STATUS AND TRENDS OF BERMUDA REEFS & FISHES: 2016 REPORT CARD

DIAGNOSTIC MONITORING OF BERMUDA'S CORAL REEF ECOSYSTEM WITH THE GCRMN-CARIBBEAN SCIENTIFIC MONITORING METHODS

THADDEUS J. T. MURDOCH, PH.D.

RESEARCH ASSOCIATES:
TAYLOR GORHAM, M.SC.; SARAH GOSLING, B.SC.;
JORGE SANCHEZ, M.SC.; CONOR MCLAUGHLIN,
STRUAN R. SMITH, PH.D.

www.BermudaBREAM.org

This report should be cited as:
Murdoch TJT (2018) Status and Trends of Bermuda Reefs and Fishes: 2016 Report Card. BREAM: Bermuda Reef Ecosystem Analysis and Monitoring Programme Report, Bermuda Zoological Society, Flatt's. Bermuda. Bermuda Biodiversity Project #266.

Raw data and statistical analyses can be viewed at: www.bermudaBREAM.org

Released: March 14, 2018

Contact:
Thaddeus Murdoch, Ph.D.
Chief Scientist
Bermuda Reef Ecosystem Analysis and Monitoring (B.R.E.A.M.) Programme
P.O. Box 513, Warwick, WKBX, BERMUDA
http://www.bermudabream.org
Tel: +441.505.8424; email:tmurdoch@bermudabream.org

Field Research Associates:
Sarah Gosling, B.Sc.; Jorge Sanchez, B.Sc., Conor McLaughlin

Laboratory Research Associate:
Taylor Gorham, M.Sc.

Editor: Struan R. Smith, Ph.D.

Contributions: TM designed techniques and equipment, TM, TG, SG, JS performed surveys or video image analysis, TM, TG, SG, did data processing, TM, TG analysed statistical data, SRS provided editorship, and TM wrote the report.

Support provided by: Bermuda Zoological Society; XL Catlin – End to End Marine Research Grant; Murdoch Marine Ltd.; The Gosling Family.

This is Contribution #266, Bermuda Biodiversity Project (BBP), Bermuda Aquarium, Museum and Zoo, Department of Environment & Natural Resources.

Contents

Figures

Tables

Executive Summary

Synopsis

Coral reefs provide vital protection of Bermuda's shores from storms, and attract the people who support Bermuda's thriving tourism and international business economies. This report presents the findings of the second year of comprehensive monitoring surveys of fish stocks and coral reef condition across the entire Bermuda Platform, since 2010, at 39 sites distributed across 4 zones: Inner Lagoon, Outer Lagoon, Rim Reef and 10-m Forereef, by the Bermuda Reef Ecosystem Analysis and Monitoring (BREAM) Long-term Ecological Monitoring (LTEM) programme. We used the newly developed IUCN GCRMN Caribbean reef monitoring protocol, and international standard for fish and reef monitoring. The GCRMN protocol focuses on various kinds of information about local reefs and reef fish populations:

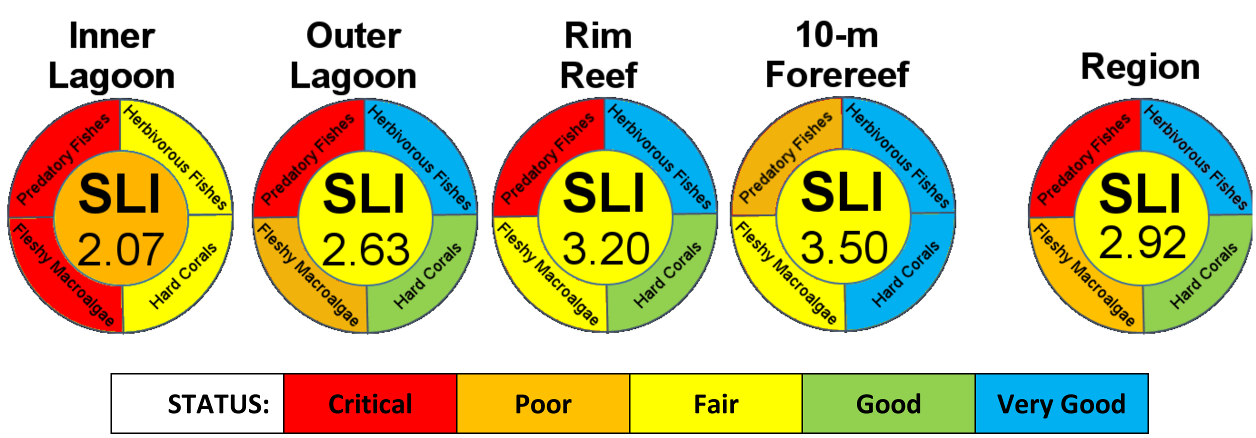
1. Fish abundance and biomass of commercially-exploited predatory fishes, plant-eating (herbivorous) fishes and other fish groups.
2. Benthic assemblage structure: cover of hard corals, fleshy macroalgae and other sessile reef organisms.
3. Abundance of juvenile hard corals and coral diseases that influence the future condition of reef corals.
4. Abundance of mobile meso-faunal invertebrates such as lobsters, plant-eating sea urchins and other reef animals.

In this report, we utilize a four-component index of reef condition, called the Sea Life Index (SLI), which we introduced in 2016 in the report on the "Baseline Status of Bermuda's Reefs and Fishes" (Murdoch and Murdoch 2016). We compared our baseline data from the same 39 sites to new data collected in the summers of 2015 and 2016, using a team of trained scientific divers. Each reef was surveyed with replication using standardized scientific methods. The results of the 2016 monitoring assessment are summarized below, ranked by the strength of their potential impact.

Main Conclusion

The Sea Life Index (SLI) for the Bermuda reef ecosystem as a whole region, shown below, remains **Fair**.

The SLI for each reef zone are shown below. SLI, and each component factor, improves as the distance from shore of each zone increases. This implies that human factors are in part driving reef condition, and, since policy and resource management is focussed on human behaviours, that reef condition can be improved though management and conservation in ways that would improve reef health.



Positive Results

Factor	Status	Regional Trend	Action
Sea Life Index	Fair	↔	**YES**
Herbivorous Fishes – Biomass	Very Good	↑	**NO**
Invasive Lionfish - Abundance	Very Good	↔	**NO**
Hard Corals – Cover	Good	↔	**NO**
Crustose Coralline Algae, Turfs, Bare Rock (CTB) – Cover	Good	↔	**NO**
Juvenile Hard Corals	Fair	↔	**NO**

- Overall, the SLI is Fair, but Stable. This indicates that reef and fish health across the four zones of the region should be improved, through directed marine resource management, while the ecosystem still retains the natural capacity for improvement.
- Herbivorous Fishes were found to be in Very Good (very abundant) and increasing condition across the region, and were seen to be in higher densities in the Outer Lagoon, Rim and 10-m Forereef zones in 2016 relative to 2015 and the Baseline surveys. Bermuda's two decades of protection of parrotfishes, following the 1990 fish pot ban, seems to be working. Surgeonfishes protection should also be considered, since these unregulated fish species are large and abundant enough to be the target of harvest.
- Invasive Lionfish were not observed in any of the 37 sites in 2016. This Very Good (absent) status contrasts sharply with most Caribbean countries. For example, lionfish were observed in over 25% of reef sites across the Mesoamerican region when using the same survey methods (Healthy Reefs Initiative 2017). The rarity of lionfish in Bermuda. specifically in shallow water reefs where juvenile parrotfish have their strongest impact to reef health, is very positive news. Eddy et al (2016) determined that juvenile parrotfishes are not a major component of the diet of Bermuda lionfish. Additional analysis of the BREAM LTEM data of juvenile parrotfish abundance may further illustrate the lack of ecological impact by lionfish across the shallow reef platform.
- Hard Corals remain in Good (high) cover in 2016, with little change from 2015 or the Baseline surveys. Hard Corals rely on the other reef factors to remain resilient to change.
- CTB was generally in Good (high) cover, but did decline on the 10-m Forereef zone. However, since Hard Corals were observed to increase in 2016 in the same zone, the reduction in CTB may be a natural consequence of this otherwise beneficial change to the 10-m Forereef habitat.
- Juvenile Corals were Fair (moderately abundant) and unchanging over the survey periods. Positive news.

Negative Results

Factor	Status	Regional Trend	Action
Predatory Fishes – Biomass	Critical	↔	YES
Territorial Damselfishes – Abundance	Poor	↑↑↑	YES
Herbivorous Snails & Hermit Crabs – Abundance	Critical	↓↓↓	YES
Herbivorous Sea Urchins – Abundance	Critical	↔	YES
Coral Diseases & Bleaching – Prevalence	Poor	↔	YES
Fleshy Macroalgae – Cover	Poor	↔	YES

- Predatory Fishes remain in Critical (very low) condition across the platform, due to overfishing. These fishes play a vital role in maintaining the condition of the ecology of Bermuda's coral reefs. Management actions to reduce the catch and increase the protection of large and mid-sized groupers, snappers and sharks, should be a national priority.
- Territorial Damselfish are in Poor (high) abundance in 2016, and have increased substantially and significantly since both the Baseline surveys and 2015. Their biomass has doubled in Lagoon since Baseline. This needs to be addressed by improving stocks of snappers and mid-sized groupers (i.e. meso-predatory fishes) on lagoonal reefs. We also recommend that the relationship between territorial damselfishes, the coral they harm, and the meso-predatory fishes that keep territorial damselfishes in check be assessed further. It may also be useful to close fishing on 2 to 4 lagoonal patch reefs for 2-3 years, to see if a reduction in human fishing pressure allows the recovery of meso-predatory fishes and a subsequent reduction in the abundance of coral-damaging territorial damselfishes.
- Microherbivorous Snails and Hermit Crabs were in Critical (low) condition, declining substantially in 2015 and more so in 2016 relative to Baseline surveys. The microherbivores maintain crustose-coralline algae habitat, which is critical for the recruitment of new hard corals. An increase in predation or in mortality caused by disease or pollution may have caused the decline. Focused surveys of the important Microherbivore group should be done as soon as possible across the Rim and 10-m Forereef zones.
- Herbivorous Sea Urchins were observed to remain in Critical (very low) condition in 2016, with an additional decline in abundance on the 10-m Forereef. It may be that predation has increased on this now rare group of sea urchins, and we recommend adding sea urchin predators such as triggerfishes to the fish assessments in future surveys. In addition, echinoderms including sea urchins often are very patchily distributed on the scales of 100-m to 10-km. Large-scale drift surveys across the Rim and 10-m Forereef zones, which document the location and extent of high-density patches of sea urchins are advised.
- Coral Disease was seen to be Poor (high) in both the Rim and 10-m Forereef, with substantial increases in coral disease in the Rim reef zone. It is recommended that further study on the dynamics and changes in coral disease in these zones be carried out as soon as possible.
- Fleshy Macroalgae remains in Poor (high) condition in 2016, and was seen to be significantly higher in the Inner Lagoon zone compared to Baseline and 2015. Inner Lagoonal reefs are in particularly poor condition. Further research into the ecology of these nearshore lagoonal reefs is required to determine the specific causes of damage and how to resolve them.

Recommendations for Action

The following recommendations are based on the condition of each factor (above) assessed in the project:

1. The restoration of grouper and snapper stocks, their enhanced protection, and improved management of all predatory fishes and sharks, to prevent future declines should be a national priority.
2. Determine whether macroalgae continues to increase in cover within the Inner Lagoon, and the causes for its increase.
3. Further study of the dynamics and changes in coral disease in Bermuda should be carried out as soon as possible.
4. The relationship between territorial damselfishes, the coral they harm, and the meso-predators that keep territorial damselfishes in check be assessed further. It may also be useful to close fishing on a very small number of lagoonal patch reefs for 2 to 4 years, to see if a reduction in human fishing pressure allows the recovery of meso-predatory fishes, and a subsequent reduction in the abundance of coral-damaging territorial damselfishes.
5. Add sea urchin predators to the fish assessments in future surveys. In addition, echinoderms including sea urchins often are very patchily distributed on the scales of 100-m to 10-km. Large-scale drift surveys across the Rim and 10-m Forereef zones, which document the location and extent of high-density patches of sea urchins is advised.
6. Focused follow-up surveys of the important Microherbivore group be undertaken as soon as possible across the Rim and 10-m Forereef zones.

Additional Recommended Management Actions or Changes to Policy

In addition to the recommendations above, we recommend that the following management strategies are implemented:

A: Support the Monitoring of Coral Reefs and Fishes

This report represents Bermuda's national assessment of the condition of our coral reefs and fishes, as part of the international Global Coral Reef Monitoring Network assessment of reefs across the Caribbean. The project was partially funded by two non-government grants by the Bermuda Zoological Society and the XL-Catlin End-to-End Marine Research Grant. However, the project was only possible through the donation of a substantial amount of time and resources by the BREAM programme and the Murdoch and Gosling families.

The Bermuda Government has committed to the protection and management of Bermuda's coral reefs and marine resources through the creation of policy and via its commitments to several local and international conventions, including the Bermuda Biodiversity Action Plan, the Convention on Biological Diversity, the Convention of Migratory Species, and the Convention of Wetlands of International Importance.

As such, future monitoring of the status and condition of fishes and coral reefs should be supported and funded, at least to some extent, by the Bermuda Government.

B. Support the Development of an Environmental Decision-Making Protocol

Changes in each factor assessed within this BREAM LTEM project should function as indicators that are directly linked to specific management and conservation actions. It would be preferable that Government and Non-Government stakeholders assisted in the development of an Environmental Decision-Making Protocol (EDMP) that defined what actions were available and appropriate responses to changes in the abundance or distribution or status of each of the critical reef health indicators we assess in this report. The development of an EDMP would accelerate the rate at which resource managers and conservationist could respond to problematic changes in the condition of our reefs or fish stocks, and would provide nationally accepted goals for marine environmental health and resilience.

C: Restoration of Predatory Fish Populations

1. Enhance the stocks of groupers by introducing a limited ban on the capture and sale of Black groupers during their spawning period (as we currently do with spiny lobster), based on evidence of the timing of their maximum aggregation at spawning sites.
2. Consider bag and size limits on grey snappers, schoolmaster snappers, yellowtail snappers, graysbys and coneys.
3. Expand our knowledge of juvenile predatory fish habitats, which are generally within the lagoon (patch reefs), along the shore (nearshore), and within enclosed bays (inshore). Many species of offshore reef fish, including predatory fish species, start life by settling as juvenile fish to coastal habitats, only to move offshore as they mature.
4. Reduce coastal development and pollution impacts to the marine environment, as many juvenile reef fishes are found the inshore and nearshore waters first before they move to outer reef areas.
5. Design coastal structures such as docks and breakwaters with rough surfaces or attachments, which mimic natural habitat, so that they provide additional habitat for juvenile and adult fishes.
6. Restore coastal mangroves, rocky intertidal and seagrass habitat, which all has declined substantially in the past 75 years.

D. Expand Marine Spatial Protected Areas

Protected areas act as a marine resource “banks” and provide “interest” in the form of continuously available fishes for commercial and recreational harvest, through the spill-over effect, and enhanced reproductive output. We recommend the expansion in the distribution of protected areas that span the reef platform from inshore bays, along lagoonal chains of reefs, out to the forereef. These areas are juvenile habitats that are current threatened due to a lack of smaller predatory fishes and high damselfish densities. Networks of protected reefs allow fish to transition from zone to zone throughout their life cycle, by providing protected paths from nearshore habitats to the lagoon, rim and forereef.

E. Expand the Fishing License Programme

Recently the Fishing License programme was expanded to include recreational spear fishers. We recommend that all recreational fishers require a licence. This would include both those fishing from the shore and those using marine craft. Access to fishing activity should not be financially onerous to those with low income, however. No-cost licences to locals who use hand lines within their parish of residence could be provided so that the financially challenged retain access to fishing activities.

F. Recommendations for Environmental Organizations

Many of the recommended actions within this report are also within the range of issues addressed by local environmental organizations. We hope that these recommendations are adopted by local stakeholders. We offer our services in providing the members of local non-government organizations with lectures and information that supports the sharing of information on how to better manage and improve the condition of Bermuda’s coral reefs.

Project Goal: to guide effective marine resource management and biodiversity conservation, through the focused monitoring of key critical coral reef and fisheries attributes across the Bermuda Platform in a statistically-rigorous manner.

Introduction

Coral reefs across the Western Atlantic provide vital goods and services to the islands and countries that support them. However, for the past 40 years, coral reefs and reef-based fisheries have been in decline (Jackson et al 2014). Bermuda's coral reefs are no exception.

Threats from local and global sources are killing reef-building hard corals, promoting the growth of fleshy macroalgae (marine plants), spreading marine diseases, and allowing exotic species to invade in high numbers (Wilkinson 1999, Harborne et al 2016). To combat the demise of Western Atlantic Reefs, the Caribbean node of the Global Coral Reef Monitoring Network (GCRMN.org) has revived a regional monitoring effort originally started in the 1990s. GCRMN teams have been formed across the Caribbean and Western North Atlantic, with the goal of providing resource managers and policy makers with accurate information on the status and trends of critical biological indicators of reef and fisheries condition. The Bermuda Reef Ecosystem Analysis and Monitoring (BREAM) programme team was invited to take part in the development and initiation of the GCRMN monitoring endeavour in 2014, and this report represents the second year of Bermuda's contribution to this important multi-national effort.

