2,759	2,012	1,880	1	,170	,063	,001	3,269
	HabitatComplexity(2)	-2,499	2,003	1,558	1	,212	,082	,002	4,160
	ManagementZone			7,743	3	,052			
	ManagementZone(1)	3,174	1,141	7,743	1	,005	23,913	2,556	223,723
	ManagementZone(2)	-16,933	12108,062	,000	1	,999	,000	,000	.
	ManagementZone(3)	-16,919	13387,356	,000	1	,999	,000	,000	.
	Constant	-1,587	1,968	,651	1	,420	,204		
Step 2[a]	ManagementZone			7,822	3	,050			
	ManagementZone(1)	3,027	1,082	7,822	1	,005	20,625	2,473	171,983
	ManagementZone(2)	-17,196	12118,636	,000	1	,999	,000	,000	.
	ManagementZone(3)	-17,196	13397,657	,000	1	,999	,000	,000	.
	Constant	-4,007	1,009	15,772	1	,000	,018		

a. Variable(s) entered on step 1: HabitatComplexity, ManagementZone.

Sharks

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B) Lower	Upper
Step 1[a]	HabitatComplexity			2,052	2	,358			
	HabitatComplexity(1)	-1,916	1,730	1,226	1	,268	,147	,005	4,370
	HabitatComplexity(2)	-1,228	1,713	,514	1	,474	,293	,010	8,413
	ManagementZone			12,795	3	,005			
	ManagementZone(1)	2,333	,669	12,154	1	,000	10,312	2,777	38,289
	ManagementZone(2)	-18,345	12033,658	,000	1	,999	,000	,000	.
	ManagementZone(3)	,816	1,218	,450	1	,503	2,262	,208	24,599
	Constant	-1,167	1,695	,474	1	,491	,311		
Step 2[a]	ManagementZone			12,266	3	,007			
	ManagementZone(1)	2,134	,629	11,497	1	,001	8,450	2,461	29,014
	ManagementZone(2)	-18,638	12118,636	,000	1	,999	,000	,000	.
	ManagementZone(3)	,486	1,181	,169	1	,681	1,625	,161	16,441
	Constant	-2,565	,519	24,436	1	,000	,077		

a. Variable(s) entered on step 1: HabitatComplexity, ManagementZone.

D. americana

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B) Lower	Upper
Step 1[a]	HabitatComplexity			1,516	2	,469			
	HabitatComplexity(1)	-22,787	28413,939	,000	1	,999	,000	,000	.
	HabitatComplexity(2)	-22,150	28413,939	,000	1	,999	,000	,000	.
	ManagementZone			2,021	3	,568			
	ManagementZone(1)	,108	,600	,032	1	,858	1,114	,343	3,612
	ManagementZone(2)	,894	,751	1,416	1	,234	2,445	,561	10,663
	ManagementZone(3)	,792	,827	,918	1	,338	2,208	,437	11,161
	Constant	21,150	28413,939	,000	1	,999	1532257286,086		
Step 2[a]	HabitatComplexity			,889	2	,641			
	HabitatComplexity(1)	-22,519	28420,716	,000	1	,999	,000	,000	.
	HabitatComplexity(2)	-22,072	28420,716	,000	1	,999	,000	,000	.
	Constant	21,203	28420,716	,000	1	,999	1615478660,751		

a. Variable(s) entered on step 1: HabitatComplexity, ManagementZone.

Categorical Variables Codings

		Frequency	Parameter coding (1)	(2)
HabitatType	Sand	28	1.000	.000
	Seagrass	36	.000	1.000
	Reef	45	.000	.000
MarinePark	Outside Marine Park	65	.000	
	Inside Marine Park	44	1.000	

***C. perezii* – Binary Logistic Regression LR Backward**

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B) Lower	Upper
Step 1[a]	HabitatType			1.539	2	.463			
	HabitatType(1)	-.339	.750	.204	1	.651	.712	.164	3.099
	HabitatType(2)	-1.393	1.136	1.504	1	.220	.248	.027	2.300
	MarinePark(1)	1.204	.736	2.678	1	.102	3.334	.788	14.105
	Constant	-2.480	.693	12.820	1	.000	.084		
Step 2[a]	MarinePark(1)	1.524	.709	4.627	1	.031	4.593	1.145	18.420
	Constant	-3.029	.591	26.246	1	.000	.048		

a. Variable(s) entered on step 1: HabitatType, MarinePark.

