REVIEW OF QUEEN CONCH (*Lobatus gigas*) SAMPLING EFFORTS IN THE COMMONWEALTH OF THE BAHAMAS

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ABSTRACT

Recognising the commercial importance of the queen conch fishery, increasing fishing effort, and high demand in international trade for resources, there are concerns about the long-term sustainability of queen conch stocks throughout The Bahamas. The objective of this study was to review the sampling efforts of queen conch in The Bahamas and evaluate the precision of the estimates when reducing the sample. Analyses were performed to quantify the spatial coverage of previous surveys. Permutation analyses were carried out on mean abundance to evaluate the precision of the estimates when reducing the sample efforts on three size classes of queen conch, from survey sites in the Ragged Island and the Jumentos Cays; Sandy Point, Abaco, and Mores Island, Abaco. The results suggested that sampling effort can slightly be reduced to expand the survey area or reallocate effort in areas that have not been surveyed. The total surveyed area was estimated at a total of 3,567 km². The total habitat of queen conch was estimated at an approximate size of 11,888 km². The layers comprised of two previously identified queen conch habitats and queen conch surveyed areas that were obtained from The Nature Conservancy - Northern Caribbean Division, Community Conch and FAO. If the spatial distribution is an accurate representation of queen conch habitat, the proportion of habitat areas that have been surveyed at least once was estimated to be at 30% of the total. Results from surveyed areas indicate queen conch density is below reproduction capacity threshold in many areas. The Bahamas must attempt to improve management efforts to conserve and ensure the sustainability of this fishery.

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Table of Contents

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 The Bahamas

The Bahamas is located within the Western Atlantic Ocean east from the state of Florida (USA), and north from the islands of Hispaniola, Cuba, and Turks and Caicos (Fig. 1). The Bahamas vast archipelago covers a surface area of 230,000 km² and a continental shelf area of 116,550 km² of limestone carbonate continental shelf (Maher, 1962; FAO, 2016). The Bahamas archipelago consists of 700 islands, and about 2,400 cays, islets, and rocks, with diverse habitats including tidal flats, mangrove forests, coastal wetlands, blue holes, extensive barrier reefs and the deep oceanic trench known as the "Tongue of the Ocean" (Maher, 1962). The population was recently estimated at 390,000 people (The Department of Statistics, 2016). The islands with exception of the capital (New Providence Island) are referred to as Family Islands.

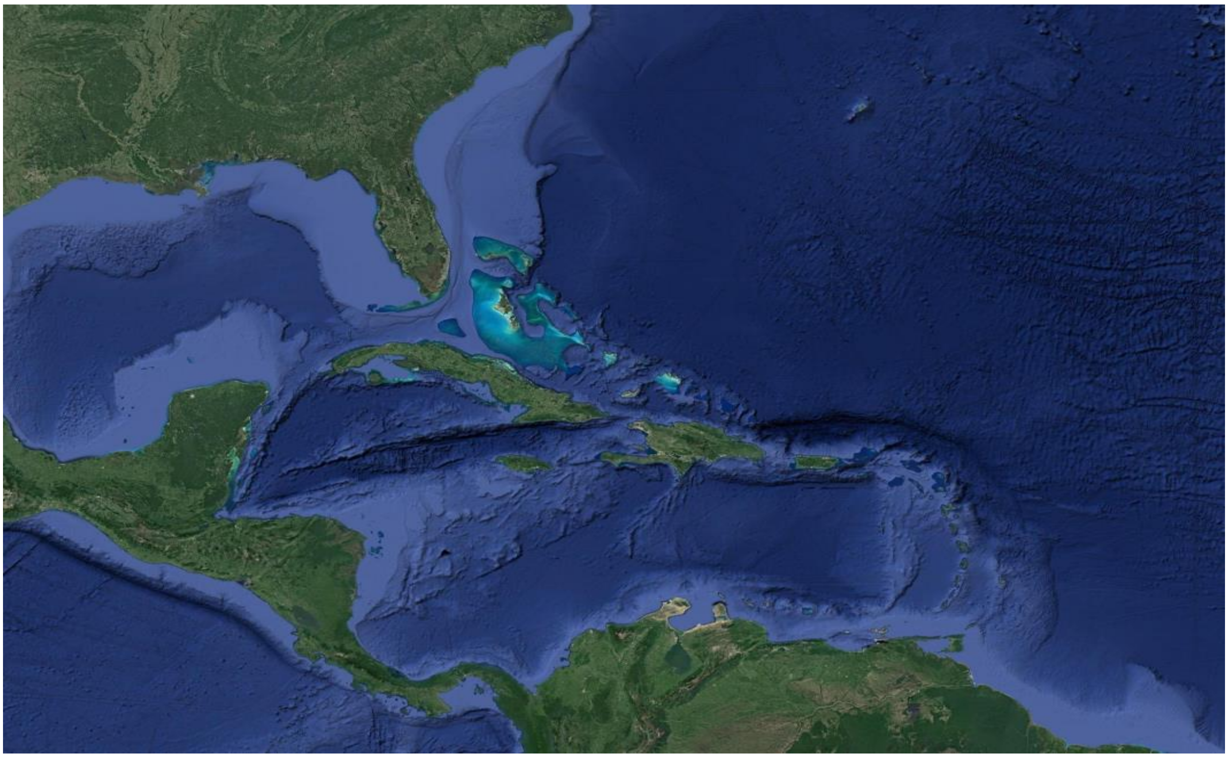

Figure. 1: Map of The Bahamas with a southeast, north and northwest periphery of the USA's Florida Cays, Hispaniola, Cuba, and Turks and Caicos Island.

1.2 Fisheries in The Bahamas

Fishing activities in The Bahamas include commercial and artisanal fisheries, aquaculture, subsistence fisheries and sports and recreational fishing (Shivlani, 2016). The national government has reserved commercial and subsistence fisheries for exploitation by Bahamian citizens within its Exclusive Economic Zone (EEZ) and is based on open-access fisheries. However, fisheries regulations allow permits for foreign sports fishing operators (FAO, 2016). The Fisheries in The Bahamas contribute significantly to the country's nutritional (which is equivalent to 10% of protein intake) and social needs as well as economic growth in terms of employment and foreign currency (FAO, 2016). The fisheries sector contributes an estimated 1 % of the GDP (The Department of Statistics, 2016). In terms of employment, the fisheries sector employs an estimate of 9,300 full-time commercial fishers and a few thousand more subsistence and recreational fishers (FAO, 2016; The Department of Statistics, 2016).

1.3 Fishing Grounds

Fishing mainly occurs in shallow waters of less than 30 m depth throughout The Bahamas (FAO, 2016). Moreover, most of the fishing activities occur on the Great Bahama Banks, the Small Bahama Banks (which are the two major fishing grounds), the Cay Sal Banks, the Acklins Bank and Crooked Island Banks (Fig. 2; FAO, 2016). The two historically important fishing grounds are located southwest Berry Islands and south end of Andros near Grassy Creek Cays and Pigeon Cay (Stoner, Davis, & Booker, 2012 b).

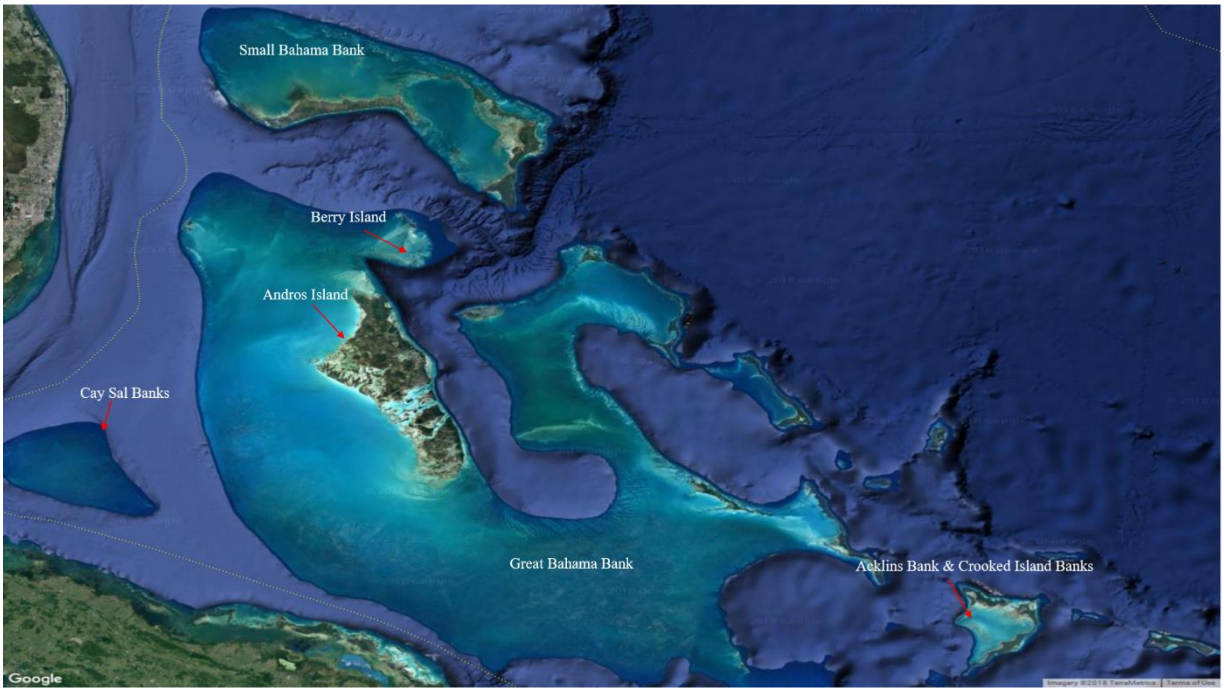

Figure. 2: Map of fishing grounds in The Bahamas

1.4 Fishing Vessels

The Bahamas fishing fleet is considered small-scale and counts approximately 4,000 fishing vessels ranging in length from 3 meters to 30 meters (FAO, 2016). There are two main categories for fishing vessels within the fishing industry. Vessels that are less than 20 feet and vessels greater than 20 feet. In both categories there is a high variability in the size of vessels. Vessels less than 20 feet are referred to as dinghies and are commonly utilised by subsistence and recreational fishers, operating on a day trip basis (FAO, 2016). Due to their size these vessels are limited by gear type and catch weight. In contrast to dinghies, vessels greater than 20 feet are considered as commercial fishing vessels and can spend up to four weeks at sea with the capability of higher fishing effort than dinghies. These vessels are required to obtain a Fisheries Department Commercial Registration Licence Number at the Department of Marine Resources (FAO, 2016). Both types of vessels often operate collectively during the conch and lobster fishing season. The commercial vessels act as mothership from which the dinghies operate (FAO, 2016). Globally, the commercial fisheries are considered to be small-scale, based on quantity of exported fisheries products, fishing gear technology and fishing vessel size (Blue Earth Consultants, LLC., 2016; FAO, 2016). However, in the Caribbean, The Bahamas queen conch and spiny lobster fisheries are considered to be industrial, along with other nations including Cuba, Jamaica, and Colombia (NOAA, 2014).