Bermuda's coral reefs provide a host of vital ecosystem services that protect our island and enhance the quality of life for Bermudians (Smith et al 2013; van Beukering et al 2015). Healthy corals on reefs actively grow new reef structure and can restore themselves if damaged by storms or human impacts. The physical structure of the reefs protects our shores and coastal infrastructure from storm damage and coastal erosion, and provides habitat for a huge variety of plants and animals. Parrotfishes and other herbivores keep macroalgae from overgrowing corals. Predatory fish keep prey species populations healthy, provide food and sport to fishermen and add excitement to snorkelling and diving activity.

Since 2002, the BREAM programme mapped at a high level of accuracy all reefs and other marine habitats into a geographic information system (GIS) and database. We subsequently assessed over 50 seagrass sites and over 200 coral reef sites across the entire Bermuda platform, so that we may build spatial models of the distribution of all hard corals, over 100 species of fish, as well as a long list of other organisms and environmental factors such as coral disease (see www.bermudabream.org for reports and online data).

In 2015, the BREAM programme initiated the focused, hypothesis-driven reef and fish monitoring effort that assessed the ecological condition of the entire Bermuda reef platform across the lagoon and down the forereef to 10-m (30ft) depth at 39 sites. We are utilizing the GCRMN monitoring protocol reference (GCRMN 2016). The GCRMN protocol focuses on five kinds of information about local reefs and fisheries:

1. Fish abundance and biomass of commercially-exploited predatory fishes, algae-eating (herbivorous) fishes and other fish groups.
2. Benthic assemblage structure: cover of hard corals, fleshy macroalgae and other sessile reef organisms.
3. The abundance of juvenile hard corals and the prevalence of coral diseases that affect the future condition of reef corals.
4. The abundance of mobile meso-faunal invertebrates such as lobsters, plant-eating sea urchins and other reef animals.
5. Water quality, as determined by simply measuring water clarity at a minimum.

In this report, we determine the status of the reef system by assessing several different factors, including a four-component index of reef condition, called the Sea Life Index (SLI), which we introduced in a 2016 report on the assessment of the baseline status of Bermuda's reefs and fishes (Murdoch and Murdoch 2016). The Sea Life Index is modelled from the Reef Health Index developed by McField and Kramer (2007), which is now utilized by many of the GCRMN monitoring collective, in places that include the Mesoamerican countries of Belize, Guatemala, Honduras and Mexico (www.healthyreefs.org), as well as Dominica, Grenada, St. Vincent and the Grenadines, and St. Kitts and Nevis in the Eastern Caribbean (http://caribnode.org). The GCRMN parameters and the Sea Life Index values in this study were compared to the baseline BREAM dataset collected from 178 coral reefs from 2004 through 2010 (Murdoch and Murdoch 2016) and the 2015 long-term monitoring data (Murdoch 2017). Long-term changes to parameters either indicate improvements or degradation of overall reef condition, following Table 1, below.

We also assessed seven other factors that indicate reef condition. These seven factors are:

1. Juvenile Hard corals
2. Coral Diseases & Bleaching
3. Territorial Damselfishes
4. Herbivorous Sea Urchins
5. Herbivorous Snails & Hermit Crabs
6. Crustose Coralline Algae, Turfs, Bare Rock (CTB)
7. Invasive Lionfishes

The manner in which each of the twelve factors interact with each other is illustrated in Fig. 1. Both the relative amount and the long-term trend in the change of each factor can impact overall reef condition in the long term. Factors illustrated with blue boxes contribute beneficially to overall reef condition, while factors in orange boxes negatively impact overall reef condition. The poor condition or a high rate of decline can indicate that the condition of the Bermuda reefs will be affected in the future, by causing a domino effect that may ultimately cause hard corals to decline in cover. Secondary impacts are not illustrated in Fig. 1, but also play an important role in overall reef health. An example of a secondary relationship that is not illustrated in Fig. 1 is that between Hard Coral cover and Herbivorous Fishes biomass. When Hard Coral cover is low, the recruitment of Herbivorous Fishes is impaired, resulting in a feedback loop that ultimately drives both Hard Coral cover and Herbivorous Fishes abundance down while also increasing the percent cover of harmful Fleshy Macroalgae (McManus and Polsenberg 2004).

In order to guide management and biodiversity conservation, each ecological factor is measured and compared to internationally accepted thresholds that indicate the status of each factor. If a factor is found to be in poor condition or to be in decline through time, we make recommendations regarding how changes in enforcement, management or policy may lead to improvements in that factor in the future.

Table 1. The twelve fundamental coral reef parameters assessed in 2016 that are the focus of this report. Arrows indicate possible long-term trends for each factor. Factors in blue contribute positively to reef condition by increasing in value, while orange factors impact reef condition negatively when increasing in value through time.

	Factor	Positive Trend	Negative Trend
1	Sea Life Index	↑	↓
2	Predatory Fishes	↑	↓
3	Herbivorous Fishes	↑	↓
4	Hard Corals	↑	↓
5	Fleshy Macroalgae	↓	↑
6	Juvenile Hard Corals	↑	↓
7	Coral Diseases & Bleaching	↓	↑
8	Territorial Damselfishes	↓	↑
9	Herbivorous Sea Urchins	↑	↓
10	Herbivorous Snails & Hermit Crabs	↑	↓
11	Crustose Coralline Algae, Turfs, Bare Rock (CTB)	↑	↓
12	Invasive Lionfishes	↓	↑

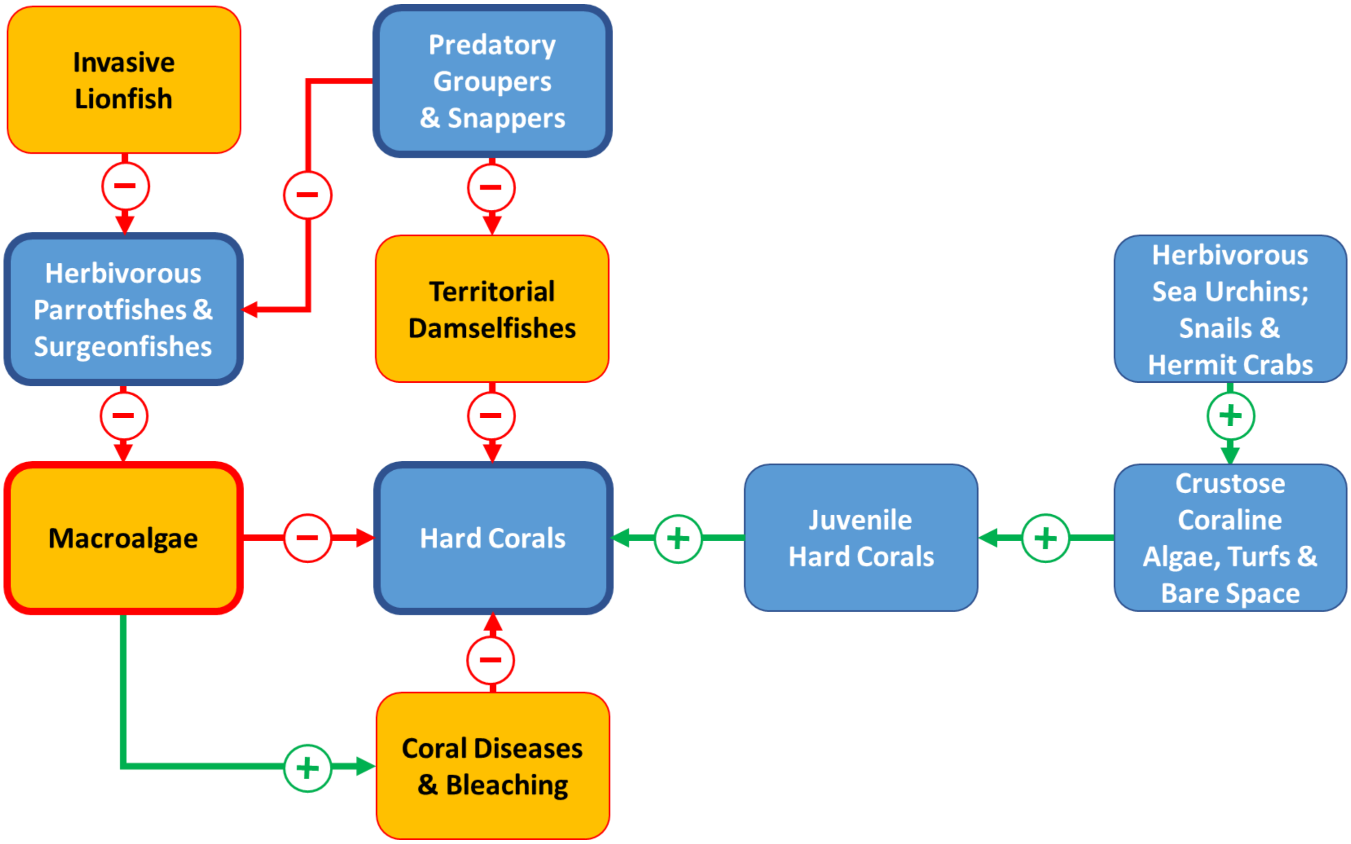


Fig. 1. A diagram of the web of interactions between the 10 biotic parameters that are monitored in the project. Positive (+) interactions are linked with green arrows. Negative interactions (-) are linked with red arrows. Orange parameters have a negative impact on overall reef condition when at higher levels. Blue parameters have a positive impact on reef condition when at higher levels. Parameters inside thick-walled boxes represent the four components of the Sea Life Index (the tenth parameter).

Methodology

In the summer of 2016, we sampled 37 sites spread across the Bermuda Reef Platform in a pattern that evenly covered the broad expanse of reef zones. The locations of the 37 sites and their zonal designations are mapped in Fig 2. Two sites in the inner lagoon were not surveyed due to time constraints, but were assessed in 2015 and in the Baseline assessments by BREAM. We utilized a version of the new GCRMN Caribbean coral reef monitoring protocol (http://www.car-spaw-rac.org/?The-GCRMN-Caribbean-guidelines, 639) to assess all reefs and fishes. We adjusted the methodology to include marine species unique or relevant to Bermuda. The methodology we employed is described below.

Transects

Five transects, each measuring 30-m in length, were assessed for both fishes and the placement of photographic quadrats to record attached corals, algae and other attached reef organisms (the benthic sessile community). Transects were placed haphazardly on patch reefs, and in a landward-to-seaward direction on rim and forereef sites. Transects were positioned 5- to 10-m apart, and placed over the tops of hard reef substrate, avoiding large sand or rubble covered areas.

Fishes and Sea Urchins

In the fish assessment, a diver counted all mobile fish present, recording each fish in size classes of 10-cm increments, of the species listed in Appendix 3, within a 30-m long by 4-m wide belt transect. The survey area was centred over the transect line and encompassed a 2-m width on either side of the transect, and extended up 2-m off the reef. Survey time was limited to 6 minutes per transect. Care was taken to include territorial damselfish, smaller benthic fishes, sea urchins and lionfish that may be present in cavities below the upper surface of the reef. Many groups of fishes were excluded from the surveys, e.g. angelfishes, grunts, wrasses, trunkfishes, to maximize survey quality for the primary species of concern. Data were recorded onto waterproof paper using a standard survey sheet (Appendix 3), and transcribed to a database once back in the laboratory.

Benthic Quadrats

Photographs of benthic quadrats (i.e. photo-quadrats) were taken along the same five transects as the fish surveys. Photo-quadrats were taken with a 12-megapixel underwater camera equipped with a scale bar that set the distance between the reef surface and the camera lens so that each photographic frame encompassed an area of the seabed measuring 90-cm in the x-dimension by 65-cm in the y-dimension (i.e photograph resolution of 45 pixels per cm of real space). 80 benthic photographs were collected at each site, by taking 16 photographs, spaced 2-m apart (i.e. at the 0-m, 2-m, 4-m...28-m, 30-m points), along each transect line. From the photo-quadrats we extracted data on benthic cover that included hard corals by species as well as other biological and reef substrate categories (Table 2).

Benthic cover of hard coral species, macroalgae, sand and other biotic and abiotic parameters were assessed from the photographic quadrat images using the online coral reef analysis tool "Coralnet" (Beijbom et al 2015; www.coralnet.ucsd.edu). This analysis tool allows the user to either assign species values to points manually, or to use an artificial intelligence and computer vision image recognition system (i.e. a "robot") to assign benthic parameter values to user-defined counts of randomly placed points on each image. The user then confirms or corrects the robot-defined data prior to data analysis. Each data-set generated by the user initiates a new robot, which learns the assignments of benthic parameters by being trained by the user. Additional photographs can also be added to a previously analysed data-set, and new runs of the robot-based assignments occur as the robot learns to define parameters with increasing accuracy. We trained the robot with human-assigned data for all benthic analysis of photographic quadrates from the 2015 dataset, at 25 random points per frame, for a total of 78,000 training points. In 2016 we re-allocated 100 random points to all of the frames, resulting in 318,000 data points from 3,180 frames in 2015 and the 296,000 points from the 2,960 photographic frames taken in 2016. We used the robot-assigned output for all benthic categories (e.g. Hard Corals, Fleshy Macroalgae and CTB) from both years in the 2016 analyses.

Table 2. The species and categories that were enumerated using CoralNet point count software.

Class	Species/Category	Class	Species/Category
MA	Calcareous Macroalgae	HC	*Agaricia fragilis*
MA	Lobophora Macroalgae	HC	*Dichocoenia stokesi*
MA	Fleshy Macroalgae	HC	*Diploria labyrinthiformis*
CTB	Bare Substrate	HC	*Favia fragum*
CTBA	Crustose Coralline Algae	HC	*Isophyllia sinuosa*
CTB	Turf covered rock	HC	*Madracis auretenra*
CTB	Rubble	HC	*Madracis decactis*
O	Anemone	HC	*Millepora alcicornis*
O	Branching Gorgonian	HC	*Montastrea cavernosa*
O	Corallimorpharian	HC	*Oculina sp.*
O	Encrusting Sponge	HC	*Orbicella franksi*
O	Palythoa	HC	*Porites asteroides*
O	Erect Sponges	HC	*Porites porites*
S	Sand	HC	*Pseudodiploria strigosa*
X	Framer	HC	*Scolymia cubensis*
X	Shadow	HC	*Siderastrea radians*
X	Unclear	HC	*Stephanocoenia michellini*
HCD	Bleached Hard Coral		
HCD	Dead Coral		

Coral Disease, Coral Bleaching and Reef-associated Invertebrates

The benthic quadrats were also assessed in the laboratory by a technician for the presence or absence of coral bleaching, coral diseases (i.e. Black Band disease, Yellow Band disease; Smith et al 2013), and for mobile macro-invertebrates such as lobsters, herbivorous sea urchins and sea cucumbers. An index of each parameter was generated by counting the number of frames per transect with each parameter, and averaging the counts across the five transects per site.

Juvenile Hard Coral Quadrats

Photographs at a smaller scale were also used to assess the recruitment of juvenile hard corals and several other benthic and biotic parameters. In this case, at each site a total of 30 photographs at 12 Mb, and measuring 25-cm x 25 cm (120 pixels per cm of real space) were taken as 6 photographs at 6-m intervals (0, 6, 12, 18, 24, 30 m) along each of the five 30-m long transects also assessed for fish and benthic parameters. Juvenile Hard Corals were defined as hard corals measuring >1 cm to <4.0 cm diameter. Juvenile Hard Corals were identified to finest taxonomic level possible (family, genus, or species). Also recorded were macroalgae cover, algae height, abundance of herbivorous snails and hermit crabs (grouped together as "microherbivores"), sessile vermetid snails, reef topographic complexity (i.e. rugosity – defined as vertical height of the substrate within each coral recruit quadrat) and substrate type (i.e. Pavement, Dead Coral, Amalgamated Rubble).

Water Quality

Part of the GCRMN methodology is the collection of water clarity data from secchi disk readings on a weekly or monthly schedule at several sites per country. Since Bermuda has other water clarity projects underway by other researchers (e.g. Fourqurean et al 2015), we omitted this portion of the GCRMN monitoring programme.

Baseline Data

Baseline data were taken from the dataset described in Murdoch and Murdoch (2016). Reefs were matched with the nearest 2015 and 2016 sites. If the same baseline site had been assessed on more than one date, then the most recent assessment data was used. Baseline data from lagoonal sites were collected in 2004 and 2005. Baseline rim-reef sites were assessed in 2006. 10-m forereef sites were assessed in 2007 or 2010 for the baseline dataset. Baseline data was collected using the AGRRA version 4 protocols (www.agrra.org), modified as described in full in Murdoch and Murdoch (2016).

Data for each site were averaged and the differences between years was assessed by analysing each factor at the zone or regional level. In this manner, an equal number of sites assessed in each level each year, in order to avoid issues of unequal sample sizes in ANOVA.

It should be noted that the AGRRA methodology differs from the GCRMN methodology used to collect the 2015 and 2016 data. Differences in the statistical accuracy, and hence statistical power, or ability to detect differences in population averages when they do exist, will be present between the AGRRA and the GCRMN data. Specifically, in the AGRRA baseline data, fish biomass was assessed by counting fish by size on 10 transects measuring 30-m long by 2-m wide. In the GCRMN 2015 data, fish biomass was assessed on 5 transects measuring 30-m long by 4-m wide. Fish counts by size were converted to biomass per 100 m^2 with the use of AGRRA standard length-biomass conversion tables (Marks and Klomp 2003).