G. cirratum

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B) Lower	Upper
Step 1[a]	HabitatType			,477	2	,788			
	HabitatType(1)	-,564	,889	,403	1	,525	,569	,100	3,246
	HabitatType(2)	,095	,953	,010	1	,921	1,100	,170	7,114
	MarinePark(1)	2,878	1,131	6,475	1	,011	17,775	1,937	163,115
	Constant	-4,103	1,151	12,719	1	,000	,017		
Step 2[a]	MarinePark(1)	2,801	1,075	6,790	1	,009	16,457	2,002	135,291
	Constant	-4,159	1,008	17,030	1	,000	,016		

a. Variable(s) entered on step 1: HabitatType, MarinePark.

Sharks

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B) Lower	Upper
Step 1[a]	HabitatType			1,335	2	,513			
	HabitatType(1)	-,582	,663	,771	1	,380	,559	,153	2,048
	HabitatType(2)	-,717	,747	,922	1	,337	,488	,113	2,109
	MarinePark(1)	1,444	,602	5,753	1	,016	4,236	1,302	13,783
	Constant	-2,063	,573	12,965	1	,000	,127		
Step 2[a]	MarinePark(1)	1,616	,571	8,013	1	,005	5,032	1,644	15,405
	Constant	-2,485	,465	28,499	1	,000	,083		

a. Variable(s) entered on step 1: HabitatType, MarinePark.

D. americana

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B) Lower	Upper
Step 1[a]	HabitatType			4,072	2	,131			
	HabitatType(1)	-,151	,627	,058	1	,810	,860	,251	2,940
	HabitatType(2)	,996	,575	2,997	1	,083	2,707	,877	8,358
	MarinePark(1)	,465	,521	,795	1	,373	1,591	,573	4,418
	Constant	-1,533	,492	9,717	1	,002	,216		
Step 2[a]	HabitatType			3,413	2	,181			
	HabitatType(1)	-,167	,624	,071	1	,790	,847	,249	2,879
	HabitatType(2)	,809	,528	2,351	1	,125	2,246	,798	6,315
	Constant	-1,269	,377	11,303	1	,001	,281		
Step 3[a]	Constant	-1,019	,229	19,818	1	,000	,361		

a. Variable(s) entered on step 1: HabitatType, MarinePark.

C. perezii

		Frequency	Parameter coding (1)	(2)
HabitatComplexity	Low	56	1,000	,000
	Medium	51	,000	1,000
	High	2	,000	,000
MarinePark	Outside Marine Park	65	,000	
	Inside Marine Park	44	1,000	

C. perezii

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B) Lower	Upper
Step 1[a]	MarinePark	1,644	,741	4,917	1	,027	5,174	1,210	22,118
	HabitatComplexity			2,622	2	,270			
	HabitatComplexity(1)	-2,584	1,623	2,534	1	,111	,075	,003	1,818
	HabitatComplexity(2)	-2,125	1,612	1,738	1	,187	,119	,005	2,814
	Constant	-,822	1,579	,271	1	,603	,440		
Step 2[a]	MarinePark	1,524	,709	4,627	1	,031	4,593	1,145	18,420
	Constant	-3,029	,591	26,246	1	,000	,048		

a. Variable(s) entered on step 1: MarinePark, HabitatComplexity.

G. cirratum

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B) Lower	Upper
Step 1[a]	HabitatComplexity			2,546	2	,280			
	HabitatComplexity(1)	-3,092	1,955	2,500	1	,114	,045	,001	2,097
	HabitatComplexity(2)	-2,698	1,950	1,915	1	,166	,067	,001	3,074
	MarinePark(1)	2,992	1,136	6,939	1	,008	19,916	2,151	184,451
	Constant	-1,496	1,915	,610	1	,435	,224		
Step 2[a]	MarinePark(1)	2,801	1,075	6,790	1	,009	16,457	2,002	135,291
	Constant	-4,159	1,008	17,030	1	,000	,016		

a. Variable(s) entered on step 1: HabitatComplexity, MarinePark.