1.5 Targeted Species

Currently, both subsistence and commercial fishers target highly valued marine resources such as wool sponge (*Hippiospongia lachne*), hard-head sponge (*Spongia barbara dura*) mutton snapper (*Lutjanus analis*), lane snapper (*L. synagris*), schoolmaster (*L. apodus*), margate fish (H*aemulon album*), sailor's choice (*H. parra*), yellowfin grouper *(Mycteroperca venenosa*), Nassau grouper (*Epinephelus striatus*), spiny lobster (*Panulirus argus*), and queen conch (*Lobatus gigas)* (The Department of Marine Resources, 2015). These species are considered valuable in the local and international markets. Also, these species are grouped together based on their economic value. In 2016 spiny lobster was 75.92 %, of the total landed weight, scale fish was 11.24%, sponge was 2.88%, crustaceans were 0.44% and queen conch was 9.51% (The Department of Marine Resources, 2017). Queen conch are targeted year-round; however, during the closed season for spiny lobster (1st April – 31st July) and Nassau grouper (1st December1 – 28th February) this species experiences intense fishing pressure as fishers aim to supplement their income (NOAA, 2014; FAO, 2016).

1.6 Problem Statement

Recognising the commercial importance of the queen conch fishery, increasing fishing effort, and high demand of international trade for the resources, there are concerns about the long-term sustainability of queen conch stocks throughout The Bahamas (Stoner & Davis, 2010). Overfishing, harvesting of juvenile queen conchs and unsustainable fishing practices appear to be the greatest threats to queen conch sustainability and the principal cause of the declining stocks (Stoner, Davis, Booker, 2012). Another plausible contributing factor is the inadequate assessment of catch landings, which results in inaccurate analysis of landed stocks and fishing pressure.

An ambiguous legislation with regards to harvest control rule is also a contributing factor in the declining stock in particular the imprecise explanation used in the description of a legally harvestable queen conch which is distinguished by "well-formed flaring lip", which is left to the fishers' interpretation and discretion (BMAMR, 1997). Research established queen conch's shell lip thickness of no less than 15mm as an indicator of sexual maturity; whereas description "well-formed flaring lip" is not an indicator of sexual maturity (Stoner A. , 1997 b). As a result, ambiguous legislation inadvertently enabled the illegal harvesting of juvenile queen conch (Mueller & Stoner, 2013).

Other human impacts to the fishery are illegal unreported and unregulated fishing; inadequate monitoring and enforcement; and illegal use of harvest apparatus (TNC, 2016). Unfortunately, the queen conch stocks are also faced with natural environmental stressors such as increased sea surface temperature and acidification. Also, The Bahamas were impacted by two category 4 hurricanes in 2015 and 2016 (Joaquin and Mathew). This impact to the queen conch fishery is unknown.

Regardless of the natural and human pressures on the queen conch population, The Bahamas continues to increase the export quota, which is reflected in the country's increased export values for foreign earnings (The Department of Marine Resources, 2015; CRFM, 1997). However, the decrease in queen conch commercial landing is indicative of the inadequate management of the queen conch fisheries (Fig. 3). Decrease in the 2016 commercial landing data may also be explained by the direct impact of the aforementioned category 4 hurricanes, which devastated the fishing fleets in Long Island and Spanish Wells, Eleuthera.
Understanding the actual status of the queen conch stock in The Bahamas and the effect of the factors listed above in the dynamics of queen conch populations is difficult, in particular because there is little information available. As stated in a report from Blue Earth Consultants "The Bahamas conch fishery does not have a standardised or consistent method of assessing stock trends and status." (Blue Earth Consultants, LLC., 2016). In particular, information of the status and assessment of the queen conch stocks are only obtained from sporadic scientific surveys carried out within important fishing grounds (Blue Earth Consultants, LLC., 2016). Therefore, this project is designed to review past scientific surveys utilised in assessing the queen conch stock.

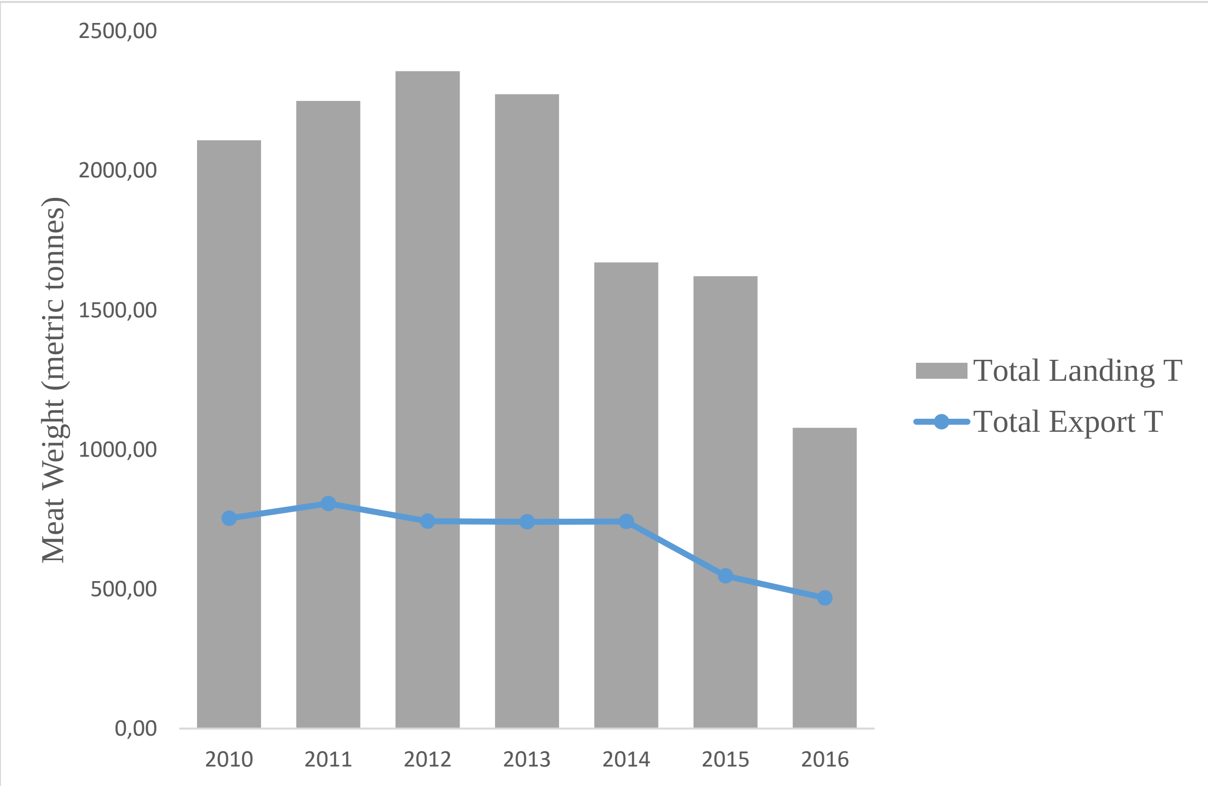

Figure. 3: Annual landing and export of queen conch meat weight (tonnes) in The Bahamas, from 2010 to 2016 (DMR 2016).

2 OBJECTIVES

2.1 General Objective

To review the sampling efforts of queen conch in the Bahamas and evaluate the precision of the estimates when reducing the sample efforts comprehensive survey methodology to ensure the sustainable harvest of this stock.

2.1.1 Specific Objectives

- Review of literature on sampling surveys and other studies that were performed in The Bahamas and in the wider Caribbean region.

- Map out potential habitat for queen conch in The Bahamas and explore the fraction that has recently been surveyed.

- Evaluate the amount of sampling effort required to obtain adequate estimates of abundance.

- Provide recommendations on sampling strategy for evaluation of the stock based on results.

3 LITERATURE REVIEW OF QUEEN CONCH

3.1 Biology

Lobatus gigas (formerly known as *Strombus gigas*), commonly known as queen conch, is a large herbivore gastropod mollusc that inhabits shallow coastal waters of the tropical North Western Atlantic (Stoner & Davis, 2010). Its geographical distribution ranges from Bermuda, to the Gulf of Mexico, throughout The Bahamas and the Caribbean Sea extending as far south as Brazil (Fig. 1; Stoner & Davis, 2010).

3.1.1 Reproduction

Like many gastropods, the biology of *Lobatus gigas* is complex. Queen conch is a dioecious species. Males are distinguished by their verge, and females by their egg grove. Females are typical larger than males (McCarthy, 2008). Mating is density dependent and therefore a significantly high density of females is required to ensure a stable fishery (Stoner, Davis, & Booker, 2012 b). Research has shown that a minimum of 50 mating pairs of conch per-hectare (conch/ha) is necessary for reproduction to occur (Stoner A., 1997). Reproduction occurs during the warmest months; in which copulations peak from July to August and can take place diurnally and nocturnally (Stoner, 2003). Fertilisation is internal. The female produces a sticky gelatinous egg string up to 23 m upon fertilisation that contains approximately 400,000 eggs (Stoner & Ray, 1996). The egg string is laid on clean sand and skilfully compacted into an egg mass and camouflaged with the surrounding substratum (McCarthy, 2008). Level of larval retention and settlement within a nursery are influenced by biotic and abiotic conditions such as physical, oceanographic process and predator abundance (NOAA, 2014). After three to five days, the eggs hatch into planktonic veliger larvae. Thus, migrating above the thermocline within the upper mixture of the water column where they remain for a period of two to five

weeks feeding on phytoplankton. Though uncommon, veliger larvae were documented at a depth of 100 m (Stoner A., 1997; NOAA, 2014). Metamorphosis occurs 16-14 days post hatching in which veliger larvae develop an embryonic shell length ~ 1.3 mm and settle as an infaunal juvenile conch within seagrass areas (Stoner, 2003), (McCarthy, 2008).
Within the Bahamas the general view is that the larvae are transported by north west surface currents. For example, Stoner (2013) suggested north west surface currents from the Jumentos Cays and Ragged Islands are one of delivery sources of larval recruitment upon nursery grounds Grassy Cay, Andros Island; Sand Bores (located at the southern tip of the Tongue of the Ocean) and the Exuma Cays, (Stoner, Davis, & Booker, 2013). Comparative studies indicated Ragged Island larval recruitment relay upon upstream surface currents from Acklins' Island and Turks and Caicos Islands (Stoner, Davis, & Booker, 2013). It is also documented that the advancement of Exuma Sound gyres to the northwest not only transport larvae onto northern nursery grounds of the Exuma Cays but reach Eleuthera Island's southern nursery grounds as well (Stoner A., 1997; Stoner, Davis , & Booker, 2014).