Hard coral, macroalgae and other benthic substrate were assessed along 100 points separated by 10-cm along six replicate transects measuring 10-m long in the baseline AGRRA surveys. In the GCRMN 2015 and 2016 assessments, hard coral cover, macroalgae cover and other benthic categories were determined by averaging the percentage of 100 points that were each substrate type across 16 quadrats measuring 90-cm by 65-cm on 5 haphazardly placed transects measuring 30-m long.

In the baseline AGRRA assessment, juvenile hard corals, hermit crabs and snails were assessed in six sets of 10-m long transects, with five 25-cm x 25-cm square quadrats assessed per transect separated by 2-m. In the 2015 and 2016 assessments, five sets of 30-m long transects, with six 25-cm x 25-cm square quadrats were used to count juvenile hard corals and microherbivores (snails and hermit crabs). Baseline counts of hermit crabs and snails were carried out directly in the field. We switched to counting hermit crabs and snails as a single group from photographs in 2015 and 2016 in order to reduce field survey time. The shells of both groups are easily observable in the photographs, which are taken close to the substrate and of areas between corals where small mobile invertebrates are unlikely to be hidden from view. We did not test the correlation between visual and photographic assessments, as many comparisons between field and photographic assessment of sessile organisms on bare substrate have shown a high degree of shared accuracy (Godet et al 2009). All data were normalized to a per sq m basis.

Project Domain

Overall 39 sites were surveyed in 2015, 19 as part of the BZS-funded grant for Long-term Ecological Monitoring (LTEM), and 20 as part of the XL Catlin End-to-End supported research project on reef-scale erosion. Of these 39, 37 sites were surveyed in 2016, with only 7 sites assessed in the Inner Lagoon. The map below (Fig. 2) shows the location of the 39 sites surveyed in 2015 and the 37 sites surveyed in 2016.

Zone Characteristics

The 39 sites were allocated in the following manner:

Inner Lagoon: 6, 7 , 37, 38, 44, 45, 51*, 52*;
Outer Lagoon: 4, 5, 11, 15, 35, 36, 42, 43, 46, 50;
Rim Reef: 3, 10, 14, 16, 21, 22, 27, 30, 34, 41;
10-m Forereef: 2, 9, 13, 17, 20, 23, 26, 29, 33, 40.

Inner Lagoon: The inner lagoonal reefs are found within the northern and western lagoon, between the shore and the 3- to 5-km midpoint to the Rim reef that forms the outer boundary of the lagoon. Depth: -0.5 to -3 m.

Outer Lagoon: The outer lagoonal reefs are found between the outer Rim Reef bounding the lagoon, and the midpoint line located at 3- to 5-km distance from shore, within the lagoon.
Depth: -0.5 to -3 m.

Rim Reefs: The reefs that form the Rim around the lagoon and island are defined as the shallowest margin between the lagoon or island and the outer forereef and the open ocean.
Depth: -0.5 to -5 m.

10-m Forereef: The 10-m forereef is located seaward of the rim, and at the seaward-most area of reef found at 10-m depth. A 15- to 20-m deep trough that intersects the 7- to 10-m deep reef habitat can be found along the western side and parts of the northern side of the Bermuda Platform. The 10-m Forereef sites selected in this study were chosen to be on the seaward side of this trough, where wave exposure from the open ocean is highest and exposure to lagoonal water from tidal flow is lowest. Depth: -8 to -12 m.

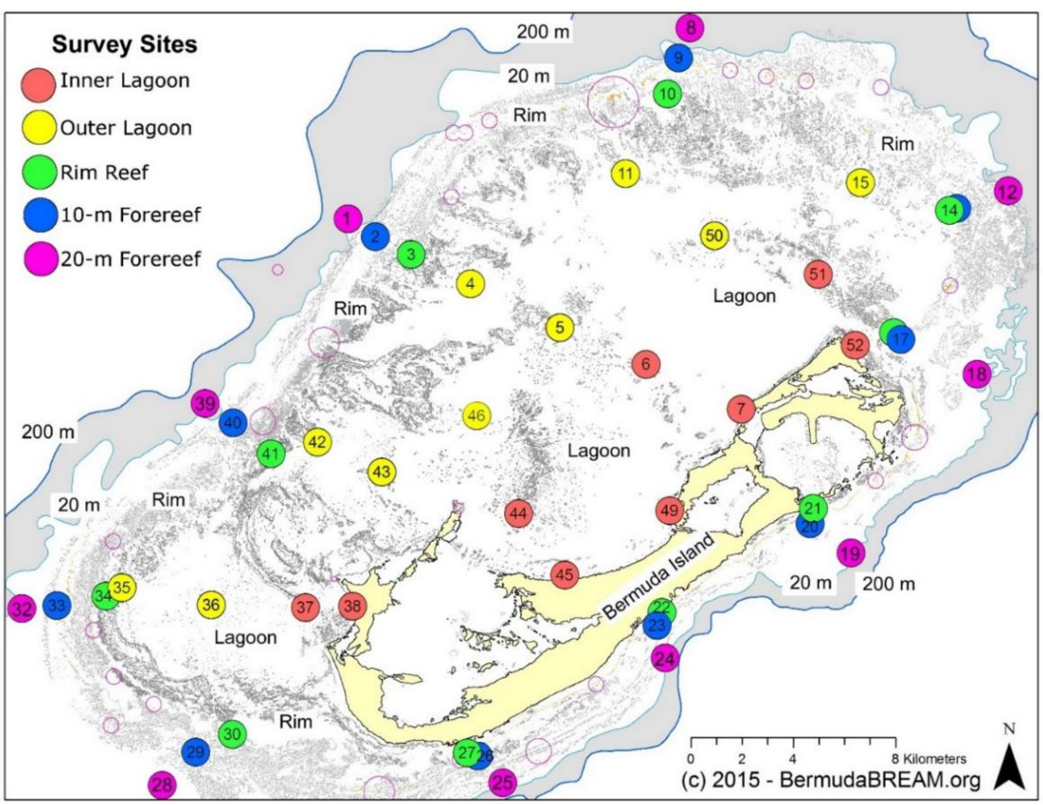


Fig. 2. Location of the 49 sites we proposed to assess for long-term trends in reef health and fish abundance. The 10 sites at 20-m depth have not been assessed to date.

Defining Reef Condition with Reef Life Score and the Sea Life Index

In this report, we focus on the four primary indicators of the ecological condition of the Bermuda forereef habitat and associated biota that we used previously in the report on the baseline condition of Bermuda's coral reef habitats (Murdoch and Murdoch 2016). The indicators also match those used in the Reef Health Index by McField et al (2011), which is now being used by many reef survey teams across the Caribbean.

The four indicators are:

1. Biomass of Predatory Fishes of the grouper and snapper families (grams per hectare),
2. Biomass of Herbivorous Fishes of the parrotfish and surgeonfish families (grams per hectare),
3. Hard Coral cover (percent cover of rocky reef substrate),
4. Fleshy Macroalgae cover (percent cover of rocky reef substrate).

We described the factors and their utility in defining overall reef condition in Murdoch and Murdoch (2016).

Briefly, each of the four factors contribute fundamentally to overall reef condition, and represent the core of a larger set of ecological factors which have been demonstrated through > 60 years of research by the scientific community to contribute to the overall condition and resilience of coral reefs (e.g. McField and Kramer 2007, Flower et al 2017). The baseline relative cover or biomass of these four biological components of reef ecology, when combined, provide a metric of both overall reef condition and reef resilience to future declines in condition from natural or anthropogenic impacts. When assessed over time, changes in the four factors can be used to indicate whether the reefs under study are undergoing improvement or deterioration in reef condition.

Not only is the ecological condition of each surveyed reef represented by the state of each of the four factors, a summary index we call the "Sea Life Index", which combines the separate levels of each of the four factors, can give an overall metric of reef health. No single factor contributes to overall reef condition nor the resilience of a coral reef against future disturbances on its own, and the combined index represents this concept of shared contribution and the need for all four components of reef condition to be at satisfactory levels for the overall reef condition to also be considered to be at a good or "healthy" state.

We selected the four indicators, and the correspondence between indicator value and relative condition, to match the Simplified Integrated Reef Health Index (SIRHI) used by the coral reef scientists of the Healthy Reefs research programme (Healthy Reef Initiative 2012, www.heathyreefs.org) who monitor the Meso-American coral reef system (McField et al 2011). We intentionally also use the same four indicator factors in the Bermuda Reef Watch programme for citizen scientists in order to assign the Reef Watch lagoon reef sites a health score, although the simplified assessment methods used by the Reef Watch programme necessitated using different kinds of data to calculate the Sea Life Index used in that programme (Murdoch 2013, 2014a, 2014b).

It is particularly important to note that the Reef Life Scores for both the Predatory Fishes and the Herbivorous fishes are based on international standards of abundance, as defined by a large consortium of scientists (McField 2012), based on the abundances of predatory fishes on healthy and unhealthy reefs. Additionally, these international standards are based on surveys that conform to the spatial extent, time of day and other details of the methodology that we used in our Bermuda surveys as well. Specifically, biomass levels are based on surveys over a 100-m area, taken between 10-am and 4-pm, across the surface of a coral reef by 30-m transect lines and with a swath of 2-m to 4-m width. Therefore, when we say in this report that a reef has Poor biomass or Good biomass, it means that a reef with a truly Poor biomass over the long-term would exhibit 420–839 $g.100m^{-2}$ when surveyed in the manner we used and at the times we did it, regardless of the biomass present using other methods or assessed during other times of day.

Sea Life Index

Sea Life Index (SLI) of each site is calculated by averaging the four component Reef Life Scores (RLS) of each site. As the values of the SLI for each site are derived from the averages of the RLS, the range of values that define each reef condition level (i.e. Very Good, Poor) do not match those of the components' Reef Life Scores. The range of values for each ranking are displayed below:

The SLI index used in the Long-term Ecological Monitoring programme is qualitatively similar to the Bermuda Reef Watch SLI. However, while the Bermuda Reef Watch SLI is comprised of measures of each of the four functional groups as assessed by citizen scientists, and taken from only ten quadrats (for benthic parameters) or one sample (for fishes and mobile organisms) across patch reefs of a standardized size, the SLI in the LTEM is quantified from 80 quadrats and fish assessed by species and size, sampled from five replicate transects measuring 30-m long, and assessed by trained scientists using internationally standardized assessment techniques. For this reason, the data which is collected using the GCRMN methods are more accurate and precise compared with the Bermuda Reef Watch dataset.

Table 3. A table of the correspondence between Reef Condition, Reef Life Score, and the range of values for the four biotic components of the Sea Life Index.

Reef Condition	Critical	Poor	Fair	Good	Very Good
Reef Life Score	1	2	3	4	5
Hard Coral Cover (%)	< 5.0	5 – 9.9	10.0 – 19.9	20.0 – 39.9	≥ 40.0
Fleshy Macroalgae Cover (%)	> 25.0	12.1 – 25.0	5.1 – 12.0	1.0 – 5.0	< 1.0
Herbivorous Fishes (g.100m^{-2})	< 960	960 – 1919	1920 – 2879	2880 – 3739	> 3840
Predatory Fishes (g.100m^{-2})	< 420	420 – 839	840 – 1259	1260 – 1679	> 1680

Table 4. The range of values of the Sea Life Index that correspond to each level of reef condition.

Reef Condition	Critical	Poor	Fair	Good	Very Good
Sea Life Index Score	1.00 to 1.79	1.80 to 2.59	2.60 to 3.39	3.40 to 4.19	4.20 to 5.00

Secondary Factors

Many additional factors provide an indication of the condition of a given coral reef (Jameson et al 2001; McField and Kramer 2007). For this brief report we will focus on the seven additional factors delineated in Table 5, below. The range of most of the factors is based on the statistical distribution of each parameter across the 178 BREAM baseline sites, according to the natural breaks (i.e. "jents") as assigned by ArcGIS™ 9.2 (ArcGIS 2006). Classes are based on natural groupings inherent in the data. ArcMap identifies break points by picking the class breaks that best group similar values and maximize the differences between classes. The features are divided into classes whose boundaries are set where there are relatively large increases in the data values.

Table 5. The range of values for each of the seven secondary factors that correspond to each level of reef condition.

Reef Condition	Critical	Poor	Fair	Good	Very Good
Reef Life Score	1	2	3	4	5
Juvenile Hard Corals (Count.m^{-2})	< 2	2 - 10	10 - 20	20 - 30	> 30
Coral Diseases & Bleaching (Proportion of quadrats)	> 0.20	0.15 - 0.20	0.10 - 0.15	0.05 - 010	< 0.05
Territorial Damselfishes (Count.100 m^{-2})	> 50	24 - 50	12 - 24	3 - 12	< 3
Herbivorous Sea Urchins (Count.m^{-2})	< 1	1 - 2	3 - 4	5 - 6	> 6
Herbivorous Snails & Hermit Crabs (Count.m^{-2})	5	5 - 20	20 - 120	120 - 200	> 200
Crustose Coraline Algae, Turfs, Bare Rock (CTB; % Cover)	< 20	20 - 30	30 - 40	40 - 50	> 50
Invasive Lionfishes (Count.100 m^{-2})	50	25	10	5	0

Juvenile Hard Corals

Juvenile Hard Corals, referred to as "recruits" in the GCRMN methods, are defined operationally for this assessment as any stony coral (except *Favia fragum*) that is greater than 1.0 cm² and less than 4.0 cm². Each coral within the target size range was recorded to species. In this report, all species are discussed as one functional group. Decreases in juvenile hard corals could be due to a loss of suitable substrate (CTB generally) due to an increase in macroalga, thick turfs, cyanobacteria or sediment. Poor water quality could also negatively impact coral recruit density. Additionally, a reduction in coral recruit density over time may be due to declining adult coral cover.

Coral Diseases and Bleaching

Several coral diseases are extant on Bermuda reefs. Poor water quality may cause an increase in coral diseases over time. We record Black-band disease, White Plague disease and Yellow-band disease. Partial and total coral bleaching are also recorded. Extreme high or low water temperatures can cause bleaching.

Territorial Damselfishes

Four species of territorial damselfish are assessed. These are the Bicolored Damselfish, Beaugregory, Cocoa Damselfish and Threespot Damselfish. All four species maintain algal turf garden territories in a manner that damages hard coral tissue. Yellowtail damselfish do not maintain algal territories and are not included in this group. Increases in territorial damselfish through time indicates that the populations of predatory fishes (mainly mid-sized grouper and snapper) are in decline.

Herbivorous Sea Urchins

Plant-eating sea urchins, primarily the long-spined sea urchin (*Diadema antillarum*), but also the "sea egg" (*Tripneustes ventricosus*), are important herbivores on the reef. They help maintain the balance between plant growth and coral cover. A lethal disease in 1983 rapidly killed prolific numbers of long-spined sea urchins across every reef system within the Western Atlantic, and region-wide recovery is still occurring (Lessios 2016). To keep algae cropped on a typical shallow reef requires 4-8 sea urchins per sq m, if no other herbivores are present (Hughes 1994, Idjadi et al 2010). Less than 1 urchin per sq. m should be considered "Poor". Herbivorous sea urchins, like most herbivores, tend to dominate Rim and 10-m reefs zones, and be rarer within the Inner Lagoon. Decreases in herbivorous sea urchins may be caused by an outbreak in disease, a decline in habitat quality, or an increase in predators. An increase in the abundance of adult sea urchins may be due to an increase in larval supply and enhanced recruitment.

Herbivorous Snails and Hermit Crabs

Algae-eating small hermit crabs and snails (i.e. microherbivores, *Cerithium litteratum* and *Calcinus verrilli*) may have a powerful effect on the overall condition of a coral reef at high densities, through the constant cropping of marine plants into small turfs (Smith 1988). We counted snails and hermit crabs separately in the baseline assessments, but grouped them together in 2015 and 2016 as we had to use photographic methods to quantify them due to time constraints. Decreases in herbivorous snails and hermit crabs may be due to an increase in predation, or a decrease in habitat quality or in population replenishment.

Crustose Coralline Algae, Turf, Bare Rock (CTB)

The CTB category, which includes crustose coralline algae, turf algae and bare space, represents substrate available for the settlement of juvenile hard corals and where adult hard corals may extend their colonies without competition. We assessed each category separately, but combined them to simplify data reporting. Crustose coralline algae are a critical settlement cue substrate for the recruitment of many marine invertebrates, including hard corals (Birrell et al 2005). Turf can vary in thickness from <1-mm to >10-mm, with seemingly small increases in turf thickness of only 2-3 mm having a strong impact on the ability of juvenile corals to recruit to the substrate (Arnold et al 2010). However, a pilot study determined that assessing turf thickness as part of the protocol required too much additional time or another diver, and so was not done in this project. CTB decreases could be due to increased cover of hard or soft corals, macroalgae, sponges, sedimentation or pollution, or a reduction in herbivores that maintain low macroalgae biomass. Diseases can also negatively impact crustose coralline algae.