Sharks

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B) Lower	95% C.I.for EXP(B) Upper
Step 1[a]	HabitatComplexity			2,507	2	,285			
	HabitatComplexity(1)	-2,066	1,617	1,632	1	,201	,127	,005	3,014
	HabitatComplexity(2)	-1,391	1,606	,750	1	,386	,249	,011	5,795
	MarinePark(1)	1,786	,601	8,846	1	,003	5,967	1,839	19,364
	Constant	-,893	1,586	,317	1	,573	,409		
Step 2[a]	MarinePark(1)	1,616	,571	8,013	1	,005	5,032	1,644	15,405
	Constant	-2,485	,465	28,499	1	,000	,083		

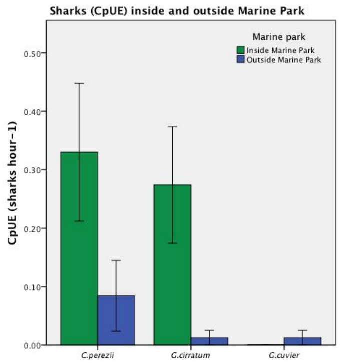
a. Variable(s) entered on step 1: HabitatComplexity, MarinePark.

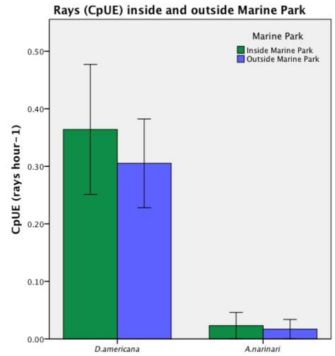
D. americana

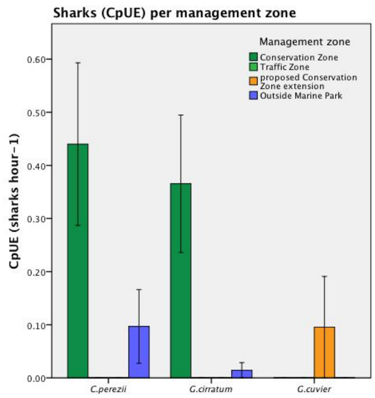
		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B) Lower	95% C.I.for EXP(B) Upper
Step 1[a]	MarinePark(1)	,186	,499	,138	1	,710	1,204	,453	3,200
	HabitatComplexity			1,009	2	,604			
	HabitatComplexity(1)	-22,527	28399,535	,000	1	,999	,000	,000	.
	HabitatComplexity(2)	-22,034	28399,535	,000	1	,999	,000	,000	.
	Constant	21,113	28399,535	,000	1	,999	1476450281,431		
Step 2[a]	HabitatComplexity			,889	2	,641			
	HabitatComplexity(1)	-22,519	28420,716	,000	1	,999	,000	,000	.
	HabitatComplexity(2)	-22,072	28420,716	,000	1	,999	,000	,000	.
	Constant	21,203	28420,716	,000	1	,999	1615478660,751		

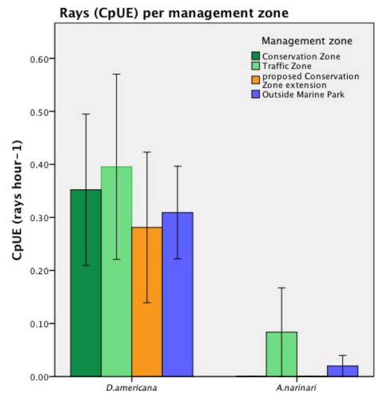
a. Variable(s) entered on step 1: MarinePark, HabitatComplexity.

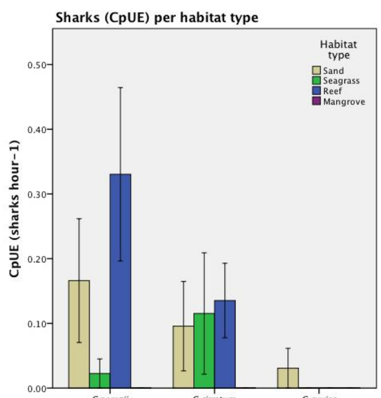
Appendix VII: Relative abundance of elasmobranch expressed in CpUE