3.1.2 Habitat Distribution

Infaunal and epifaunal juveniles, sub-adults and adults' niches are constrained by several biotic and abiotic factors including predation, water temperature and circulation, availability of sunlight and food, and substratum type (Stoner, 2003; Stoner A, Davis M, Booker C, 2011; Morris R., 2016). Generally, queen conchs are known to "… migrate inshore during warmer months to aggregate and return to deeper waters during the fall…" (NOAA, 2014). Queen conch spatial distribution, growth and depth range are also influenced by anthropogenic factors such as fishing pressure (Stoner, Davis, Booker, 2012).

3.1.3 Juvenile Queen Conch

Juvenile queen conch are known to have specific habitat requirements based on regional location. In the Bahamas, Cuba, Turks and Caicos, and Venezuela juvenile queen conch are known to inhabit seagrass beds (*Thalassia testudinum*) within shallow water banks and inlets protected by emergent reefs or cays at depths between 2 - 4 m forming large aggregations located within tidal current pathways (Stoner, 2003; NOAA, 2014). Migration patterns are associated with ebb tide forming single or multiple year classes (Stoner & Sandt, 1992). Also, juvenile queen conchs are known to inhabit shallow algal flats in Florida, United States of America (NOAA, 2014). However, there are unique cases where juvenile queen conchs were documented in depths of 60 m in Pedro Bank, Jamaica (Stoner, 2003). Comparatively, juvenile queen conch in Puerto Rico and Virgin Islands inhabit "… shallow coral reef rubbles environment" (Stoner, 2003). Like many gastropods, scientific studies have shown active habitat selection behaviour exhibited by juvenile queen conch (Stoner & Walte, 1990). One of the biotic factors that governs juvenile queen conch distribution is the presence of moderate *Thalassia testudinum* (Turtle grass), algal epiphytes and microdetritus, which they graze on (Stoner & Walte, 1990). High density of these biotic factors can also contribute to its physiological constrains with regards to mobility (Stoner & Walte, 1990). Sexually immature juveniles are recognised as subadults by their flare lip at shell length greater than 10 cm and are estimated to be between two to three years old (Stoner & Davis, 2010; Stoner, Mueller, Brown-Peterson, Davis, & Brooker, 2012 c). They are often observed in water depth greater than 6 m that is associated with a mixture of sand, seagrass, and hard-bottom habitat (Stoner & Davis, 2010), (Mueller & Stoner, 2013).

3.1.4 Adult Conch

Possessing a well-formed flare lip, adult female queen conch reach sexually maturity at 15 cm shell lip thickness, while males reach sexually maturity at 10 cm shell lip thickness. The age of sexual maturity is estimated to be between 3.5 and 4 years old possessing a well formed flared lip. Somatic growth of shell length cease upon sexual maturity as shell lip thickness increases with age in which fecundity is viable (Stoner, Davis, Booker, 2012; McCarthy, 2008). Adults are known to disperse over a wide range of habitat such as coral rubble, algae-covered hard stratum, bare sand, and seagrass meadows at depth less than 70 m (Stoner, Davis, Booker, 2012; NOAA, 2014). In the Bahamas adult stocks were observed within stratum of sand, macroalgae hard bottom and sporadically among hard and soft corals at depths no greater than 35 m (Stoner & Ray , 1996; Kough, Cronin, Skubel, & Belak, 2017). Also, adults' ecosystem constraints are dictated by depth limitation is a direct correlation with light reduction within water column thus limiting their photosynthetic food source (McCarthy, 2008; NOAA, 2014). It is believed that anthropogenic factors such as intense fishing pressure influence adult distribution. For example, depth stratum surveys in Puerto Rico revealed a low density at 0.05 queen conch/ha at 20-25 m depth in a heavily fished area, while the U.S. Virgin Islands reported a maximum adult density at 17.1 conch/ha observed in 15-20 m depth in less heavily fishing area (Stoner A. , The Status of Queen Conch, Strombus gigas, Research in the Caribbean, 1997 b). Deep water spawning population of western Puerto Rico (within the U.S. EEZ) that are not accessible to free diving or ban from scuba access density range were observed between 70 -323 queen conch/ha (NOAA, 2014). The estimated life span of queen conch is 25 years (Davis, 2005).

3.2 Historical Use

Historically queen conch was harvested within The Bahamas for domestic consumption, and the fishery contributed to socioeconomic growth throughout The Bahamas' chain of Family Islands. Through the decades, queen conch meat developed into a cultural delicacy and became a symbol for the tourist industry in The Bahamas. The species were mainly harvested by free diving and using a looking glass scoop in shallow waters. However, historical records indicate queen conch shells and its pearls were considered a highly valued marine resource, with the shell export value reported at £ 1,200 per annum and the pearl at £ 3,000 per annum during 1883 (Addereley, 1883). Shells were also utilised as ship ballast, building material and ornaments. Other by-products like pearl and operculum are an extremely valuable commodity in the jewellery industry (Davis, 2005). Prior to 1992 queen conch meat was not exported and all consumption was domestic (NOAA, 2014; FAO, 2016).

3.3 Management of Queen Conch

The Ministry of Agriculture and Marine Resources are designated as the entity responsible for the management of the fishing industry. The Department of Marine Resources (DMR) was established within the Ministry as the legal authority responsible for the management, development and administration of the fisheries sector (DMR, 2014). DMR's mission stipulates "…development of the fisheries sector through sustainable use and integrated management of the fishery resources, coastal zone, and marine environment for the well-being of Bahamians" (TNC, 2016).

The Fisheries Jurisdiction and Conservation Act of 1977 is the primary regulatory framework for the management of the queen conch fisheries (DMR, 2014; BMAMR, 1997). The regulatory document stipulates provision restriction against harvesting, possessing or selling queen conch that do not possess “a well-formed flaring lip” (BMAMR, 1997). Subsequently, the aforementioned Act was amended in 1985, 2009, 2012, 2013, 2015, and 2017 to address the biological harvest management of fisheries such as the illegal harvesting of juvenile queen conch. Outlined in the amendments were restrictions in the use of SCUBA in harvesting queen conch. However, the use of hookah/compressor was granted via special license (FAO, 2016). The amendments also “grant relevant agencies the power to perform surveillance and enforcement of conch fisheries” (TNC, 2016). In addition to the 1977 Fisheries Act, The Wildlife and Conservation and Trade Act also addresses the export trade for conch fisheries by implementing CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora) (BMAMR, 1997). The Bahamas queen conch fishery is also governed by export quota that is inclusive of queen conch landing weights over a period of few years. No single year has a major impact on the quota.

3.4 Regional Management

In 1992 *Lobatus gigas* was listed on the CITES Appendix II as a result of the overexploitation of international trade that might have resulted in negative implications to the species population and distribution (FAO, 2005). CITIES also conducted a review of the queen conch trade from 2001 to 2003 due to continuous growth in international trade and deficiencies in enforcement within its members states. The review revealed numerous countries were in violation of their obligations under international trade treaties (FAO, 2005; NOAA, 2014). As a result, several countries including Haiti, Dominican Republic, Honduras, Antigua and Barbuda, Barbados, Granada, Trinidad and Tobago, Turks and Caicos, and Anguilla were prohibited from exporting queen conch (NOAA, 2014). In addition, FAO initiated a recommendation of responsible management for this fishery (FAO, 2014). “A guideline Monitoring and Management of Queen Conch” was developed through a collaboration between FAO, the Caribbean Regional Fisheries Mechanism (CRFM) and Caribbean Fisheries Management Council (CFMC) (FAO, 2005). In 2006 a regional administration workshop was held to improve capacity for the management of queen conch within the Western Atlantic and the Wider Caribbean. The workshop resulted in a memorandum of understanding and as stated in the FAO memorandum “signed between the Western Central Atlantic Fishery Commission (WECAFC) and the Regional Coordinating Unit of the Caribbean Environment Programme (UNEP-CAR/RCU) to aid Specially Protected Areas and Wildlife’s (SPAW) selected parties to develop management plans for their Queen Conch Fisheries” (FAO, 2017). In 2017, FAO in collaboration with WECAFC successfully developed the first agreed regional fisheries management and conservation plan for queen conch. The aim of the agreed document is to guide regional countries to identify and develop management measures the can be utilised for the sustainability of the queen conch population, ensuring healthy fisheries and the livelihood of its citizens (FAO, 2017).

3.5 Bahamas Queen Conch Landing and Export

In many Caribbean countries, the development of commercial fisheries for queen conch correlates with the growth of tourism in the 1970s (Davis, 2005). On the other hand, the commercial fishery in The Bahamas did not develop until 1992 (NOAA, 2014); (Davis, 2005). In 1992 only 0.5% of queen conch landings were exported (NOAA, 2014). The following year, queen conch export increased up to 51% of landings (NOAA, 2014). Between 2010 and 2016 the Queen Conch Fishery was the second most important fishery in The Bahamas, accounting for 3% of the fisheries’ export earnings, approximately greater than USD $300 million in 2010 (The Department of Marine Resources, 2015). In 2014 there was a decrease in queen conch landings. In that year 44% of the landings, which depicted the highest percentile exported in the last seven years. The residual was sold in the domestic market (Fig. 3).

4 METHODOLOGY

4.1 Evaluation of Survey Efforts in The Bahamas

A literature review of queen conch surveys in the Bahamas was carried out to identify the areas that were surveyed with primary focus on queen conch abundance and distribution. In addition, extracted quantitative data (studied sites: coordinates, size, depth range, number of transect, length and width of transects, distance between transect, and the number of sample stations) were compiled from surveys performed from 1996 and 2016. The quantitative data was examined to assess the sample scheme of the surveys.

4.2 Spatial Analyses

Spatial analyses were performed to quantify the spatial coverage of the surveys carried out up to this date. The spatial extent of each survey was estimated by calculating the area of polygons encompassing the locations sampled. Polygons were manually digitised using QGIS, and an open source Geographic Information System software (QGIS Development Team, 2009) . For some surveys, the location of individual sampling sites was made available, and the polygons were drawn around the sites. For the remaining surveys, maps were scanned from reports or peer-review articles and georeferenced using the map grid or recognisable geographic locations. Polygons were then digitised over the georeferenced maps.