Invasive Lionfish

Much has been written elsewhere about the threat of lionfish to Bermuda reefs and Caribbean-wide. We took great care to assess each transect for lionfish presence, i.e. inspecting holes and overhangs, due to their perceived threat locally.

Statistical Analysis

Region-scale (all sites) and zone-scale (Inner Lagoon, Outer Lagoon, Rim Reef, 10-m Forereef) data are presented in bar graphs of average values with 95% confidence intervals illustrated by error bars. When factor values on the Y-axis correspond with a qualitative value, such as "Poor, or "Good" condition, for example, the range of those conditional values is presented in each graph as fields of colour. Data cleaning and organization was carried out in Excel and "R". All graphing and statistical analyses were carried out using GraphPad Prism version 7.02 for Windows (GraphPad Software, La Jolla California USA; www.graphpad.com).

We carried out statistical analyses with the goal of determining whether each parameter had changed in a significant manner in the most recent year, relative to the Baseline condition, and the direction of that change. We calculated repeated-measures Analyses of Variance (RM_ANOVA) and subsequent multiple comparisons with Dunnett's multiple comparisons test (i.e. post-hoc analysis), with data from each site compared between Baseline and 2015 and 2016 separately.

Results and Discussion

Sea Life Index

The average SLI values for the entire platform during the Baseline assessment, in 2015, and again in 2016 are illustrated in Fig. 3. At a regional scale, Bermuda's reefs displayed no statistically significant change, but a numerically small increase was noted in the average Sea Life Index value in 2016 relative to the Baseline years. In 2015, the average SLI value for all sites was 2.545, while the Baseline value was 2.872, representing a significant decline of 0.327 points. In 2016, the SLI was observed to increase again to 2.93, with a higher range of variability. In general terms, the overall condition of Bermuda's reefs was assessed as Fair in the Baseline assessment, declined to Poor in 2015, but returned to Fair in 2016.

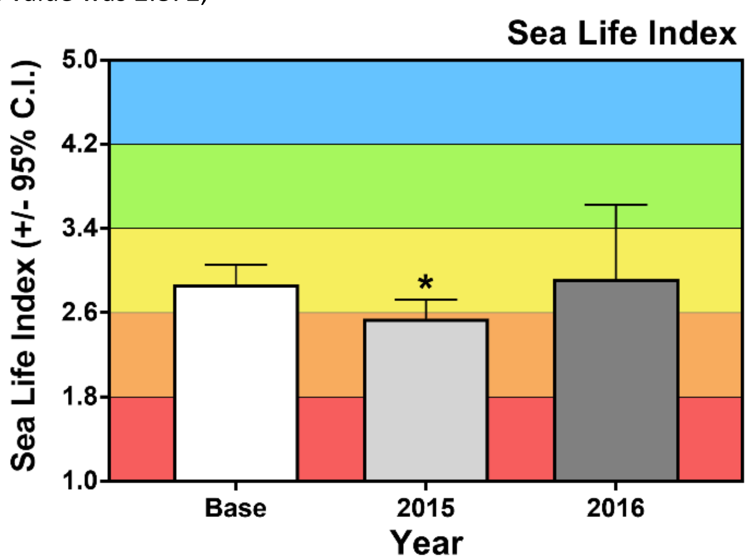


Fig. 3. The average Sea Life Index (+ 95% Confidence Intervals) for the Bermuda Reef Platform, based on data from 39 sites during the Baseline years (2004 – 2010), 2015, and 2016. * = significant difference with Baseline.

The SLI values of each zone are displayed in Fig. 4. In 2016 the Inner Lagoon SLI was Poor (2.07). The SLI values of the Outer Lagoon and the Rim Reef was Fair (2.63, 3.20, but improved over 2015) and the SLI value of the 10m Forereef was Good (3.50; Fig. 4). Dunnett's post-hoc test for multiple comparisons after ANOVA (www.bermudabream.org) found that the SLI in the Inner Lagoon was significantly smaller than Baseline in 2016, while the SLI in the 10m Forereef was significantly higher than baseline, while the other two zones displayed no significant change in SLI in 2016.

In Fig. 5, one can see both the distribution of reef condition status across all reefs, and also how the SLI changed at each site and zone through time from the Baseline surveys through to 2015 and 2016. Generally, sites have remained in the same condition through time, with a few sites in the northern Rim and Forereef flickering in condition between Fair and Good. Three reefs in the northern end of the Outer Lagoon improved in condition from Poor to Fair, and several reefs in the western and southern Rim and 10m Forereef improved from Fair to Good.

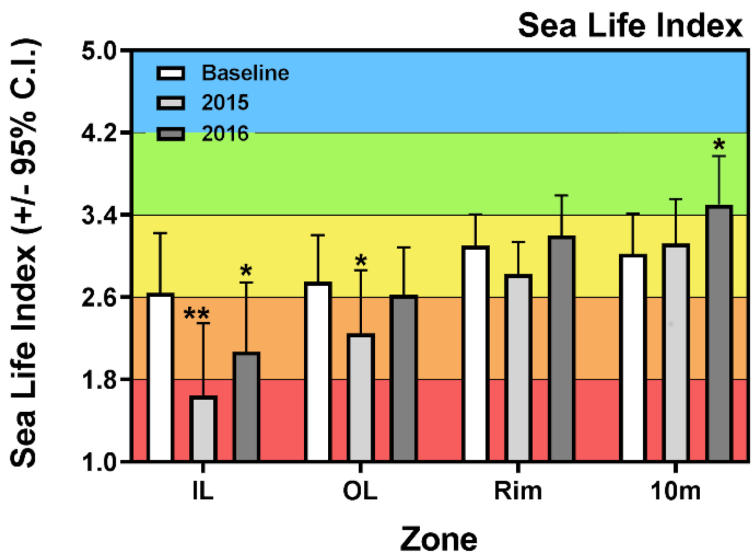


Fig. 4. The average values of the Sea Life Index (+ 95% C.I.), as assessed across multiple sites within four zones of the Bermuda Platform. Sites were assessed in the Baseline years of 2004-2010 and compared with assessments carried out in 2015 and 2016. * = significant difference with Baseline.

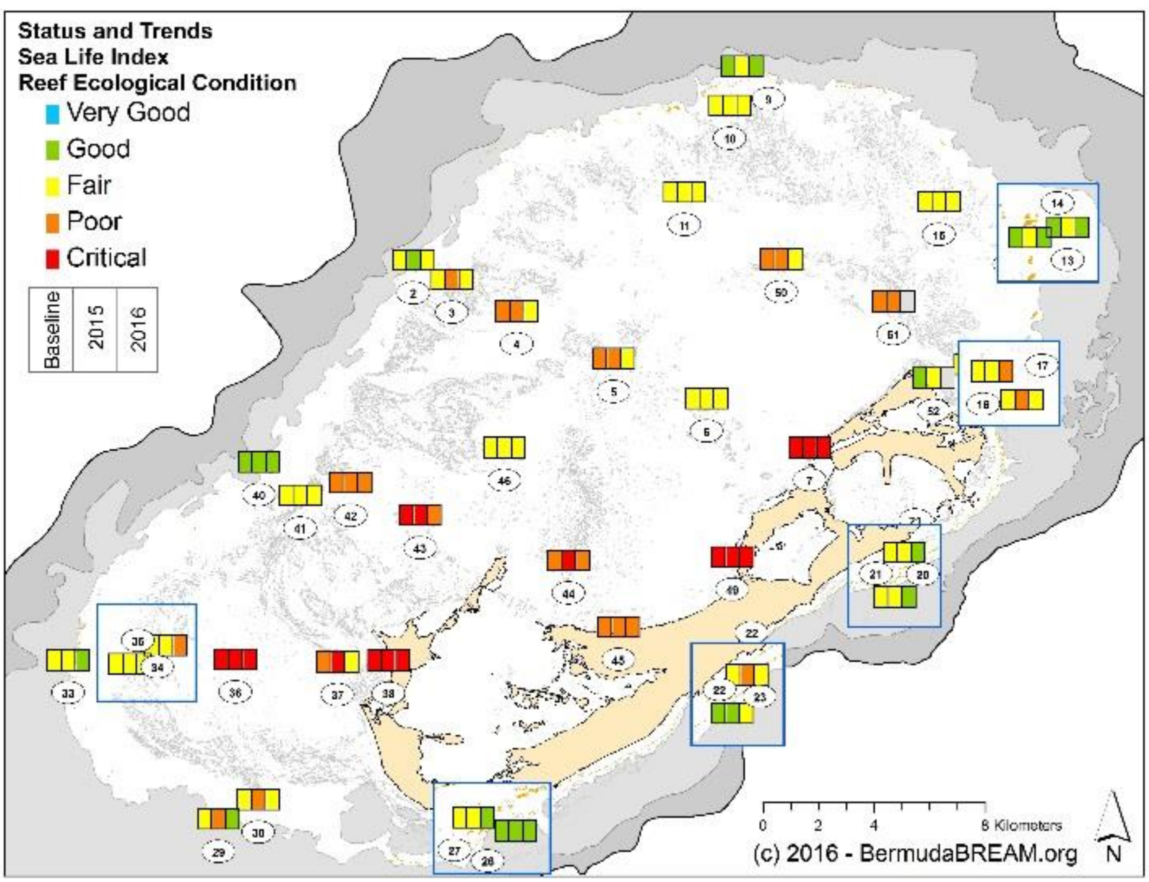


Fig. 5. Site-specific changes in the SLI across all 39 sites distributed across the Bermuda Reef Platform over the time period of the study. Blue boxes in this and all following charts illustrate pairs of sites that would otherwise overlap due to their close proximity despite being in different depth zones.

Predatory Fishes

Predatory fishes (snappers and groupers) were found to be critically low in average biomass in the original baseline analyses carried out from 2004 to 2010 (Fig. 6 to Fig. 8). In 2015, and again in 2016, we found the average biomass for predatory fishes remained critically low. While predatory fish biomass increased from 216.3 g.100m^{-2} in the Baseline years to 235.2 g.100m^{-2} in 2015, and 233.5 in 2016, the change was found to lack statistical significance (One-way ANOVA, df (2,112), F=0.053, P=0.949). It should be noted that biomass levels in the 200 g.100 m^{-2} range indicate a critically overfished system that may be well past the point of short-term recovery.

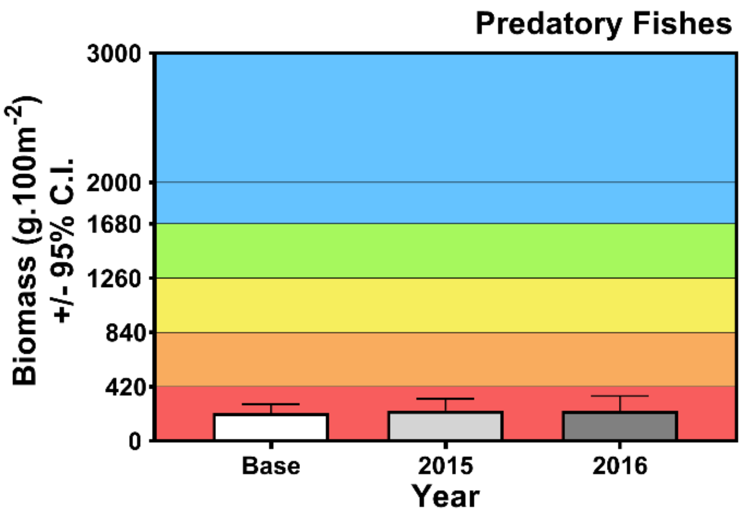


Fig. 6. The regional average biomass of predatory fishes as measured in the baseline surveys in 2004-2010, and in the LTEM assessments of 2015 and 2016.

We also compared the biomass of predatory fishes across four zones of the Bermuda platform, the Inner Lagoon (IL), the outer lagoon (OL), the rim reefs (Rim) and the 10-m forereef (Fig. 7). Predatory fishes were observed to be at critically low levels across all zones, both in the baseline years and in 2015, except for the 10-m zone in 2015 and in 2016. In these years average biomass of predatory groupers and snappers increased from 255.9 g.100m^{-2} to 489.9 g.100m^{-2} (2015) and the slightly lower value of 477.1 g.100m^{-2} in 2016. No significant differences were found between years for any zone, except in the 10-m Forereef. The increase in biomass of predatory fishes in 2015 raised the grade to Poor from Critical (Fig. 6).

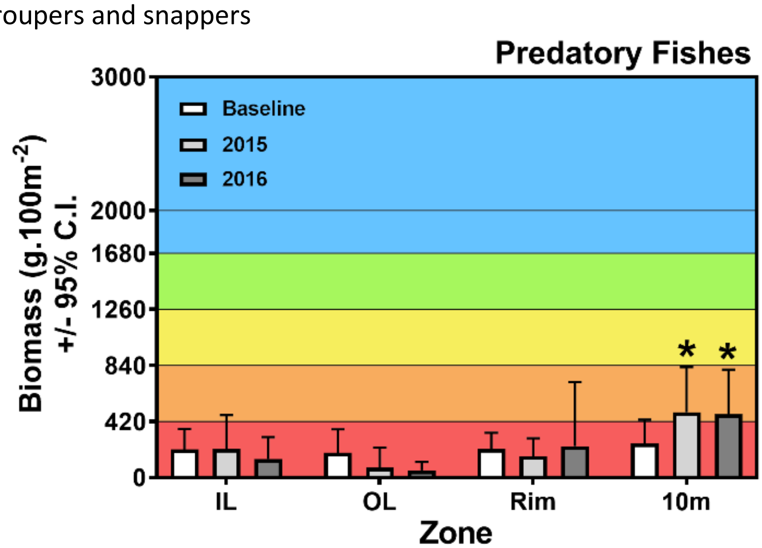


Fig. 7. The average biomass (g per 100m^2) as assessed at Baseline, 2015 and 2016, across four zones (IL: Inner Lagoon; OL: Outer Lagoon; Rim: Rim Reef; 10-m: 10-m Forereef). * = significant difference with Baseline.

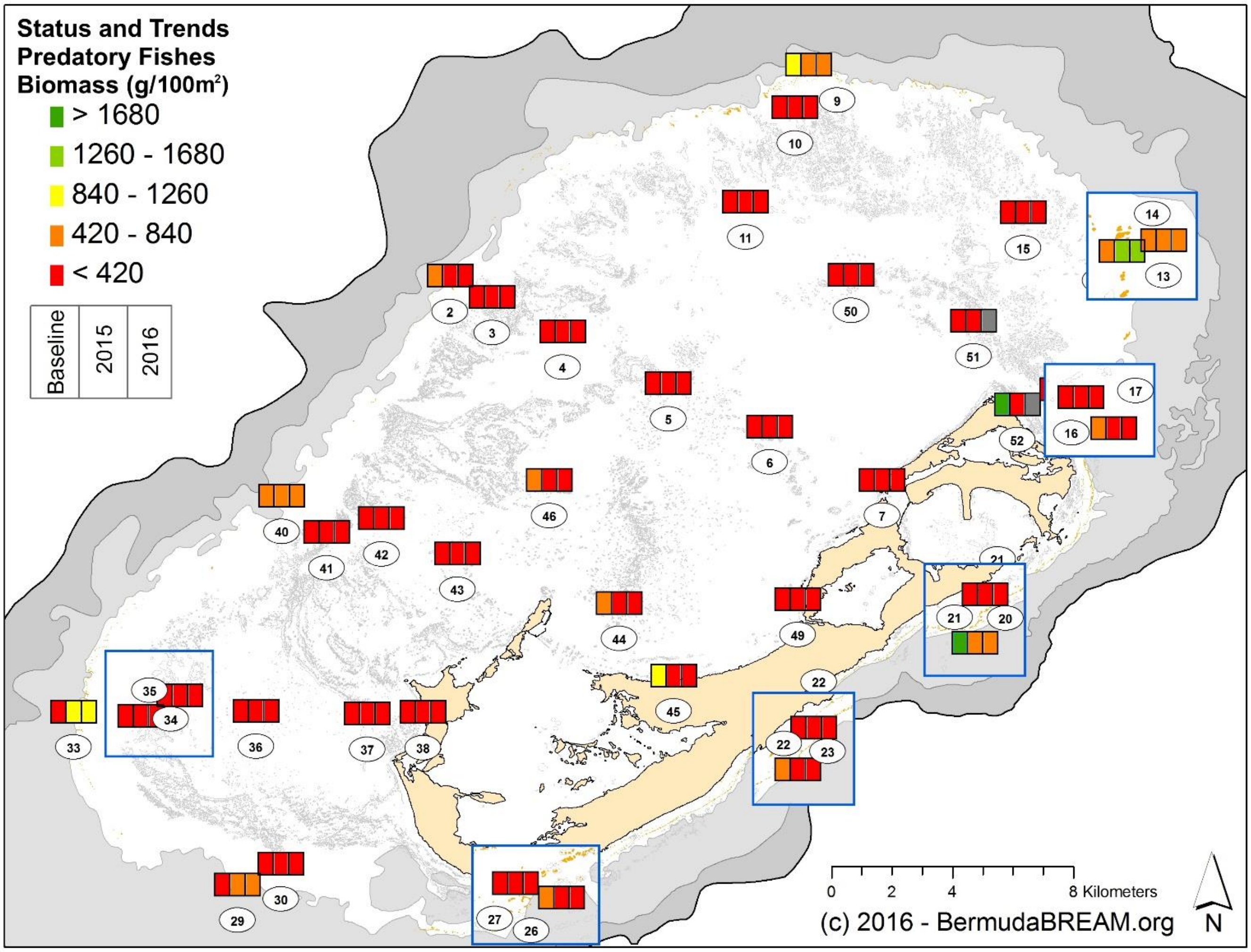


Fig. 8 Biomass (g) of Predatory fishes (Groupers and Snappers) per 100m^2 in Baseline, 2015 and 2016. Sites 51 and 52 were not assessed in 2016.