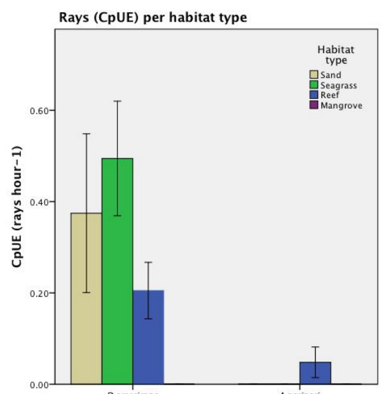


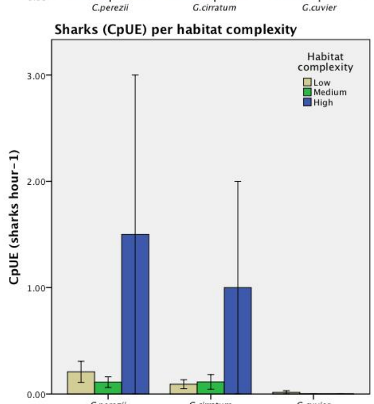


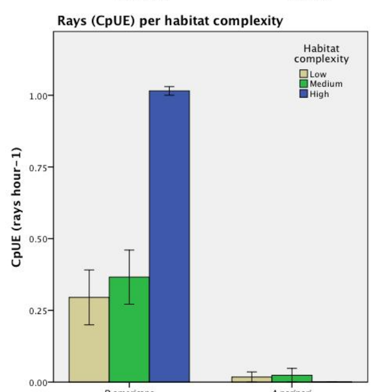




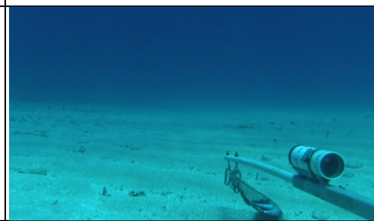
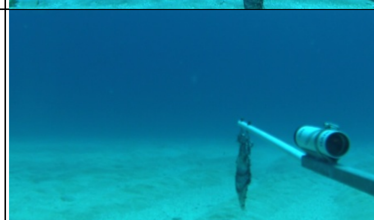
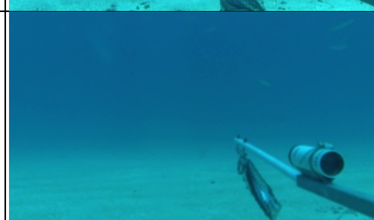
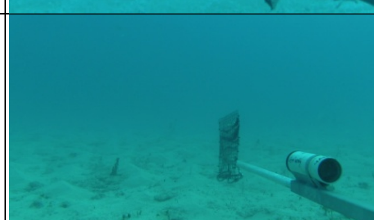
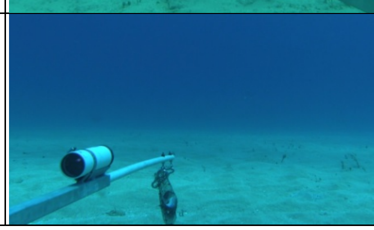


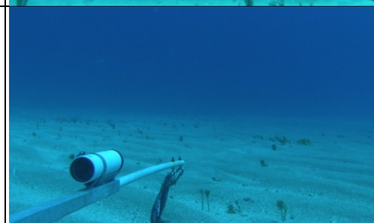
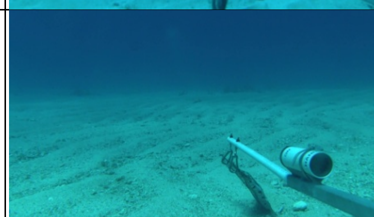
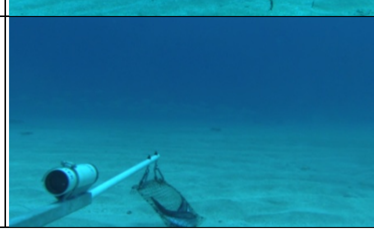


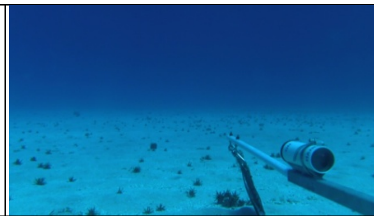
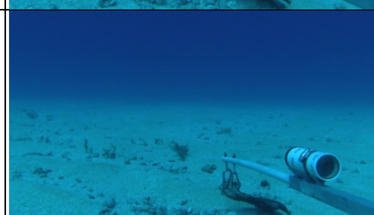
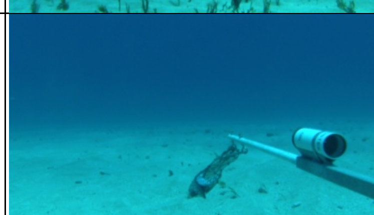
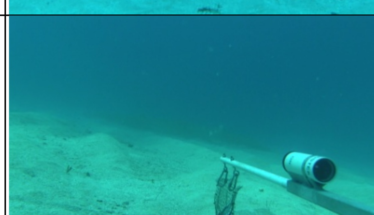