In order to evaluate the representativeness of the survey, the sum of the areas surveyed was compared to three indicators of potential queen conch habitat: a) the extent of areas within the Bahamian Exclusive Economic Zone (EEZ) in which water depth is 30 m or less; b) the extent of areas with low to intermediate seagrass coverage; and c) the extent of known queen conch habitats. To quantify the extent of areas with shallow (<30m) waters, a raster with bathymetry data was obtained from the ETOPO1 Global Relief Model, with a resolution of 1 arc-minute. The data was projected to UTM (Universal Transverse Mercator) zone 18, resulting in cells with an area of 3.07 km2. The total extent was estimated from the number of cells within the Bahamian EEZ with depths between 0 and 30 m. The extent of seagrass meadows with low to medium intensity was based on the estimate of seagrass coverage produced by Wabnitz et al. 2008, who performed an analysis of Landsat satellite imagery and estimated that the total extent of seagrass areas in the Bahamas is 65.436 km2. Wabnitz et al. (2008) did not provide estimates of the extent of seagrass areas with low to medium coverage, but from the maps presented it is possible to assume that 70% of the seagrass areas have low to medium densities (Wabnitz, Andrefouet, Torres-Pulliza, Muller-Karger, & Kramer, 2008). Finally, the extent of known queen conch habitats were obtained from two sources: the queen conch habitat map presented in the report “Fisheries and Aquaculture in The Bahamas: A Review” (FAO, 2016), which was georeferenced and digitised, and a shapefile with queen conch habitat provided by The Nature Conservancy- Northern Caribbean Region (Shenique Albury-Smith, Director of Norther Caribbean Program). An examination of both set of polygons showed that some areas sampled during the surveys were not considered queen conch habitat. Therefore, a consensus queen conch habitat polygon was produced by combining the polygons obtained from both sources with the polygons demarcating the survey areas. The areas of all polygons, were computed by rasterizing them to obtain a raster with the same origin, extent and resolution as the bathymetry raster, and computing the number of cells included within the polygons. All analysis was performed using the R statistical environment (R Core Team, 2017).

4.3 Estimation of Adequate Sampling Effort in Performed Conch Survey

Data were obtained from 2011, 2012 and 2013 surveys on three size classes of queen conch. The surveys were performed and facilitated by lead scientist Dr. Allan Stoner in collaboration with Community Conch, a non-governmental organisation promoting the sustainable use of the queen conch. Studied sites included Ragged Island and the Jumentos Cays, Sandy Point and Mores Island, Abaco Island. Permutation analyses were carried out on mean abundance to evaluate the precision of the estimates when reducing the sample efforts. Results were generated by sample randomly with replacement stations in sequence of tens or twenties 2000 times, with respect to the total number of sample stations at each ground. The evaluations were performed using the R statistical environment (R Core Team, 2017). The results will help determine the minimum sampling effort required to obtain adequate survey results of various queen conch stocks.

5 RESULTS

5.1 Overview of Queen Conch Surveys Methodology

Queen conch stock assessment and distribution surveys were carried out throughout the central and northern areas of the archipelago. Based on literature review no surveys were performed around the southern islands. Overall review encompassed studies that were conducted on queen conch within the last two decades. Temporal sequence of surveys varies. Some surveys were focused on queen conch stock assessment, distribution and population structure relative to biotic, abiotic and anthropogenic factors. Some surveys also encompassed larval transport, recruitment and reproduction.

The surveys were carried out during the months of May through October to minimise potential temporal variation in reproductive behaviour analysis (Stoner & Ray-Culp, 2000). Queen conch surveys were categorised as shallow water tow or scuba dive dependent on the depth of study sites (Table 1). A combination or either one of the selected survey methods was performed. Scuba surveyors would normally swim parallel to the isobaths to prevent lag due to current (Stoner & Ray , 1996). Depth stratified surveys were mainly conducted to facilitate sampling for stock assessment and spatial distribution. The majority of the earlier surveys followed Stoner surveyed protocol that was developed in 1996, which was a direct relation to survey method utilised by Stoner 1994 surveys (Stoner & Schwarte, 1994; Stoner & Ray , 1996). Utilizing Global Positioning System (GPS) Stoner (1996) recorded latitude and longitude the beginning and end point of each transect. This method resulted in the calculation of the total surveyed area of the study sites. The number of surveyed transect varies based on research design and targeted spatial coverage. However, transect dimension for bank surveys were standardised (Table 2). Depth stratum surveys were conducted along each transect lines based on depth intervals. Shallow waters surveys comprised of depth interval range from 2.5 -10 m with transect length was 1 km and width at 6 m. Distance between transect was estimated at 1 km (Table 2). Deeper waters were surveyed by SCUBA at reflective depth stratums (Table 2). Towed speed was estimated at 2.96 km/hr; however, this varies due to sand bank or obstructed landmass. Length and direction of scuba surveys were determined by calibrated flow meter and compass carried by a diver. Scuba surveys required two divers (Stoner & Ray, 1996; Stoner, Davis, & Booker, 2009). SCUBA swim distance was estimated at 350 ± 6 m (Table 2). Latter surveys protocol was slightly modified by Stoner (2009) under the umbrella of Community Conch. Bank transect length and width remained the same with distances between transect slightly increased. However, distance between shelf transect was defined to 1 nautical mile and SCUBA swim distance was defined to 7 minutes with width remaining the same (Table 2). Different size classes of queen conch were recorded based on the Stoner classification scheme (Table 3).

Table 1: Survey methods utilised in conducting queen conch surveys.

Type of Survey	**Description**
Tow Observer	Snorkeller is towed on the surface of the water column in shallow waters by a skiff. Tow line is normally at an adequate length designed for snookers safety. Tow speed is constant and adequate for observers to detect targeted species.
Scuba Observer	Observers performed underwater surveys using scuba gear to detect target species.
Combination	Involves both tow and scuba observer

Table 2: Survey protocol reflective of Stoner and Community Conch's survey methodology.

Pubulish Year	Location	Bank Tow Transect Length (km)	Tow Transect Width (m)	Distance between Bank Transect (nauticle mile)	Distance between Shelf Transect (nauticle mile)	Tow Speed	Scuba swim distance (m)	Scuba Width (m)	Depth Intervals (m)
1996	LSI & WW (ECLSP)	1	6	~ 0.54	1 - 2	1.6 knots	360 ± 6	8	2.5 - 5 5 - 10 10 - 15 15 - 20 20 -25 25 - 30
2009	Berry Islands	1	6	~ 1	1	1.6 knots	7 min	8	0 - 2.5 2.5 - 5 5 - 10 10 - 15 15 - 20

Table 3: Description of queen conch size classification adapted from Stoner (1996)

Category	Description	Age Range
Juvenile	Small queen conch. Shell length less than ~10 cm shell	1-2
Subadult	Large juvenile queen conch presenting with flare lip and lip thickness ~10 mm	2.5 - 3.5
Adult	Sexual mature queen conch possessing a flared lip and lip thickness at 15mm	3.5 ±
Mating Pairs	Two adult conchs in copulation orientation with shell in direct contact	2 or more adult conchs

5.2 Density of queen conch within surveyed areas

Depth stratum surveys were mainly performed along shelf edge or within deeper coastal waters. As a result, studies have shown adult queen conch distribution ranges from 0 to 25 m in The Bahamas; however, adults are uncommonly observed in shallow waters (Stoner A. , 1997 b). Peak abundance and distribution of adult queen conch are characterised as highly variable and primarily dependent on stock location within the central and northern Bahamas (Stoner, Davis, & Booker, 2009; Stoner A. , 1997 b). In recent surveys the adult conch abundance ranged from 122 ± 138 conch/ha in Jumentos Cays & Ragged Islands in 2012 to only 0.7± 1.8 at the west bank of Berry islands in 2009 (Fig. 4 and Table 4). During the same set of surveys in Berry Island the highest mean density of adult queen conch observed among the three-study location was 118 ± 282 conch/ha in the south west fishing grounds. However, the highest value of queen conch at 332.9 ± 407.5 conch/ha in the south sector fishing grounds, was found along depth intervals of 5 - 10 m, (Stoner, Davis, & Booker, 2009). Similar depth distribution with a mean value of 30.1 ± 59.3 conch/ha (Table 4) was observed on Little Bahama Bank (Stoner, Davis , & Booker, 2014). Comparatively, shell lip thickness was relatively thinner at Little Bahamas Bank and Lee Stocking Island than Jumentos Cays and Ragged Island, which is evidence of a heavily fished population. (Stoner, Davis, & Booker, 2009).
Also, Jumentos Cays and Ragged Island, adult queen conch distribution is relatively similar to Berry Islands and Little Bahama Bank at depth intervals 5-10 m and 10 – 15 m that reflects a high abundance of 140 ± 146 conch/ha and 140 ± 101 conch/ha (Stoner, Davis, & Booker, 2013). On the other hand, the highest adult abundance observed at Lees Stocking Island fishing ground in 2011 was recorded at 9.42 ± 8.48 conch/ha within a depth zone of 20 - 25 m (Stoner A, Davis M, Booker C, 2011).
In the ECLSP Marine Reserve the average abundance of adult queen conch was recorded at 53 conch/ha in 1996 (Table 4). However, the highest density of adult during this period was observed at 270 ± 85 at conch adults/ha depth interval 10-15 m in 1996 (Stoner A., 1997) . Comparatively in 2011 the average density of adult queen conch decreased at 16.6 ± 50.5 with the highest density recorded at 144.5 ± 45.5 at 5-10 m in ECLSP Marine Reserve (Fig. 4 and

Table 4: Stoner, Davis, Booker, 2012). Study indicates at this location "…maximum reproductive activity occurs in the depth range 10 – 20 m on bare-sand with shallow sound waves..." (Stoner & Ray-Culp, 2000). Investigation in the Exuma Cays also revealed no mating behaviour occurred with densities less than 56 conch/ha indicating a reproductive threshold greater than the aforementioned value (Stoner & Ray-Culp, 2000). Surveys performed near Grassy Cay, Andros, observed a maximum of five mating pairs at depths of 5.6 m with a mating frequency of 11.9%. Density was recorded at 117 ± 162 conch/ha (Stoner & Davis, 2010). On the other hand, Sandy Point and Mores Island, Abaco investigation shown a low density in queen conch spawning population that was below the critical threshold (~ 56 adults/ha) for reproduction to occur (Table 4). However, there were two mating pairs observed at 16.7 adult/ha at depths of 4.4 and 3.8 m out of 115 tows performed (Stoner, Davis, & Booker, 2012 d). The highest number of mating pairs recorded was 107 where adult densities were greater than 85 adults/ha in the Jumentos Cays and Ragged Island surveys (Stoner, Davis, & Booker, 2013). In the Berry Islands survey MPA, observation of one mating pair was recorded along with three egg masses at 19 m depth, but adult density was low at 4.4± 8.5 conch/ha (Table 4). Subadult queen conch were found at depth intervals 0 - 10 m throughout the island chains. High abundance tended to aggregate at depth intervals 0 - 2.5 m and with fluctuating density beyond that depth. The highest mean abundance was in 2011 at Lee Stocking Island, 73,1 ± 18.9 conch/ha and the lowest only 0.6± 1.9 at the West bank of Berry Islands in 2009 (Table 4). The highest abundance in individual transect of subadult conch was observed in the Jumentos Cays and Ragged Island at 155 ± 247 conch/ha within depth intervals 0-2.5 m in 2013; as suspected results showed fluctuation with subadult abundance with decreasing depth (Stoner, Davis, & Booker, 2013). Similar distribution patterns were observed throughout the surveyed area in the central and northern Bahamas (Stoner, Davis, & Booker, 2014; NOAA, 2014).