Herbivorous Fishes

The regional average biomass for Herbivorous fishes was observed to decrease from 3437 g.100 m^{-2} to 2726 g.100m^{-2} between the years of Baseline study and 2015, but then increase substantially and highly significantly, to 4796 g.100m^{-2} in 2016 (Fig. 9).

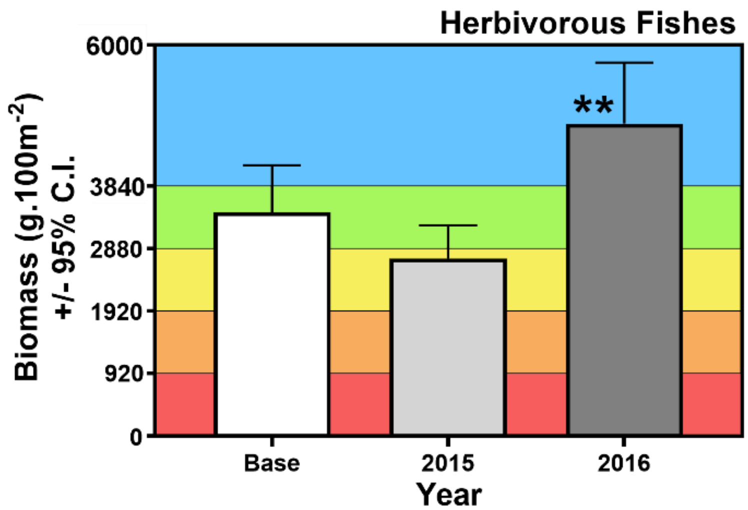


Fig. 9. The average biomass of herbivorous fishes (Parrotfishes, Surgeonfishes and Silvery Fishes) across all sites in the Baseline years and in 2015. ** = highly significant difference with Baseline.

Herbivorous fish biomass increased in all zones in 2016 relative to both the Baseline and 2015 (Fig. 10), but only in a statistically significant manner in the Outer Lagoon. Substantial increases were seen at three sites (i.e. 4, 5, 50), all of which are located in the North Lagoon, relatively near the North Shipping Channel which was re-dredged in the autumn of 2015 (Fig. 11). Qualitatively, herbivorous fish biomass in the Inner Lagoon increased from Fair to Good, while the biomass of herbivorous fishes in the Outer Lagoon, Rim Reef and 10m-Forereef increased to Very Good.

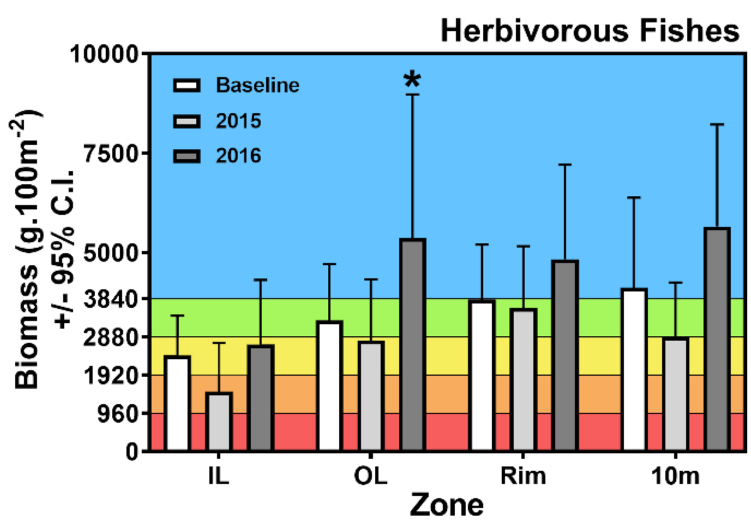


Fig. 10. The average biomass of herbivorous fishes across the four zones of the Bermuda Reef Platform assessed in the Baseline years and again in 2015. * = significant difference with Baseline.

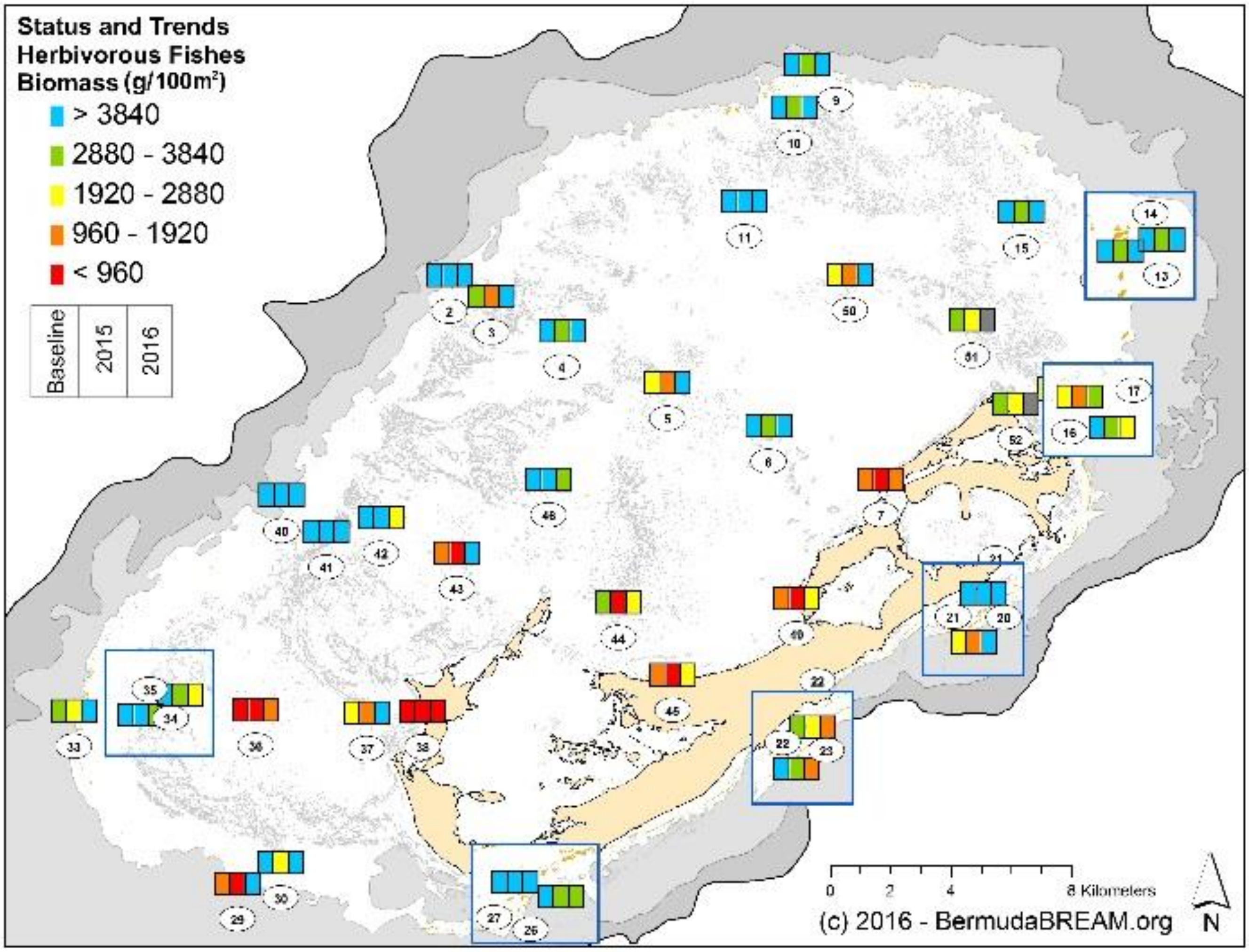


Fig. 11. Biomass (g) of Herbivorous fishes per 100 m^2 (parrotfishes and surgeonfishes).

Herbivorous fishes seem to be increasing in the North Lagoon, with little obvious change in their abundance across the other areas of the reef platform. 2015 was characterized by stormy weather for much of the summer, but the surveys in 2016 were carried out during a month of calm weather. Parrotfishes may have moved from the tops of patch reefs in the lagoon to graze on the sides in the rough weather during sampling in 2015, and been observed grazing at the top of the reefs during the calmer 2016 period.

Hard Corals

The average percent cover of Hard Corals across the entire Bermuda Reef Platform was observed to be 28.84% in the Baseline years, but decreased by 5.187% to 23.65% in 2015 (Fig. 12, Fig. 14). Analysis of the 2016 data, however, demonstrated an increase in the cover of Hard Corals at a regional scale back to 28.32%. Hard Corals remained in "Good" condition across all study periods, and there was no significant difference in the cover of Hard Corals from Baseline to 2016.

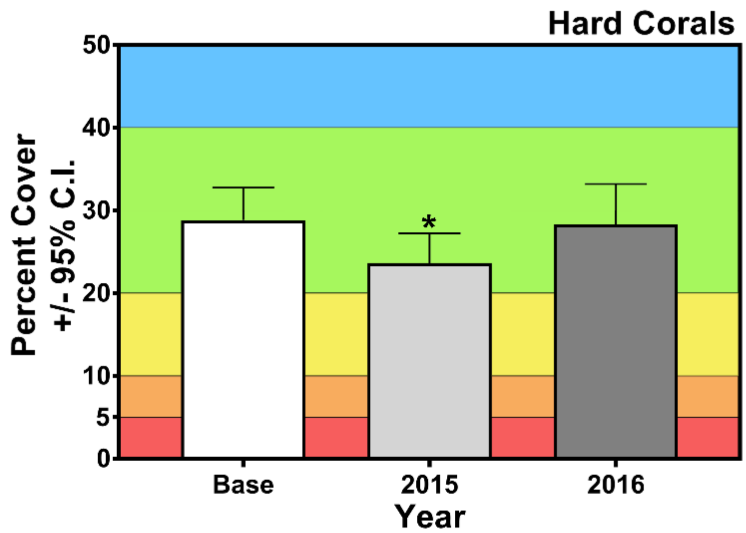


Fig. 12. Average percent coral cover of all 39 sites assessed in the Baseline, 2015, and 2016. * = significant difference with Baseline.

All zones displayed a significant decline in the average percent coral cover, except the 10-m Forereef zone, from the Baseline assessment years to 2015, but these declines were not observed in 2016 (Fig. 13). In other words, in 2016, we observed no significant declines in Hard Coral cover across each of the four zones (Fig. 13). Instead, the 10-m Forereef zone displayed a significant increase in Hard Coral cover from 38.66% at Baseline to 45.03% in 2016. In the Inner Lagoon, coral cover remained at Fair levels, while in the Outer Lagoon and Rim Reef zones, coral cover remained in the Good condition. The 10-m Forereef increased from Good to Very Good condition in 2016. The distribution of Hard Coral cover values across all survey sites (Fig. 14) shows that the 10-m Forereefs seaward of South Shore, Bermuda, are in the best condition, while some Inner Lagoon reefs near Sandys Parish and the east end are in Poor or Critical condition. Most reefs are in Good Condition.

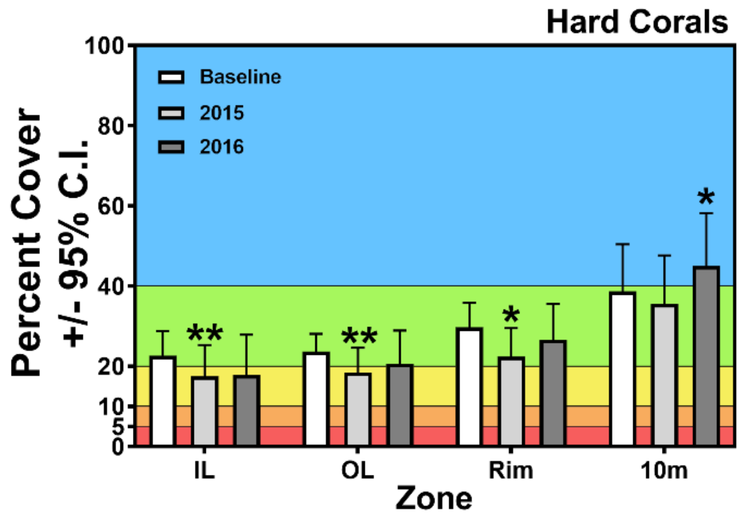


Fig. 13. Average percent coral cover of sets of reefs assessed in four zones of the Bermuda Reef Platform in the Baseline years, 2015, and 2016. * = significant difference with Baseline, more asterisks indicate greater statistical significance.

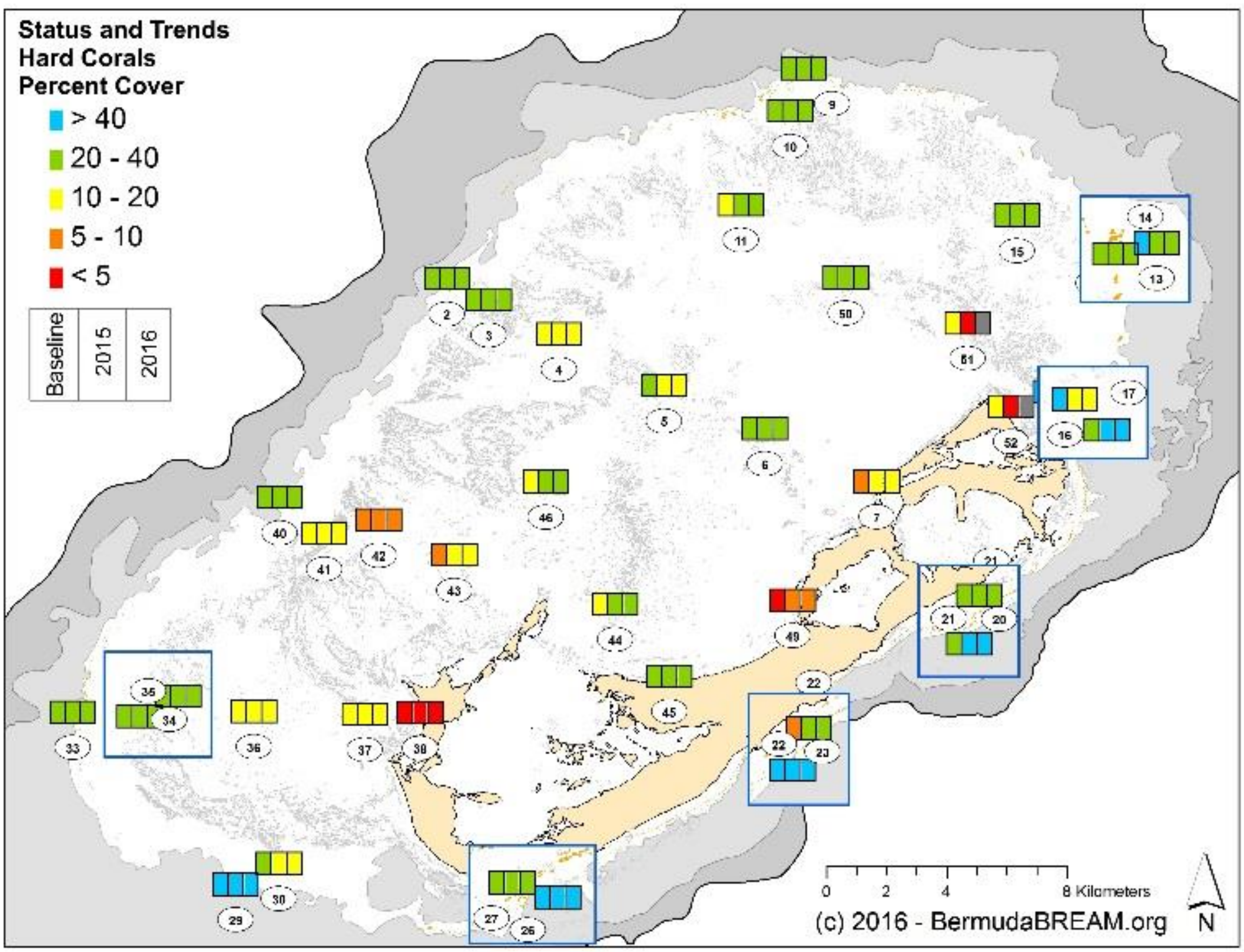


Fig. 14. Average percent cover of hard corals at each of the 39 reef sites assessed over all three time periods.

Fleshy Macroalgae

Fleshy macroalgae increased in percent cover from 12.30% during the Baseline years to 23.07% in 2015, but decreased to 17.51% cover in 2016. This still represented at significant increase relative to Baseline, and corresponds with an undesirable change in SLI grade from Fair to Poor at the regional scale.