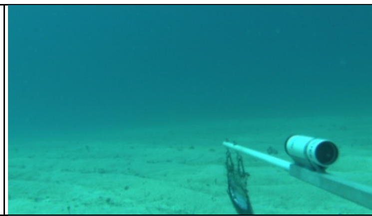
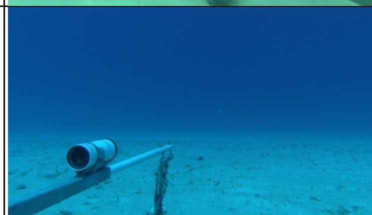
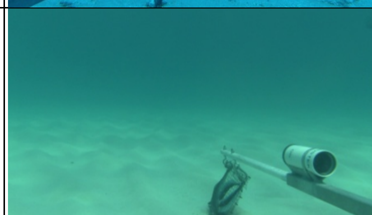
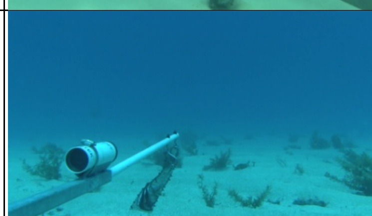
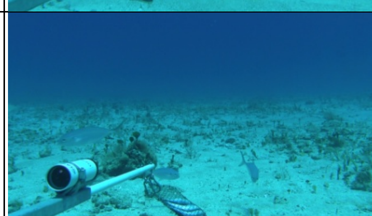


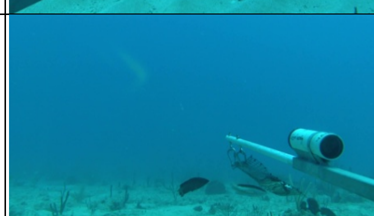
Appendix VIII: Habitat images including classification

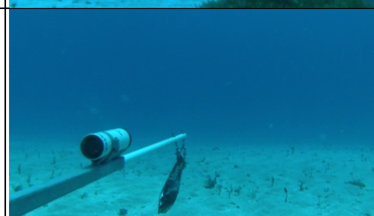
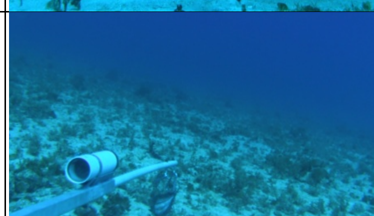
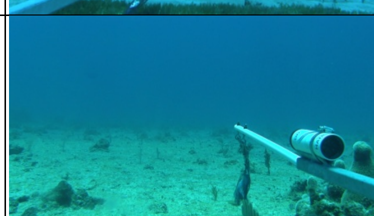
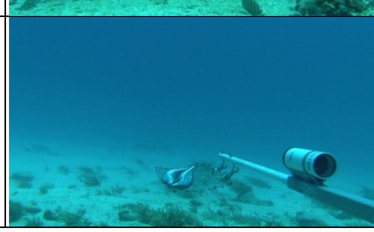
Location code	Habitat image	Habitat complexity Low/Medium/High	Polunin index	Habitat type
1_Proposed_20mar		Low	0	Sand
3_Trafficzone_20mar		Low	0	Sand
4_Proposed_24mar		Low	0	Sand
4_Trafficzone_21mar		Low	0	Sand
5_ConservationZone_12mar		Low	0	Sand
5_OutsideCoastal_4mar		Low	0	Sand
5_Proposed_24mar		Low	0	Sand

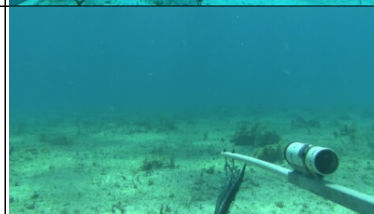
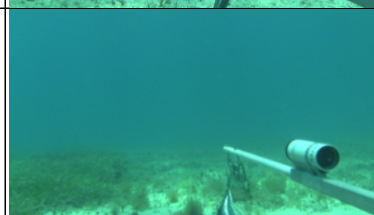
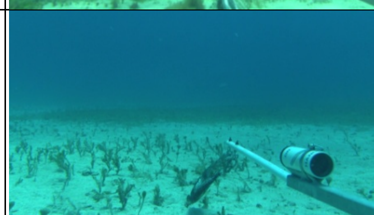
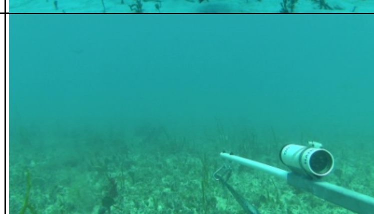
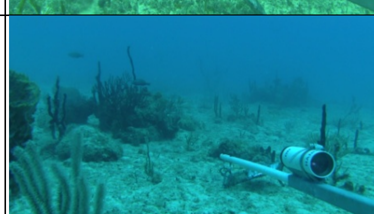
5_Trafficzone_2apr		Low	0	Sand
6_Trafficzone_12apr		Low	0	Sand
7_Proposed_24mar		Low	0	Sand
8_ConservationZone_16mar		Low	0	Sand
9_Trafficzone_23apr		Low	0	Sand
10_Trafficzone_23apr		Low	0	Sand
14_ConservationZone_20mar		Low	0	Sand
15_OutsideCoastal_16mar		Low	0	Sand