Juvenile queen conchs were also observed within shallow banks and inlets forming large aggregations located within tidal current pathways (Stoner, 2003; Davis, 2005). Distribution patterns were observed at depth interval 0 - 9 m throughout the central and northern Bahamas (Stoner & Ray , 1996; Stoner, 2003). Studies indicate juvenile aggregation on the Great Bahama Banks occurs within 5 km of coastal inlets associated with tidal flow fields and intermediate densities of *Thalassia testudinum* at approximately 608 to 864 shoots/m^2 in the presence of algal epiphytes and microdetritus (Stoner & Walte, 1990; Stoner & Schwarte, 1994; Stoner, 2003). Density of juvenile conch was recorded at 125 conch/ha at ECLSP Marine Reserve in comparison to 64.9 ± 41.8 conch/ha found at Lee Stocking Island in 1996 (Fig. 4 and Table 4). Lower juvenile densities were recorded in several studies conducted between 2012 and 2016 with values between 4.9 ± 29.3 conch/ha and 15.84 conch/ha (Table 4). Similar studies were performed at two study sites on Lee Stocking Island between 1988 and 1990. At Shark Rock, the highest density in individual transect was 1.28 ± 0.33 m^{-2} at sample station 6; and the highest density of individual was recorded at 1.53 ± 0.42 at Children's Bay Cay sample station 1 (Stoner & Ray, 1996 b).

Table 4: Queen conch density based on surveys performed from 1996 – 2016

Overview of *Lobatus giga* Surveys in The Bahamas 1996-2016								
Location surveyed	Year of survey	Type of Survey	Number of survey lines	Density of “juvenile” (no./ha)	Density of “subadults” (no./ha)	Density of “adults” (no./ha)	Shell length (mm)	Lip thickness (mm)
Exuma Cays, Warderick Wells ECLSP	1996	Combination	39	125	NA	53.6	202 ± 21	24 ± 7
Exuma Cays, Lee Stocking Island (LSI)	1996	Combination	56	64.9 ± 41.8	NA	1.71	188 ± 20	12 ± 6
Berry Islands, SW fishing ground	2009	Combination	73	NA	70.2 ± 140.5	118 ± 282	153 ± 20	15 ± 3
Berry Islands, West bank	2009	Combination	70	NA	0.6 ± 1.9	0.7 ± 1.8	nd	nd
Berry Islands Marine Fishery Reserve	2009	Combination	42	NA	12.4 ± 30.5	4.4 ± 8.5	190 ±30	3 ± 2
Andros Island, East coast	2010	Combination	82	NA	53.8 ± 65.7	3.5 ± 15.2	210 ±42	8 ± 9
Andros Island, Grassy Cay	2010	Combination	58	NA	35.1 ± 60.1	117 ± 162	177 ±27	15 ± 7
Exuma Cays, LSI (banks only)	2011	Combination	70	9	73.1 ± 18.9	5.8 ± 15.2	190 ± 21	9 ± 7
Exuma Cays, ECLSP (banks only)	2011	Combination	52	NA	10.9 ± 4.5	16.6 ± 50.5	200 ± 22	21 ± 10
Eleuthera Island (bank)	2012	Combination	57	13.5	31	10.6	NA	NA
Abaco Island, Sandy Point, (Bight)	2012	Combination	87	15.84	10.1 ± 18.9	6.4 ± 9.6	187 ± 19	6 ± 4
Abaco Island, Mores Island (Bight)	2012	Combination	115	5.3	7.8 ± 20.6	9.8 ± 16.7	198 ± 24	9 ± 5
Jumentos Cays & Ragged Islands	2013	Combination	176	12.34	14.8 ± 49.1	122 ± 138	186 ± 20	19 ± 7
Little Bahama Bank	2014	Combination	215	NA	8.3 ± 17.7	30.1 ± 59.3	205 ± 19	11 ± 7
Eastern Sand Bores	2015	Combination	157	NA	3.9 ± 9.7	52.1 ± 55.6	186 ± 15	20 ± 4
Exuma Cays, Warderick Wells ECLSP	2016	Combination	244	4.9 ± 29.3	6.7 ± 27.3	7.2 ± 24.3	NA	NA

5.3 Spatial analyses of percental surveyed area and queen conch habitat

The total spatial coverage of queen conch surveys was estimated as 3,567 km² (Fig. 8). The total queen conch habitat was estimated as 11,888 km², defined as the combination of the habitat polygons derived from FAO (2016), the habitat polygons provided by The Nature Conservancy-Northern Caribbean Division, and the polygons encompassing the survey areas (Fig. 4, 5, 6 and 7). If these polygons are an accurate representation of the queen conch habitat, the proportion of habitat’s area that has been surveyed at less than once was estimated at 30%.
Based on bathymetry, the extent of shallow waters less than 30 m within The Bahamas was estimated at 109,000 km². Consequently only 3.3% of shallow waters at this depth range were surveyed (Fig. 8). Based on predictive seagrass habitat maps (Wabnitz et al. 2008, FAO 2016) it is evidence that a high proportion of shallow water substratum contains a moderate distribution of seagrass coverage. Wabnitz, et al. estimated that the total coverage of seagrass in The Bahamas was 65.436 km². From examining the maps, it can be safely assumed that approximately 70% of this area corresponds to areas with seagrass with low to intermediate density, corresponding to an area of 45,800 km². Based on these models it was calculated that only 7.8% of moderate seagrass habitats were surveyed (Fig. 9).

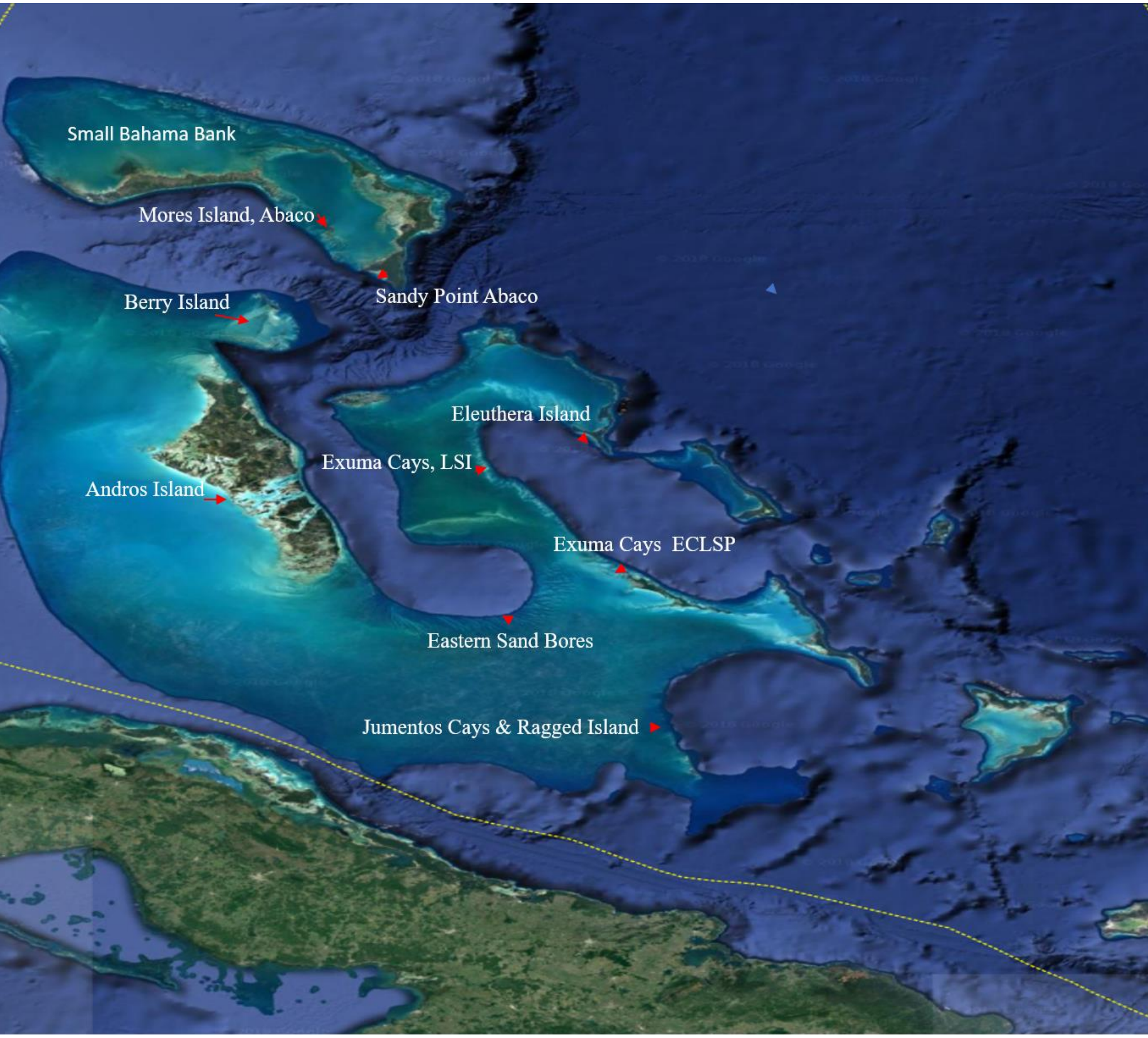

Fig. 4: Label map of survey area in The Bahamas from 1996 – 2016

Fig. 5: Map illustrating queen conch surveyed area from 1996 - 2016. The total spatial coverage of queen conch surveys was estimated as 3,567 km².

Fig. 6: Map of queen conch habitat in The Bahamas obtained from FAO report on “Fisheries and Agriculture in The Bahamas: A Review”.

Fig. 7: Map of queen conch habitats obtained from The Nature Conservancy, Northern Caribbean Division.