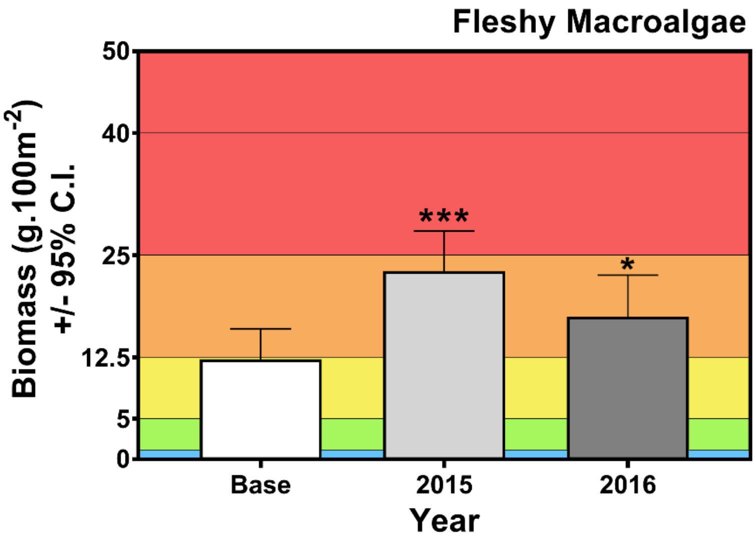


Fig. 15. Regional average percent cover of fleshy macroalgae as measured in the Baseline years and re-measured in 2015 and 2016 across 39 reef sites on the Bermuda Reef Platform. *** = highly significant difference with Baseline.

Fleshy macroalgae increased in a statistically highly significantly high degree from baseline to 2015 in both the Inner and Outer zones of the Lagoon (IL: t=3.986; df=35; P<0.001; OL: t=4.533; DF=35; P<0.001) in 2015, but only increased significantly in the Inner Lagoon relative to Baseline in 2016. Within the Inner Lagoon, Fleshy Macroalgae increased from 23.85% average Baseline cover to 40.83% average cover in 2015, with a small decrease to 37.61% cover in 2016. In the Outer Lagoon, Fleshy Macroalgae increased in cover from 9.033% average at Baseline to 27.35% average percent cover in 2015, but decreased to 17.67% cover of fleshy macroalgae in 2016. Small and statistically insignificant increases were also recorded in the Rim and 10-m Zones in both 2015 and 2016. These changes indicate the Inner Lagoon has transitioned from Poor to Critical in 2015 and 2016, while the Outer Lagoon has changed from Good to Critical in 2015, but improved to Poor since the baseline assessment period. The Rim zone remains in Good condition and appears to be improving in 2016. The 10-m zone declined in fleshy macroalgae condition from Fair to Poor in 2015 but improved to Fair again in 2016.

It can be seen in the map of macroalgae cover across the 39 survey sites (Fig. 17), that the Inner and Outer Lagoon reefs are characterized by Poor (> 12.5%) to Critical (>25%) cover by marine plants. Reefs in the 10-m Forereef and Rim reef areas tended to have less macroalgae compared to the reefs in the two lagoonal zones.

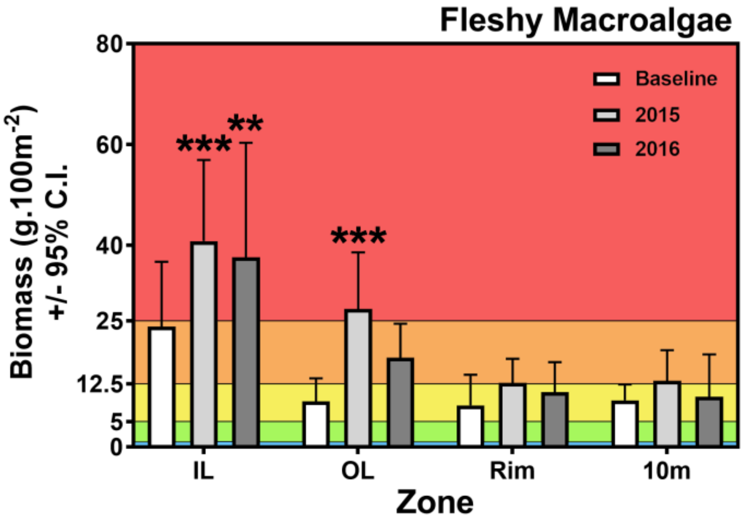


Fig. 16. Average percent cover of fleshy macroalgae across sites located within four zones of the Bermuda Reef Platform. Sites were originally assessed in the Baseline years of 2004 – 2010, and reassessed in 2015 and 2016. ** = highly significant difference with Baseline, more asterisks indicate greater statistical significance.

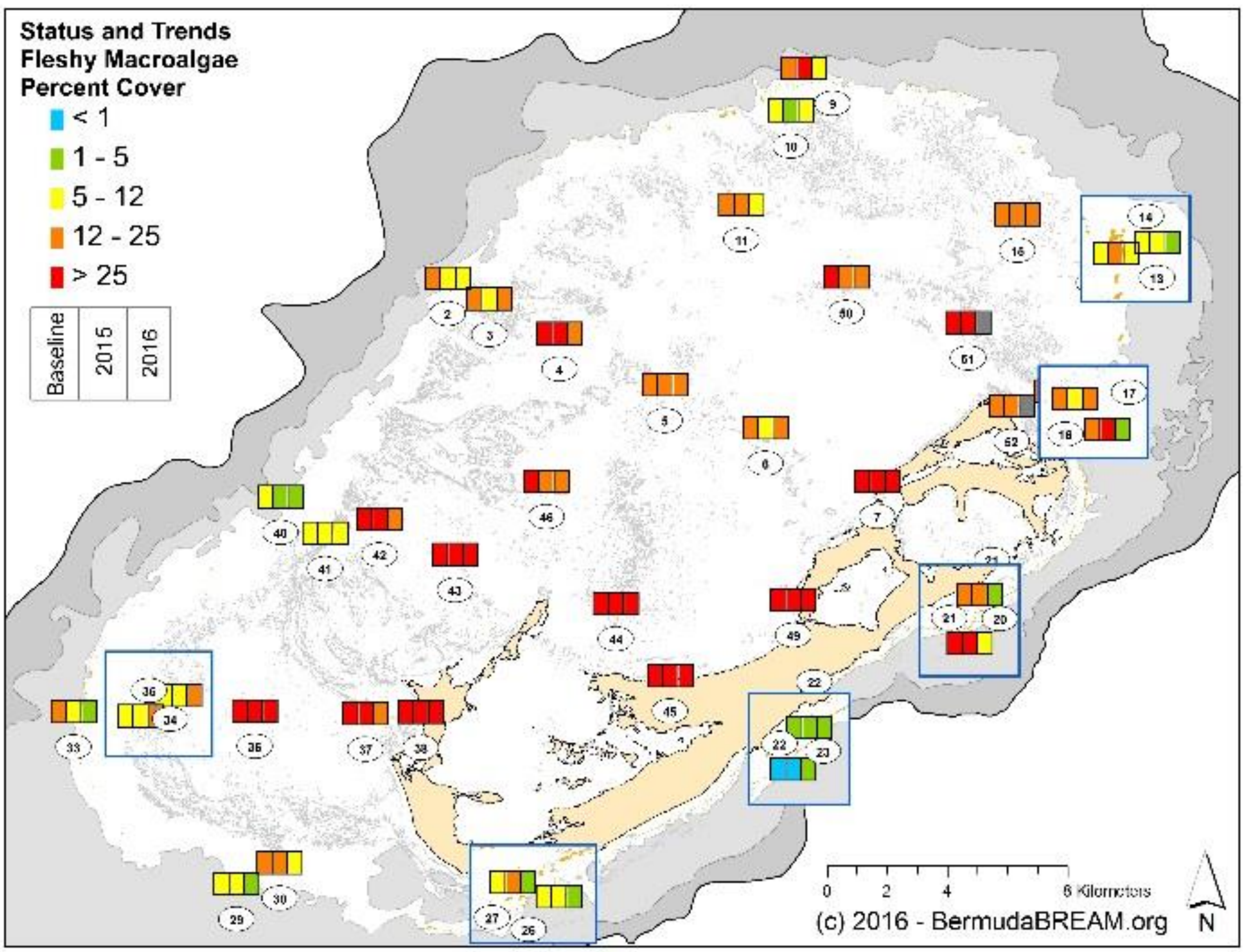


Fig. 17. Spatial pattern of cover by macroalgae across the Bermuda Reef Platform.

Juvenile Hard Corals

Juvenile Hard Corals, (i.e. referred to as "recruits" in the GCRMN methods) are defined operationally for this assessment as any stony coral (except *Favia fragum*) that is greater than 1.0 cm ^{2} and less than 4.0 cm ^{2}. Each coral within the target size range was recorded to species. In this report, all species are discussed as one functional group. Juvenile hard corals were observed to be very highly significantly higher in abundance in 2015 across the platform relative to the matched sites from the baseline period. However, in 2016 the abundance of juvenile corals was observed to be only marginally, and not statistically significantly, higher than at Baseline (Fig. 19), and this trend occurred across all zones (Fig. 21)

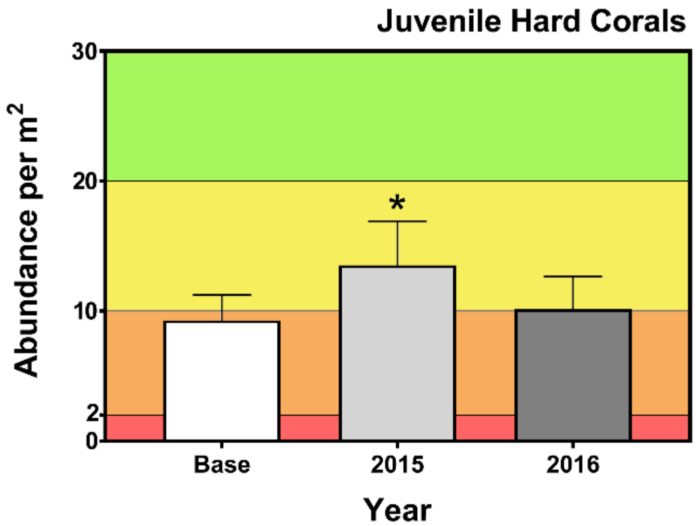


Fig. 18. Average abundance of Juvenile Hard Corals per square meter across the Bermuda Reef Platform in the Baseline assessment in 2015, and in 2016. * = significant difference with Baseline.

The pattern of increased abundance in Juvenile Hard Corals was observed across sites located in all reef zones in 2015, but many sites demonstrated lower recruit abundance in 2016. Note there is a very high level of variability within each zone in the 2015 and 2016 survey years (Figs. 20, 21).

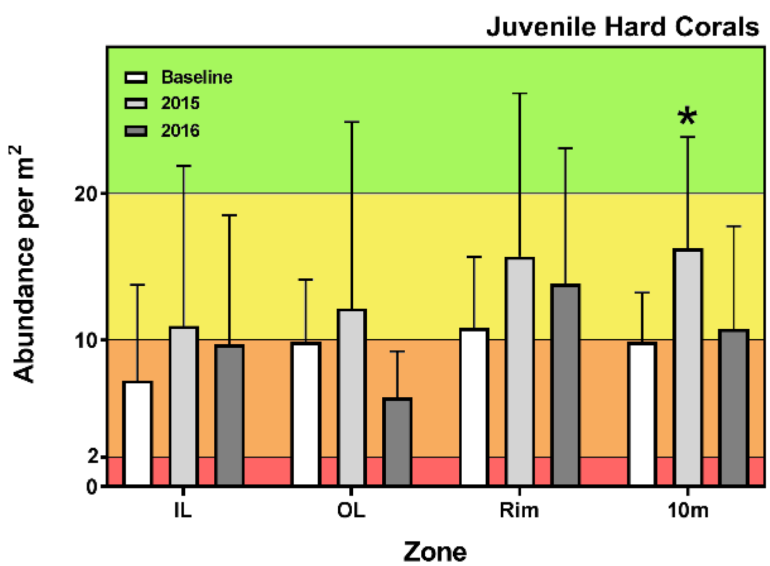


Fig. 19. Average abundance of Juvenile Hard Corals across the Baseline assessment period, 2015, and 2016, over the four zones surveyed across the Bermuda Reef Platform. * = significant difference with Baseline.

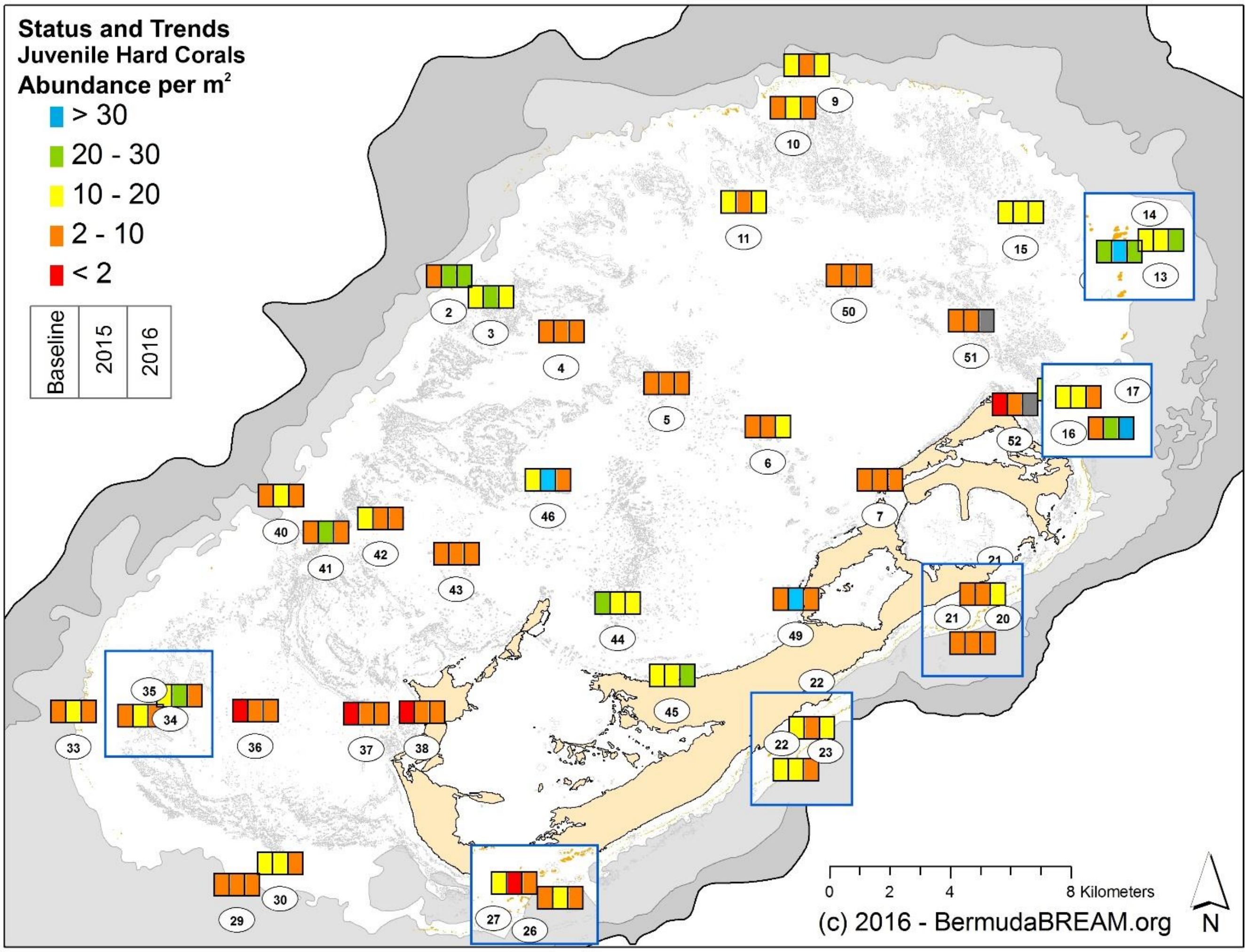


Fig. 20. Spatial distribution of abundance values per square meter for Juvenile Hard Corals (< 4 cm) across the Bermuda Reef Platform.

Coral Disease

The proportion of frames with coral disease was found to be 0.2099 (Critical) in 2015, but declined to 0.0956 (Good) in 2016 (Fig. 22). Coral diseases increased across all zones in 2015 (Figs. 23, 24), but not significantly in the Lagoon zones. Coral diseases increased at very highly significant level in the Rim Reef zone in 2015 but not significantly in 2016. Coral diseases only increased significantly in the 10-m Forereef zone in 2016.

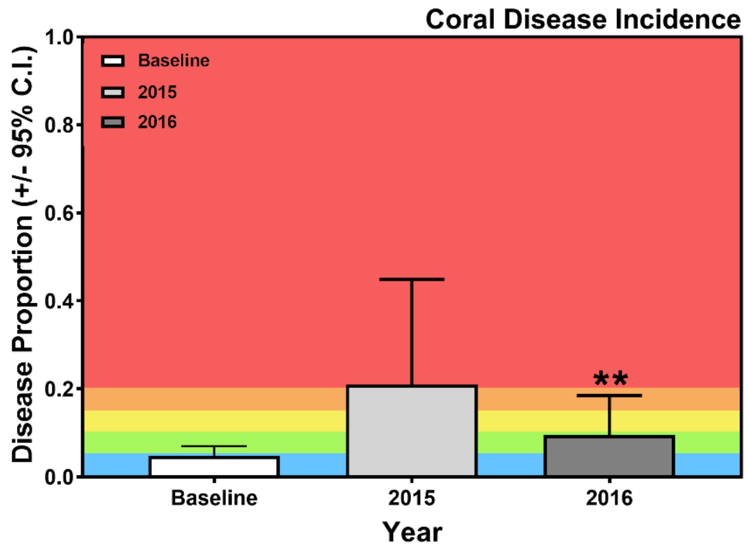


Fig. 21. Average proportion of frames in which coral disease was observed at each site in 2015 and 2016. Coral diseases assessed were black band disease, yellow band disease, and white plague. ** = highly significant difference with Baseline, more asterisks indicate more statistical significance.