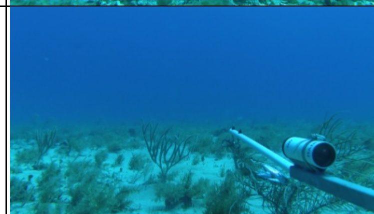
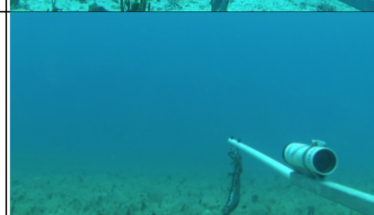
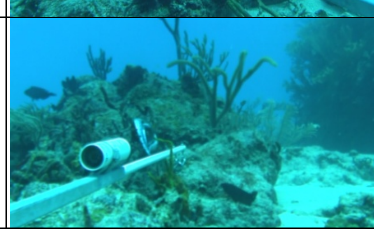
21_OutsideCoastal_21mar		Low	0	Sand
23_ConservationZone_25mar		Low	0	Sand
23_OutsideCoastal_1apr		Low	0	Sand
24_ConservationZone_25mar		Low	0	Sand
25_ConservationZone_2apr		Low	0	Sand
27_ConservationZone _23apr		Low	0	Sand
34_OutsideCoastal_3apr		Low	0	Sand
42_OutsideCoastal_5apr		Low	0	Sand

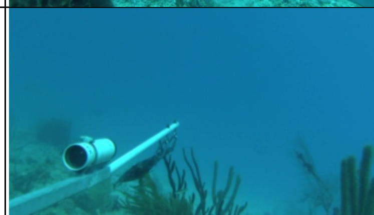
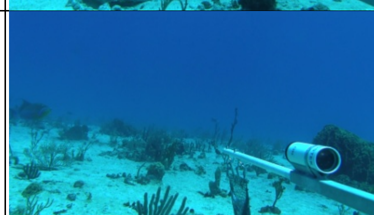
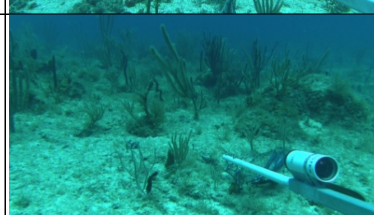
44_OutsideCoastal_5apr		Low	0	Sand
52_OutsideCoastal _8apr		Low	0	Sand
60_OutsideCoastal _12apr		Low	0	Sand
63_OutsideCoastal _12apr		Low	0	Sand
2_ConservationZone_12mar		Low	1	Reef
3_Proposed_24mar		Low	1	Reef
6_ConservationZone_12ma		Low	1	Reef
7_ConservationZone_16mar		Low	1	Reef

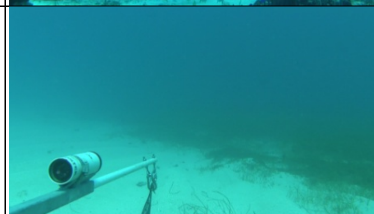
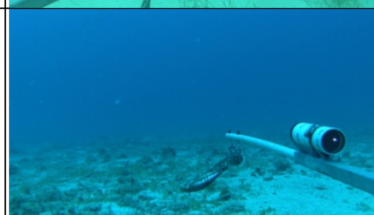
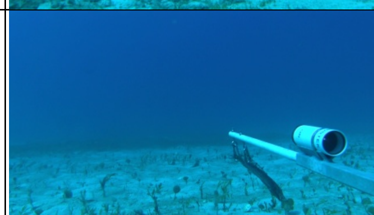
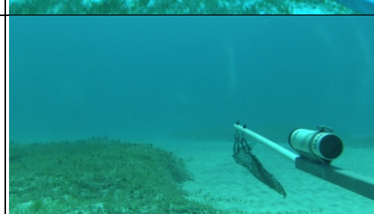
7_OutsideCoastal_7mar		Low	1	Reef
7_Trafficzone_12apr		Low	1	Reef
8_Proposed_24mar		Low	1	Reef
8_Trafficzone_23apr		Low	1	Reef
9_Proposed_24mar		Low	1	Reef
10_ConservationZone_16mar		Low	1	Reef
11_OutsideCoastal_10mar		Low	1	Reef
13_ConservationZone_20mar		Low	1	Reef