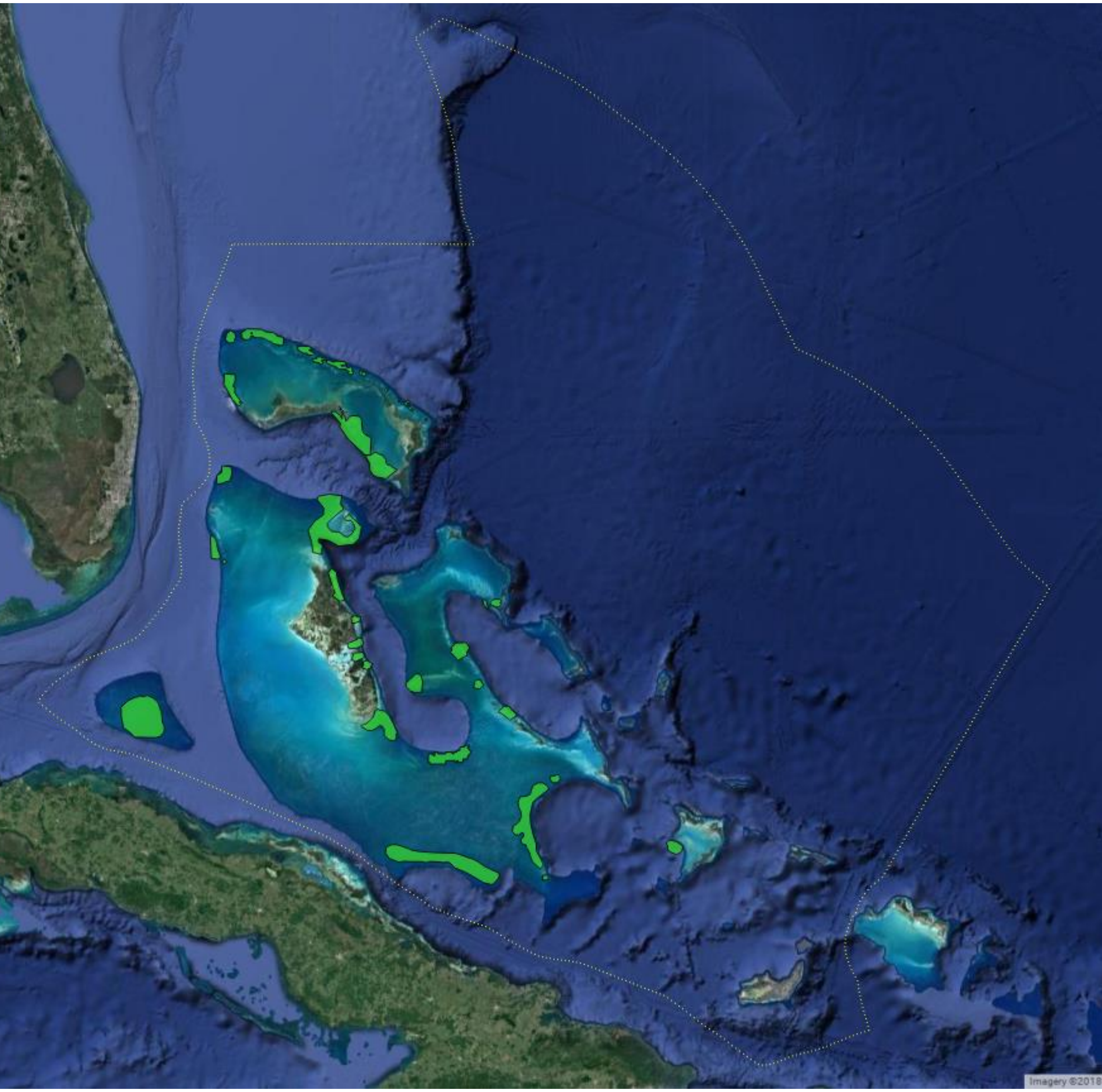

Fig. 8: Map depicting queen conch habitat based on polygon union merged with three data sets. Queen conch habitat was at an approximate size of 11,888 km².

Fig. 9: Predicted seagrass distribution in The Bahamas (Wabnitz et al. 2008). Dark green indicates areas with high seagrass density, while light green indicates areas with low to moderate seagrass density.

5.4 Analysis of decreasing the number of stations within specific surveys

The mean abundance of adult queen conch was estimated to be 5.8 ± 15.2 conch/ha of the two study sites near Lee Stocking Island 2011 research studies (Table 4). The permutation results had on average a much lower adult queen conch median abundance when utilising only 10 – 30 sample stations comparative to the survey mean abundance. There was a high variance in those results, but when 80 stations or more out of 135 were samples, the results were consistent. Subadult size class median was also relatively close to the survey mean abundance when utilising 60 sample stations (Fig. 10). The mean subadult abundance was estimated at 73.1 ± 18.9 conch/ha (Table 4). Juvenile median abundance was relatively close to survey mean abundance at 9 conch/ha when utilising 40 sample stations (Table 4). However, the results also showed a reduction in median abundance value when utilising 50 and 60 sample stations (Fig. 10). The high variance in the generated mean abundance values of adult queen conch when few stations were sampled reflects a patchy distribution in the survey, with few stations of high abundance.

Jumentos Cays and Ragged Island adult queen conch abundance was estimated to be 122 ± 138 conch/ha during 2013 (Table 4). The permutation results had on average a much lower adult queen conch median when utilising only 20 – 40 sample stations comparative to the survey mean abundance. There was rather high variance in those results, but when 80 stations or more out of 176 were samples were considered, the results were consistent (Fig. 11). Also, subadult size class median was relatively close to the survey mean abundance when utilising 80 sample stations (Fig. 11). The mean subadult abundance was estimated at 14.8 ± 49.1 (Table 4). Similar to adults, juvenile queen conch median was relatively close to survey mean abundance when utilising 60 sample stations. However, the results also showed a reduction in median value when utilising 80 sample stations, in which an increase occurred and was relatively close to the survey mean at 12.30 conch/ha when utilising 100 or more sample stations (Table 4).

Mores Island, Abaco 2012 studies permutation results had on average a slightly lower adult queen conch median abundance when utilising only 10 – 60 sample stations comparative to the survey mean abundance. The mean abundance of adult queen conch was estimated to be 9.8 ± 16.7 conch/ha (Table 4). There was decreasing variance in those results, but when 70 sample stations or more out of 115 were samples, the results were consistent (Fig. 12). Similar to adult size class, subadult size class median was relatively close to the survey mean abundance when utilising 70 sample stations, where the results remained constant (Fig. 12). The mean subadult abundance was estimated at 7.8 ± 20.6 conch/ha (Table 4). However, juvenile median abundance was relative close to survey mean abundance at 5.30 conch/ha when utilising 60 sample stations, where the results were consistent (Fig. 12).

At Sandy Point in 2012, the permutation results from adult queen conch had slightly lower median than the survey mean value estimated at 6.4± 9.6 when utilising only 10 – 20 sample stations (Fig. 13). When considering 30 sample stations or more out of 87 sample stations, the results were consistent (Fig. 13). Subsequently, subadult permutation results had lower median values when utilising 10 – 30 sample stations comparative to the survey mean abundance. At 40 sample stations, juvenile median was relatively close to the survey mean of 15.84 conch/ha and remained consistent (Fig. 13 and Table 4).

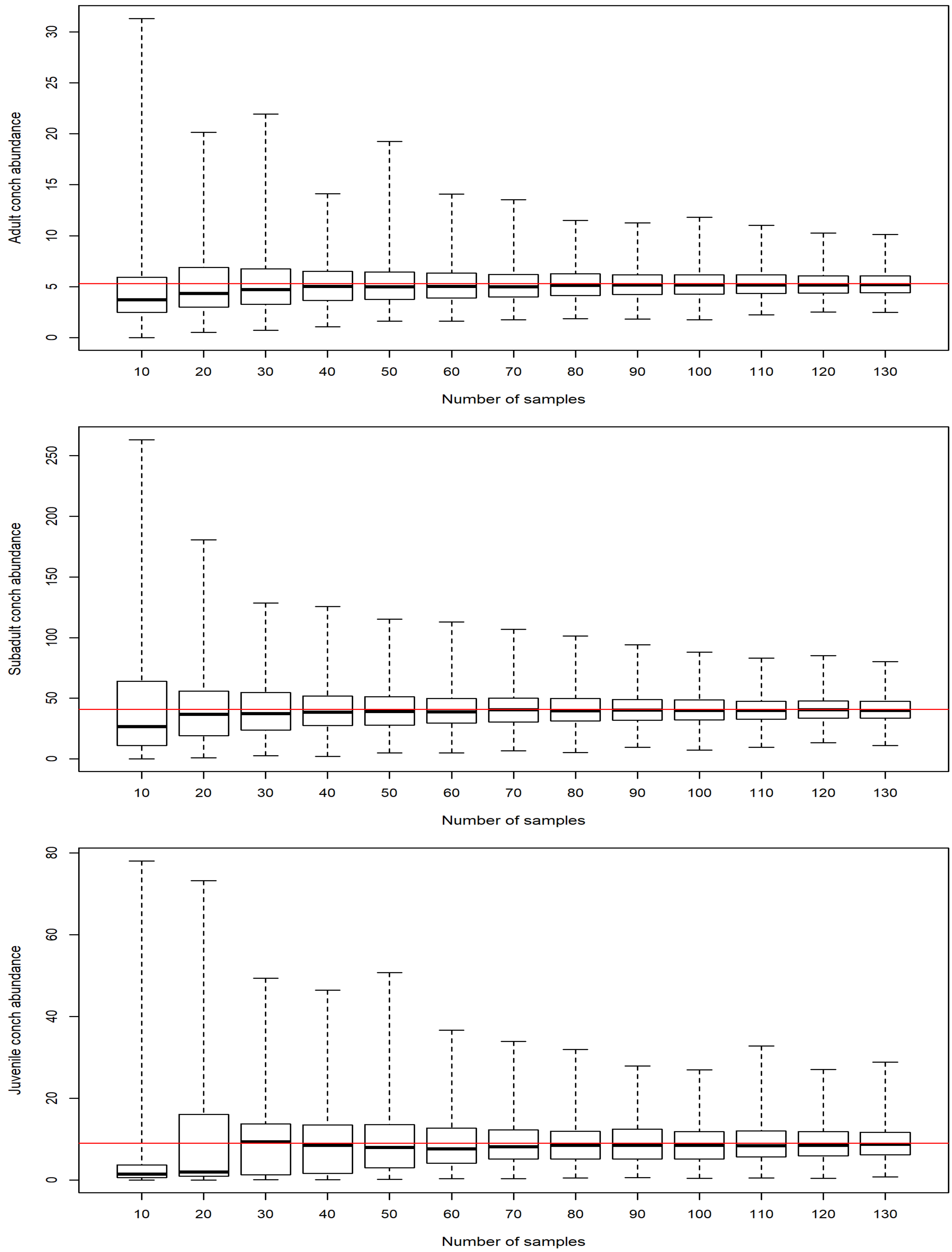

Fig. 10: Boxplot of queen conch mean abundance generated from 2000 randomly sampled intervals from 10 to 130 sample stations between age classes. The data frame comes from the Lee Stocking Island survey of 2011. The average abundance from the actual survey is depicted with the red line, and the total number of stations in the survey was 135. Heavy bars represent median values, boxes represent the 25-75% range, and the broken lines indicate the range of values.