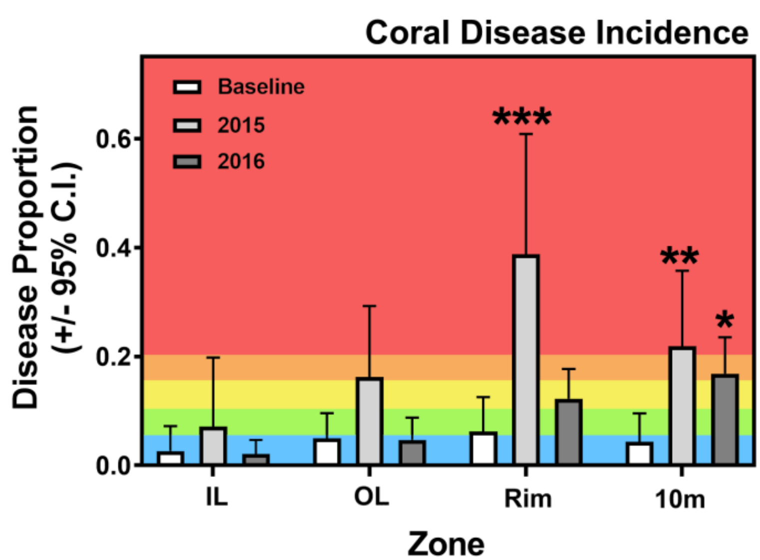


Fig. 22. Average proportion of frames with Coral Disease within each zone of the Bermuda platform in 2015 and 2016. * = significant difference with Baseline, more asterisks indicate greater statistical significance.

It should be noted that reporting disease frequency per quadrat probably overstates the incidence of disease relative to a "per colony" assessment such as that done by Weil and Cróquer (2009). Instead, the observation of sites with high proportions of quadrats with disease provides an indication (or "Red Flag Warning") that follow-up assessments at "Poor" and "Critical" reef sites is warranted.

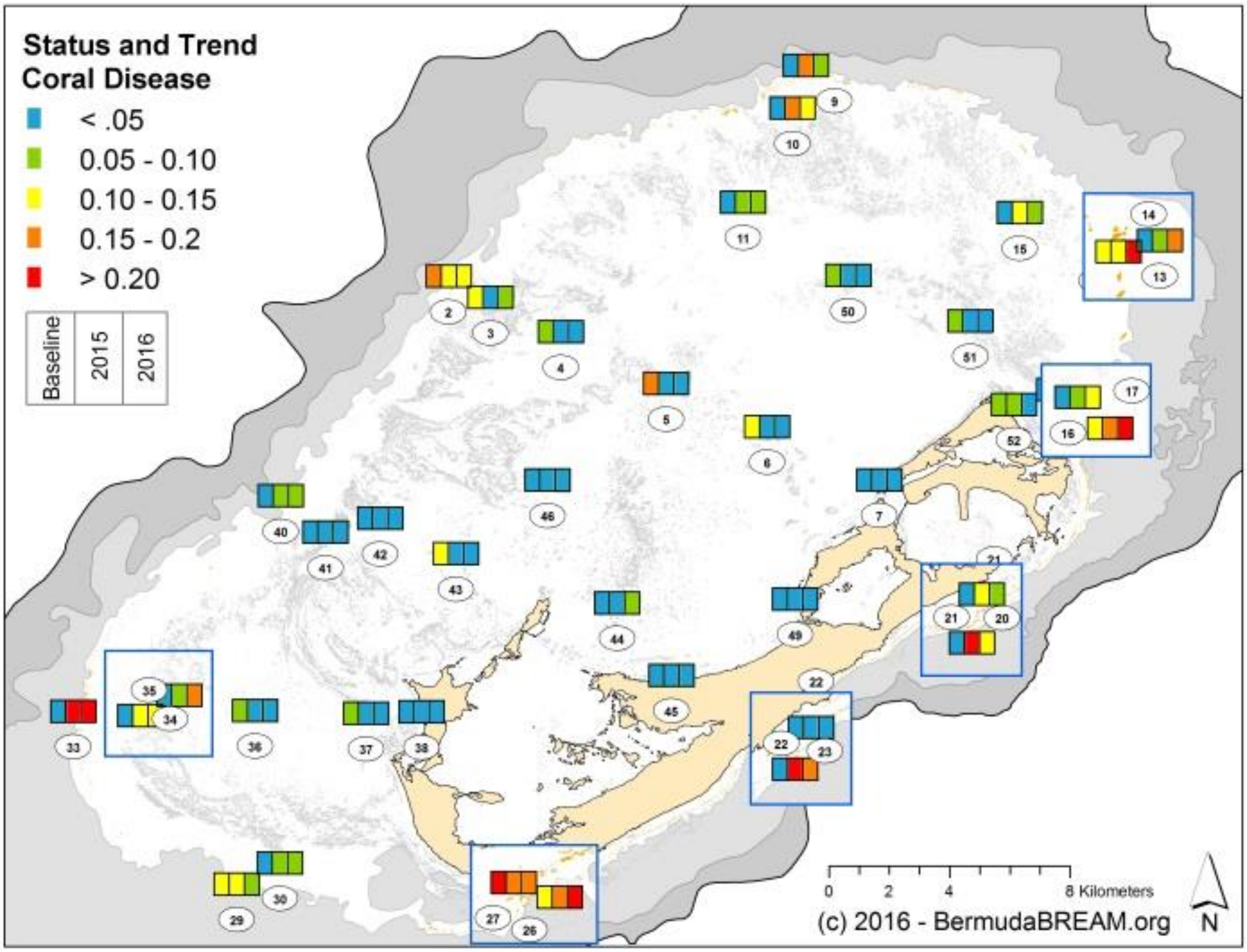


Fig. 23. Status and trends in the proportion of coral colonies (Baseline) or frames (2015, 2016) displaying coral diseases across the Bermuda Reef Platform.

Damselfishes

Damselfishes kill hard corals to create territorial turf algae patches that they then farm for food. The average abundance of territorial damselfishes (four species) in Baseline years, 2015, and 2016 is graphed in Fig. 24 below. Qualitatively, at a broad scale, damselfishes across the platform appear to have remained in Good abundance, but this is because the Rim and Forereef sites with low abundance are masking trends of high and increasing abundance occurring on the reefs surveyed in the lagoonal zones, as explained below.

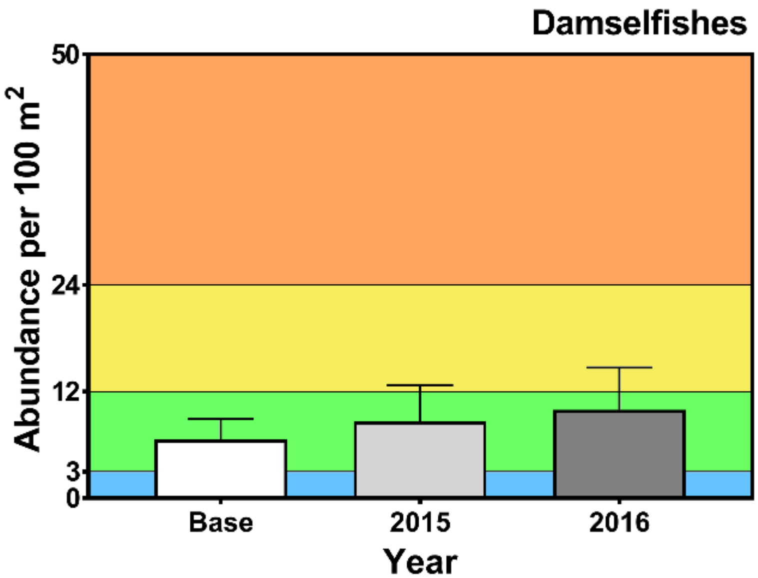


Fig. 24. Average abundance of territorial damselfishes per 100m^2 across the Bermuda Reef Platform in Baseline years, 2015 and 2016.

Damselfishes in Bermuda are abundant within the lagoon while rare in the Rim Reef and 10-m Forereef zones. Analysis at the level of reef zones confirmed that damselfishes are highly significantly more abundant in the Inner Lagoon and Outer Lagoon, and less abundant in Rim and 10-m Forereef habitats (Fig. 25, Fig. 26). Additionally, since the baseline assessments, abundances of damselfishes have been observed to have nearly doubled within the inner lagoonal zone (from 7.9 per 100-m^2 [Good] to 14.76 per 100-m^2 [Fair]), and very highly significantly increased within the Outer Lagoon (from 15.27 per 100m^2 [Fair] to 24.92 per 100-m [Poor]). There is a high degree of variability among reefs. This appears to be because lagoonal reefs within the middle of the lagoon are primarily displaying high abundances of damselfish, but these reefs are split between the Inner Lagoon and Outer Lagoon zones, while reefs close to shore in the Inner, and reefs near the Rim Reef zone in the Outer Lagoon, are not affected. Rim and 10-m Forereef zones exhibited Very Good (low) abundances of damselfishes across all years.

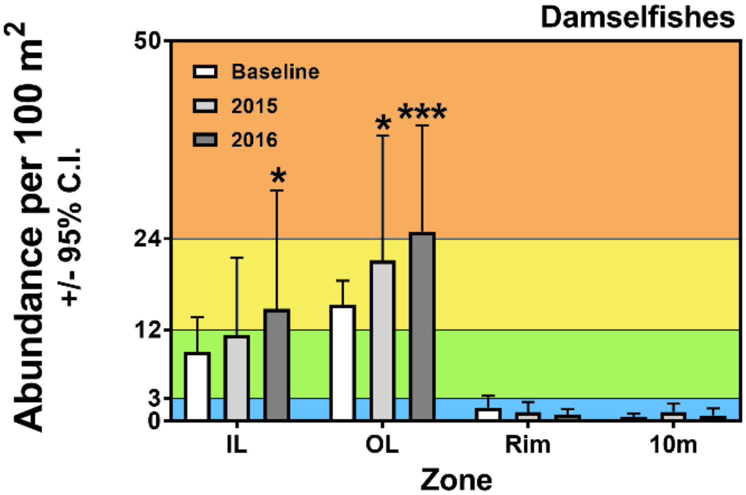


Fig. 25. Average abundance of territorial damselfishes per 100 m^2 across the four zones in Baseline years, 2015 and 2016. * = significant difference with Baseline, more asterisks indicate greater statistical significance.

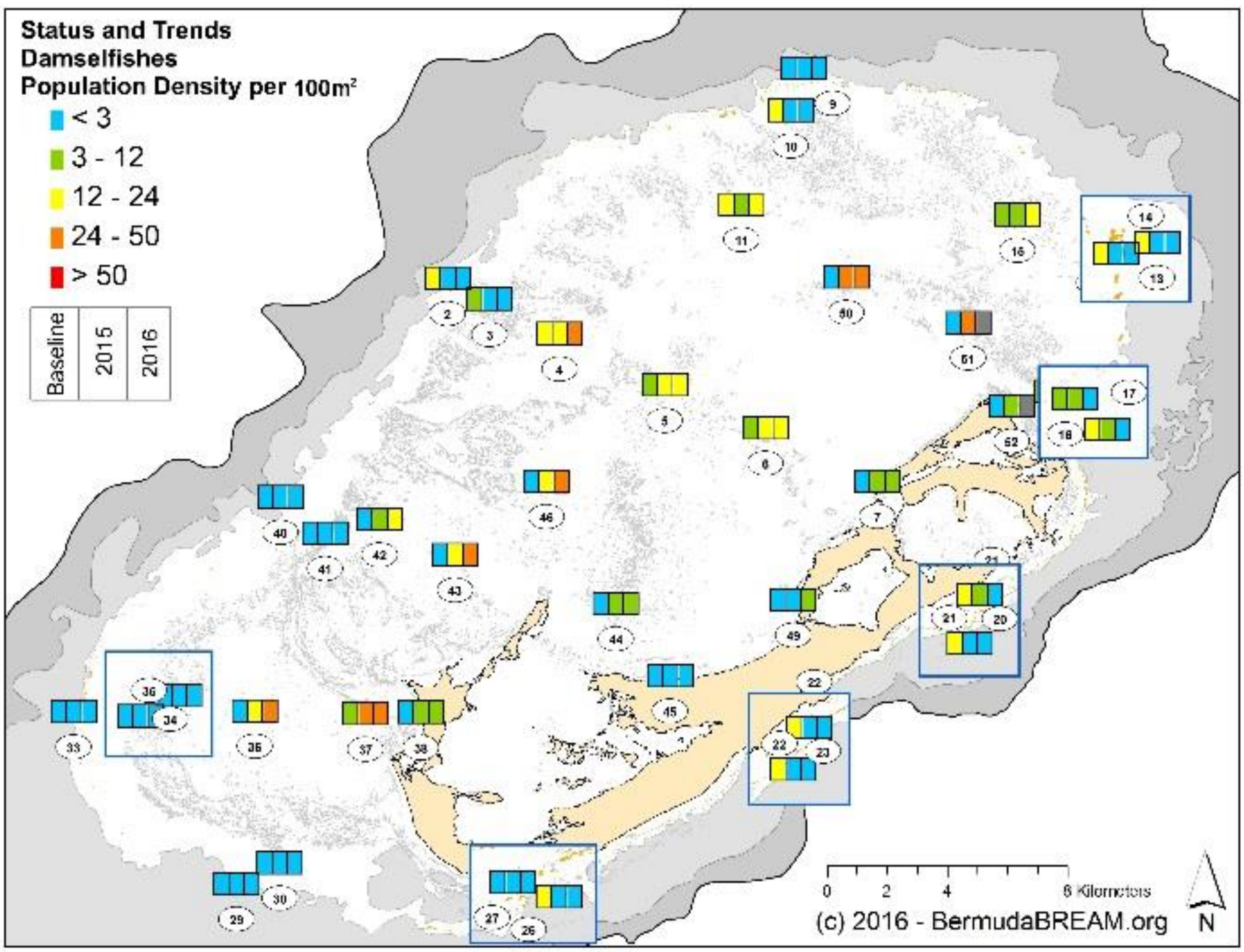


Fig. 26. A map of the density of territorial damselfishes per 100m^2 across the 39 sites surveyed.

Herbivorous Sea Urchins

Plant-eating sea urchins were observed to be at Critically low levels (below 1 per m^2) across the platform in 2015 and 2016. Their abundances are 1/3 what we observed during the Baseline surveys. The high degree of variability observed within zones is occurring because a few sites display a high abundance of sea urchins, while most sites were observed to have few to no sea urchins.

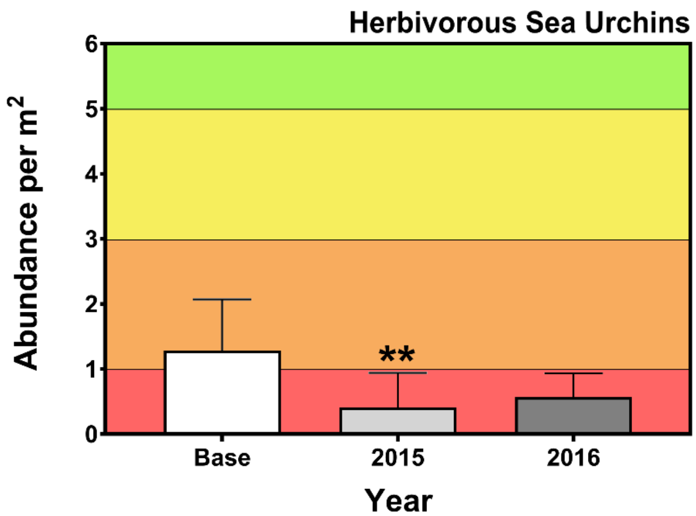


Fig. 27. A graph of the average abundance of herbivorous sea urchins across the Bermuda Reef Platform in Baseline years, 2015 and 2016. ** = significant difference with Baseline.

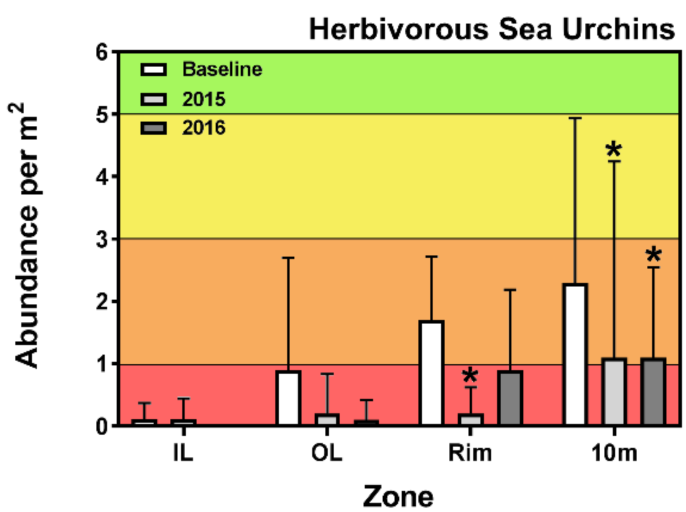


Fig. 28. Average abundance of herbivorous sea urchins within each of the four assessed reef zones on the Bermuda Reef Platform, during the Baseline, 2015 and 2016 assessment periods. * = significant difference with Baseline.