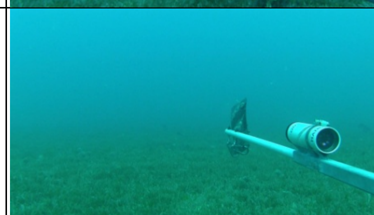
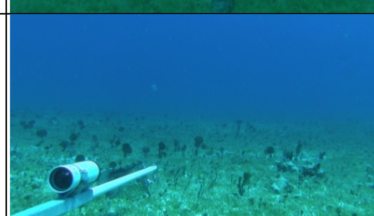
15_ConservationZone_20mar		Low	1	Reef
19_ConservationZone_25mar		Low	1	Reef
19_OutsideCoastal_20mar		Low	1	Reef
20_ConservationZone_25mar		Low	1	Reef
28_ConservationZone_23apr		Low	1	Reef
29_OutsideCoastal_2apr		Low	1	Reef
31_ConservationZone_24apr		Low	1	Reef
32_ConservationZone _24apr		Low	1	Reef

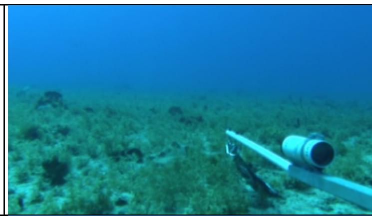
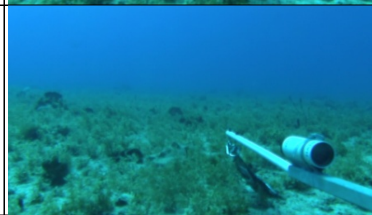
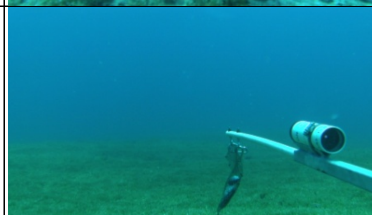
33_OutsideCoastal_2apr		Low	1	Reef
40_OutsideCoastal_5apr		Low	1	Reef
43_OutsideCoastal_5apr		Low	1	Reef
46_OutsideCoastal_5apr		Low	1	Reef
50_OutsideCoastal_8apr		Low	1	Reef
4_OutsideCoastal_4mar		Medium	2	Reef
10_OutsideCoastal_10mar		Medium	2	Reef
11_ConservationZone_20mar		Medium	2	Reef

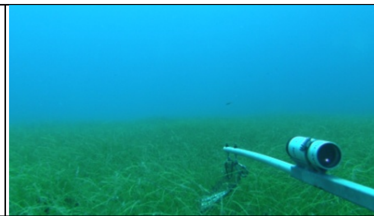
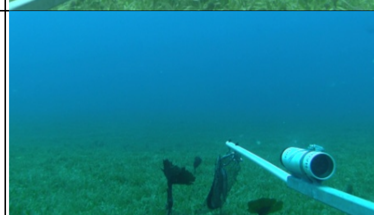
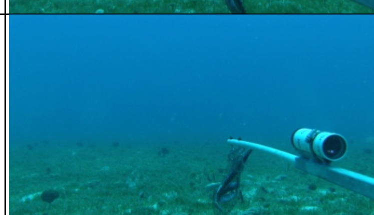
11_Trafficzone_23apr		Medium	2	Reef
12_ConservationZone_20mar		Medium	2	Reef
14_OutsideCoastal_10mar		Medium	2	Reef
30_ConservationZone_ 24apr		Medium	2	Reef
51_OutsideCoastal_8apr		Medium	2	Reef
64_OutsideCoastal_3apr		Medium	2	Reef
1_ConservationZone_12mar		Medium	3	Reef
3_ConservationZone_12mar		Medium	3	Reef