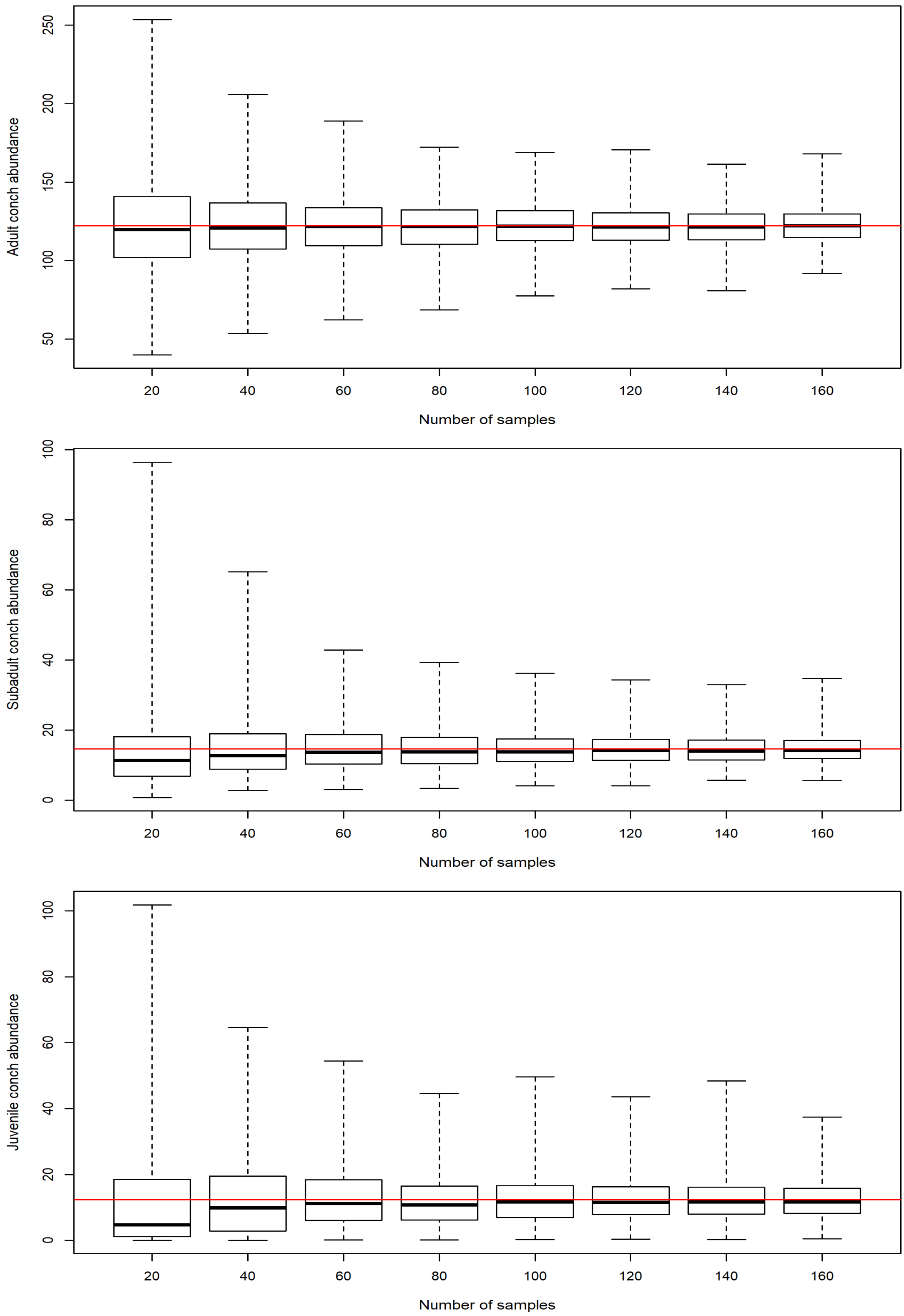

Fig. 11: Boxplot of queen conch mean abundance generated from 2000 randomly sampled intervals from 20 to 160 sample stations. The data frame comes from the Jumentos Cays and Ragged Island 2013. The average abundance from the actual survey is depicted with the red line, and the total number of stations in the survey was 176. Heavy bars represent median values, boxes represent the 25-75% range, and the broken lines indicate the range of values.

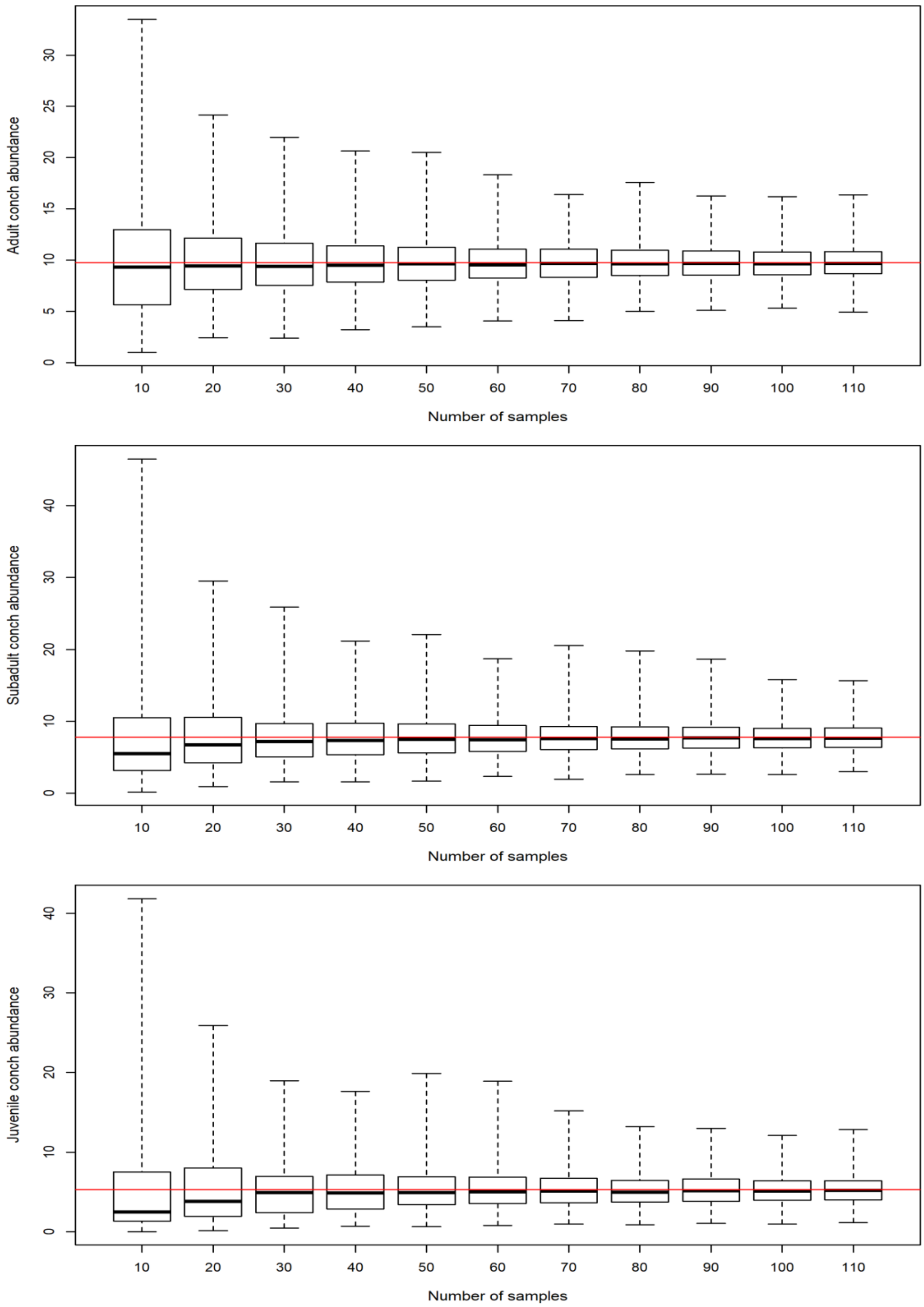

Fig. 12: Boxplot of queen conch mean abundance generated from 2000 randomly sampled intervals from 10 to 110 sample stations. The data frame comes from the Mores Island, Abaco survey of 2012. The average abundance from the actual survey is depicted with the red line, and the total number of stations in the survey was 115. Heavy bars represent median values, boxes represent the 25-75% range, and the broken lines indicate the range of values.