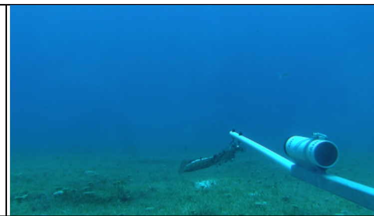
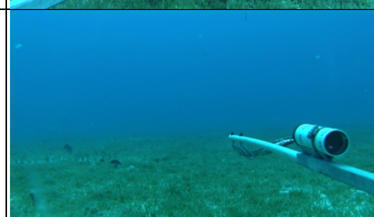
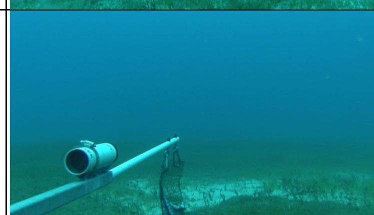
9_ConservationZone_16mar		Medium	3	Reef
9_OutsideCoastal_10mar		Medium	3	Reef
13_OutsideCoastal_10mar		Medium	3	Reef
17_ConservationZone_21mar		Medium	3	Reef
21_ConservationZone_25mar		Medium	3	Reef
26_ConservationZone_ 23apr		Medium	3	Reef
37_OutsideCoastal_3apr		Medium	3	Reef
12_OutsideCoastal_10mar		High	4	Reef

16_ConservationZone_21mar		High	4	Reef
1_OutsideCoastal_3mar		Low	-	Seagrass 0-10
28_OutsideCoastal_1apr		Low	-	Seagrass 0-10
29_ConservationZone_ 23apr		Low	-	Seagrass 0-10
2_Trafficzone_16mar		Medium	-	Seagrass 10-100
8_OutsideCoastal_7mar_WP33		Medium	-	Seagrass 10-100
36_OutsideCoastal_3apr		Medium	-	Seagrass 10-100
45_OutsideCoastal_5apr		Medium	-	Seagrass 10-100

1_Trafficzone_16mar		Medium	-	Seagrass 10-100
2_OutsideCoastal_3mar		Medium	-	Seagrass 10-100
2_Proposed_20mar		Medium	-	Seagrass 10-100
3_OutsideCoastal_3mar		Medium	-	Seagrass 10-100
4_ConservationZone_12mar		Medium	-	Seagrass 10-100
6_OutsideCoastal_4mar		Medium	-	Seagrass 10-100
6_Proposed_24mar		Medium	-	Seagrass 10-100
18_ConservationZone_21mar		Medium	-	Seagrass 10-100

22_ConservationZone_25mar		Medium	-	Seagrass 10-100
22_OutsideCoastal_1apr		Medium	-	Seagrass 10-100
24_OutsideCoastal_1apr		Medium	-	Seagrass 10-100
25_OutsidCoastal_1apr		Medium	-	Seagrass 10-100
26_OutsideCoastal_1apr		Medium	-	Seagrass 10-100
27_OutsideCoastal_1apr		Medium	-	Seagrass 10-100
31_OutsideCoastal_2apr		Medium	-	Seagrass 10-100
32_OutsideCoastal_2apr		Medium	-	Seagrass 10-100

35_OutsideCoastal_3apr		Medium	-	Seagrass 10-100
38_OutsideCoastal_5apr		Medium	-	Seagrass 10-100
39_OutsideCoastal_5apr		Medium	-	Seagrass 10-100
41_OutsideCoastal_5apr		Medium	-	Seagrass 10-100
47_OutsideCoastal_8apr		Medium	-	Seagrass 10-100
48_OutsideCoastal_8apr		Medium	-	Seagrass 10-100
49_OutsideCoastal_8apr		Medium	-	Seagrass 10-100
53_OutsideCoastal_ 9apr		Medium	-	Seagrass 10-100

54_OutsideCoastal_ 9apr		Medium	-	Seagrass 10-100
55_OutsideCoastal_ 9apr		Medium	-	Seagrass 10-100
56_OutsideCoastal_ 10apr		Medium	-	Seagrass 10-100
57_OutsideCoastal_ 10apr		Medium	-	Seagrass 10-100
62_OutsideCoastal_ 12apr		Medium	-	Seagrass 10-100
1_InshoreCoastal_3apr		-	-	Mangrove
2_InshoreCoastal_3apr		-	-	Mangrove
3_InshoreCoastal_3apr		-	-	Mangrove

4_InshoreCoastal_ 10apr		-	-	Mangrove
1_OutsidePelagic_25mar		-	-	Pelagic
2_OutsidePelagic_25mar		-	-	Pelagic
61_OutsideCoastal_ 12apr		-	-	-