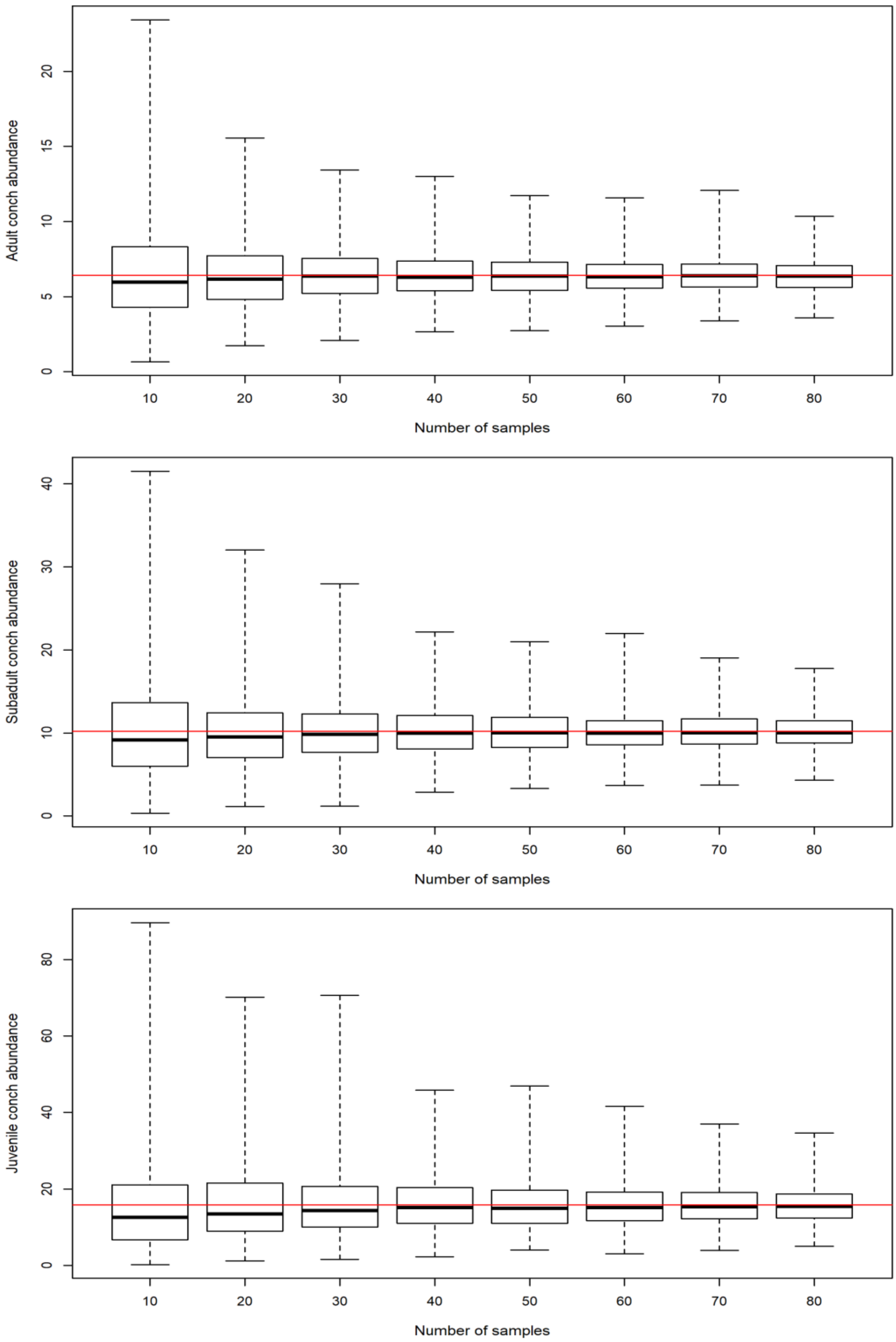

Fig. 13: Boxplot of queen conch mean abundance generated from 2000 randomly sampled intervals from 10 to 80 sample stations. The data frame comes from the Sandy Point, Abaco survey of 2012. The average abundance from the actual survey is depicted with the red line, and the total number of stations in the survey was 87. Heavy bars represent median values, boxes represent the 25-75% range, and the broken lines indicate the range of values.

6 DISCUSSION

Speculative suggestions indicate decline of queen conch stock is prevalent in the Caribbean as overfishing of adults and sexually immature juveniles tends to be one of the major contributing factors along with an increase in fishing efforts (FAO, 2017). Like many species, density of sexually mature adult queen conch is a critical factor in the sustainability of the population (Stoner A., 1997). (McCarthy, 2008). Stoner (1997) suggested a threshold of 50 and 100 conch/ha is required for males and females to detect one another and mate (Stoner, Mueller, Brown-Peterson, Davis, & Brooker, 2012 c), (Stoner A., 1997).

Queen conch stock assessment in Sandy Point and Mores Island, Abaco was indicative of reproduction capacity well below critical threshold in which predicted population was approaching collapse (Stoner, Davis, & Booker, 2012 d). Subsequently, previous surveys also revealed adult density was below reproduction capacity threshold with few adults possessing a flared shell lip thickness greater than ≥ 15 mm. Similar, the British Virgin Islands 1993 and 2003 surveys revealed a collapse of reproductive capacity that have dire implications on recruitment (NOAA, 2014).

The true viable status of The Bahamas queen conch fishery has still not been established as research efforts were focused on locations within the north and central regions of the country. Due to the lack of information regarding the status of the southern stock, efforts should be made to encourage and promote forthcoming studies to be directed to this area of the archipelago. As permutation analysis suggested sampling effort and cost of surveys can be slightly reduced. In reducing the sampling stations, expenditure to conduct expensive surveys can be more feasible and sampling efforts and resources can be allocated towards surveying areas that have not been surveyed.

Larval transport in the Bahamas is considered to be interdependent and retention relies on local recirculation patterns (Stoner, Davis, & Booker, 2013). In the Exuma Cays, it was suggested that two subpopulations of juvenile recruitment were dependent on deep water spawning populations from the Exuma Sound and the ECLSP shallow water populations (Stoner A, Davis M, Booker C, 2011). Therefore, connectivity between fecundity of deep and shallow water spawning stock, larval transport and juvenile recruitment should be considered when establishing MPA.

Studies indicate moderate turtle seagrass (*Thalassia testudinum*) meadows defined with algal epiphytes and microdetritus were shown to influence active habitat preference of juvenile queen conch (Stoner & Walte, 1990). As an elucidating mechanism of juvenile distribution information on seagrass distribution should be useful. However, quantitative analysis of seagrass distribution within The Bahamas is very limited. As mentioned in the spatial analyses section, a high proportion of shallow water substratum contains a moderate distribution of seagrass coverage in which only 6.6% of moderate seagrass habitats were surveyed (Wabnitz, Andrefouet, Torres-Pulliza, Muller-Karger, & Kramer, 2008). A comprehensive study of seagrass distribution can inform where future surveys can be conducted and influence prediction of high density of queen conch distribution regarding predictive queen conch habitat models.

Like in many other Caribbean countries, The Bahamas have imposed a harvest size requirement; however, the ambiguity of an imprecise description of a legally harvestable queen conch results in the harvesting of sexually immature queen conch. Studies have shown that shell lip thickness should be the criterion for legal harvest of queen conch instead of physical features, which correlates with histological evaluation of ovaries and testes maturity (Stoner, Mueller, Brown-Peterson, Davis, & Brooker, 2012 c). In addition, studies have shown sexual maturity for female queen conch ranges from 17.5 – 26.2 mm and males 13.0 – 24.0 mm throughout the Caribbean. Therefore, it has been suggested that "… a minimum LT of no less than 15 mm should be established for legal harvest throughout the Caribbean region." (Stoner, Mueller, Brown-Peterson, Davis, & Brooker, 2012 c).

Unlike its neighbouring country Cuba, The Bahamas does not have catch quota but does have an export quota (NOAA, 2014). Cuba queen conch fisheries is governed by catch quota system that is dictated by abundance surveys within each of its fishing zones. Fishing zones are subject to closure if regulatory requirements are not complied with (NOAA, 2014).

In an attempt to increase queen conch abundance and conserve stock numerous management measures have been utilised throughout the Caribbean. Countries such as Jamaica, Cuba, The Cayman Islands along with The Bahamas have prohibited the use of SCUBA in attempt to conserve deep water spawning stock (NOAA, 2014). However, unlike Cuba and the Cayman Island compressors are utilised via special license to target queen conch and spiny lobsters in The Bahamas, which is counteractive in protecting deep water stock (FAO, 2016). Management measures such as closed season has also been implemented in Belize, Cuba, Dominican Republic, The Cayman Islands, and Jamaica. Queen conch closed season in Jamaica only applies to industrial fishers and not to recreational; also, industrial fishing is restricted to a depth up to 30 m. In addition, Jamaica only allows 3 conchs per person per day in their recreational fishery (NOAA, 2014).

Due to the decrease in queen conch landing in the past several years alongside undeniable surveys results, The Bahamas must attempt to improve management efforts to conserve and ensure the sustainability of this fishery. In addition, sporadic sequence of surveys does not allow comparative analysis of temporal changes of the stock or impact from natural stressors such as category 4 hurricanes Joaquin and Mathew that occurred in 2015 and 2016. Understanding the status of the queen conch stock in The Bahamas will not only provide an insight into the viability of the stock but will also improve management efforts.

7 MANAGEMENT RECOMMENDATION

The following management recommendation is an attempt to increase queen conch abundance to sustainable level for the harvesting of its resources and cushion the cost-effective surveys in The Bahamas:

1. Update the seagrass maps Wabnitz et al. (2008) utilising state-of-the-art remote sensing imagery, for example using high-resolution imagery from the Sentinel satellites (European Space Agency). Sentinel data is available at low or no cost, and at a high spatial resolution (5-10 mts). An analysis and classification of satellite imagery will provide a map of habitats in the shallow areas of the Bahamas, including not only seagrass beds but potentially other bottom types.

2. Develop a habitat suitability model (HSM) for queen conch in The Bahamas. Habitat suitability models predict the distribution of species based on environmental variables known to influence their distribution. An HSM will use existing data on queen conch distribution and abundance, the updated habitat map developed above, bathymetry, and

other available data. HSM will produce a map showing which areas are more suitable for queen conch, which will aid in the development of a survey design.

2.1. Collaborative efforts should include DMR, The Bahamas National Geographic Information Systems (BNGIS), Bahamas Customs Department (BCD), The Royal Bahamas Police Force (RBPF) and The Royal Bahamas Defence Force (RBDF). This will also aid in reducing cost towards conducting surveys.

3. Increase budget allocation to allow fishery-independent surveys that do not depend solely on contributions from NGOs.
   3.1. Carry out fishery-independent quantified surveys on queen conch abundance within known queen habitat and potential habitats identified from the HSM.
      3.1.1. Temporal sequence to conduct surveys should be established based on abundance surveys' findings.
         3.1.1.1. Establish a survey plan in which the major fishing grounds are covered every 2-4 years in order to generate data time series that will allow to track the dynamics of the stock.
   3.2. Utilise the aforementioned government department resources to decrease overhead expenditure.

4. Explore survey methods based Boman et al., 2016 underwater video methods to supplement surveys using divers. Low-cost underwater image systems have recently become available, which can provide high-resolution video and can be deployed from small vessels. Underwater video systems do not provide information on biological parameters, but allow to estimate queen conch density. A survey using underwater video stations for density estimation combined with dive stations for biological parameters may be able to cover a wider area than the current surveys.

5. Implement a closed season for industrial/commercial fisheries at heavily fished locations that result in unsustainable stocks based on abundance surveys results.
      5.1.1. Coincide close season with regional closed seasons suggested by the Regional Queen Conch Fisheries Management and Conservation Plan (FAO, 2017).

6. Amend regulations to reflect landing of queen conch with shell possessing a shell lip thickness no less than 15mm, which has been scientifically proven as the average size of sexual maturity within the Caribbean. This will discourage and eventually eliminate illegal harvesting of species.

7. Develop monthly systematic inspection to increase enforcement management efforts with regards to commercially governed species.
   7.1. Collaborative efforts should include DMR, BCD, RBPF and RBDF.

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