Microherbivore Snails and Hermit Crabs

We observed a substantial, and highly significant decline of microherbivores from ~60 per square meter in the Baseline surveys to only ~ 3 per square meter in 2016 (Fig. 31). Microherbivores were very abundant in the 10-m Forereef zone in the Baseline surveys across all sites (Fig 32), but their abundances in this zone showed a dramatic decline from over 170 per m^2 to ~3 per m^2. Baseline surveys were carried visually in the field, while 2015 and 2016 surveys were by visual assessment photographs. However, since the photographs were taken from a short distance from the reef surface, and at a high-resolution (i.e. at 120 pixels per linear centimetre of actual space), we do not expect the differences in method to have reduced our ability to observe the hermit crabs and snails in each quadrat.

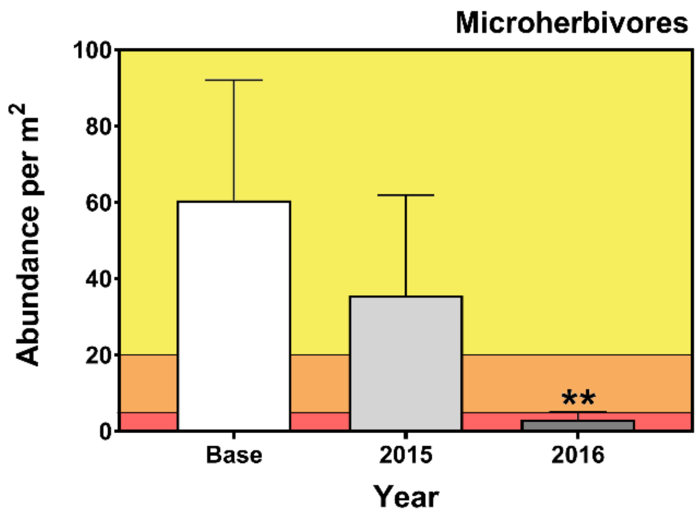


Fig. 29. The average abundance of microherbivorous snails and hermit crabs at Baseline and in 2015 and 2016 across the Bermuda Reef Platform.

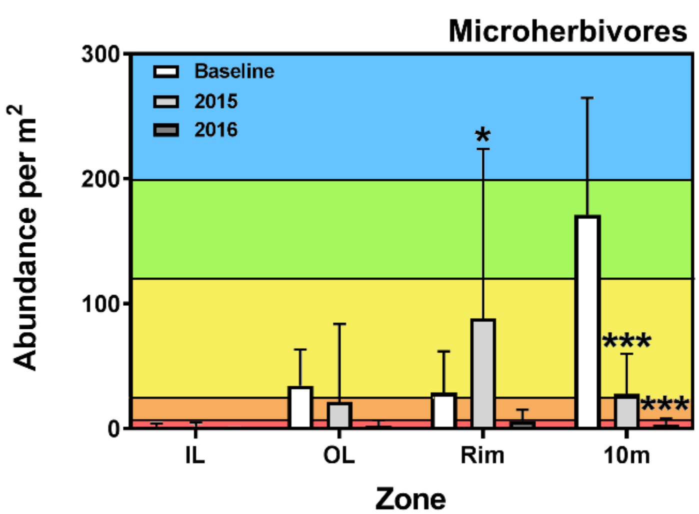


Fig. 30. The average abundance of microherbivorous hermit crabs and snails across four reef zones in Baseline years, 2015, and 2016. * = significant difference with Baseline, more asterisks indicate greater statistical significance.

CTB: Crustose Coralline Algae, Turf, Bare Space

We observed no statistically significant change in region scale CTB cover from the baseline years to 2016 (Fig. 34). However, significant declines of CTB from ~49% in the Baseline to ~35% cover in 2016 were observed in the 10-m Forereef zone, while all other zones showed no significant changes.

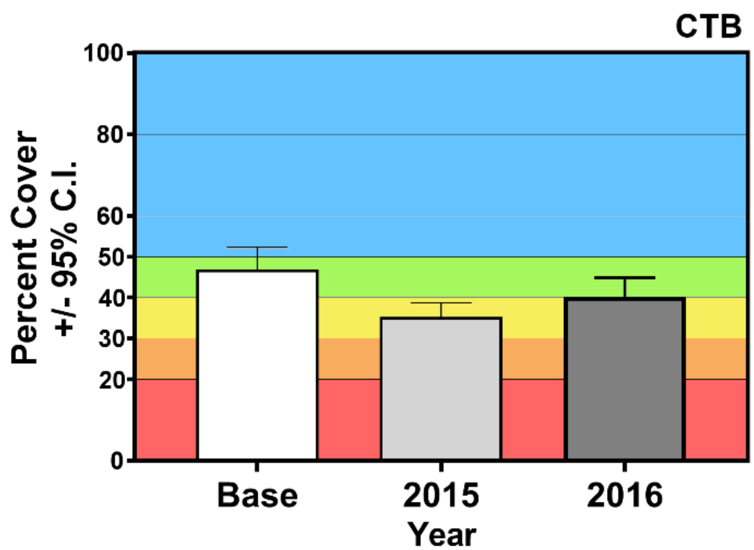


Fig. 31. A graph of the average percent cover of the CTB functional category during the Baseline assessment and in 2015 and 2016, across the Bermuda Reef Platform.

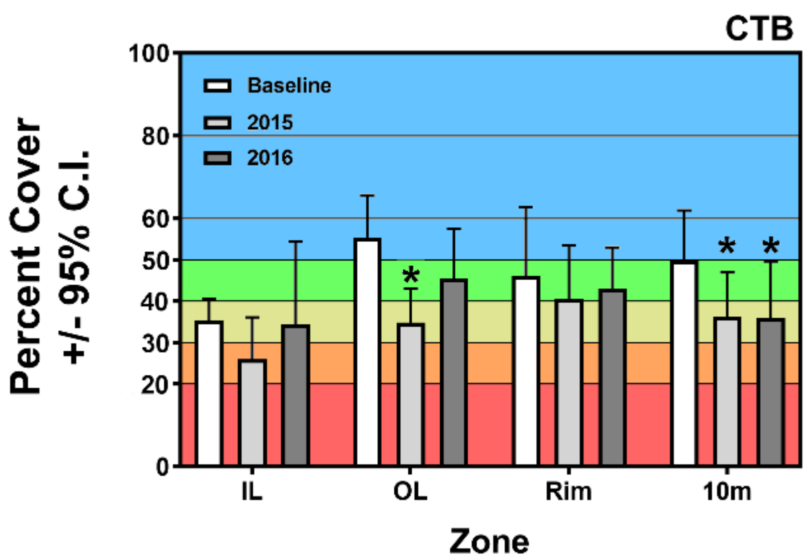


Fig. 32. The average percent cover of CTB over the four reef zones in the Baseline assessment period and in 2015 and 2016. * = significant difference with Baseline.

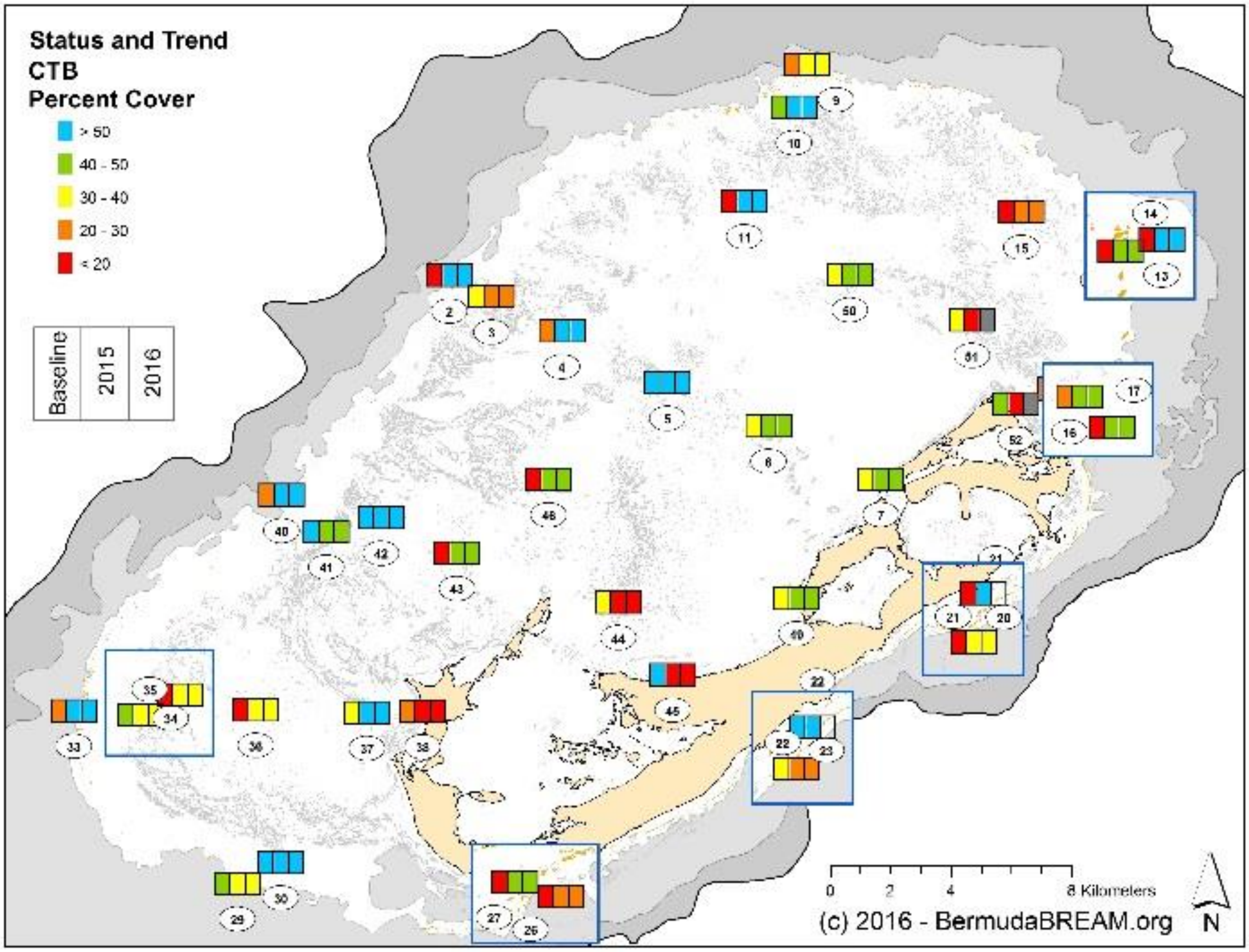


Fig. 33. A map of the distribution of CTB cover values across the Bermuda Reef Platform at the 39 monitoring locations.

Invasive Lionfishes

We have carried out rigorous and comprehensive surveys of Lionfishes since 2004 across all fish survey transects and along benthic transects.

Zero Lionfish were observed at any of the 39 survey sites in either the Baseline nor in years 2015 or 2016.

Comprehensive Results

The Sea Life Index and Component Reef Health Score for grouped sets (i.e. by Zone and by Region) of the 39 reefs assessed are illustrated in Fig. 34 and Fig. 35, and listed in Table 6 and Table 8 below. The manner that the Sea Life Index and component Reef Health Score parameters were spatially distributed across the 39 surveyed reef sites is illustrated Fig. 35, also below.

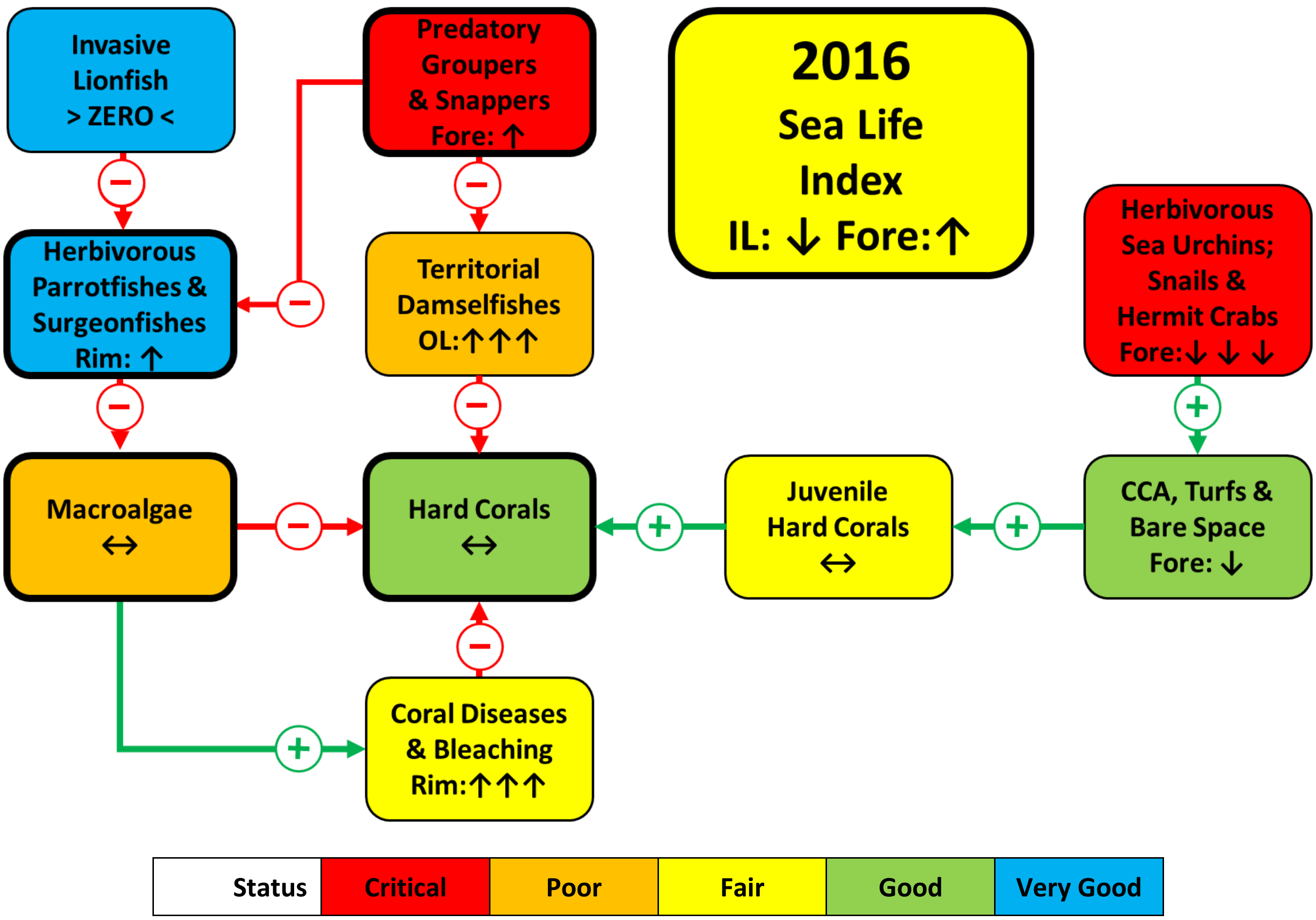


Fig. 34. A graphic representation of the status (box colour) and trend (arrow direction) of the 11 key factors of the 2016 long-term ecological monitoring project. ↑ arrows indicate a positive change in condition. ↓arrows indicate a negative trend in condition. The number of arrows indicates the degree of statistical significance of that change (i.e. ↑ =< 0.05; ↑↑ =< 0.01; ↑↑↑ =< 0.0001). ↔ indicates no significant statistical difference between baseline and 2016. Zones listed in boxes exhibited significant effects only. The four components of the Sea Life Index are represented by thick-walled boxes.

Table 6. The average values for the Sea Life Index scores for each zone, and for the Bermuda Reef Platform overall (Region) in the Baseline assessment and in 2015 and 2016. SLI values range from 1 to 5. Reef Life Scores are shown for each of the 4 categories in the three assessment periods. Predatory Fishes (PF) and Herbivorous Fishes (HF) values in g per 100m^2. Hard Corals (HC) and Fleshy Macroalgae (FM) values in percent cover. ↑ arrows indicate a positive change in condition. ↓arrows indicate a negative trend in condition. The number of arrows indicates the degree of statistical significance of that change (i.e. ↑ =< 0.05; ↑↑ =< 0.01; ↑↑↑ =< 0.0001). ↔ indicates no significant statistical difference between baseline and 2016. Green arrows indicate beneficial changes, red arrows indicate changes that reduce the resilience of reef assemblages.

Factor & Year	Units	Inner Lagoon	Outer Lagoon	Rim Reef	10-m Forereef	Region
Sea Life Index – Baseline	SLI	2.64	2.75	3.1	3.03	**2.78**
Sea Life Index – 2015	SLI	1.64	2.25	2.83	3.13	**2.55**
Sea Life Index - 2016		2.07	2.63	3.20	3.50	**2.92**
Status and Trend		↓	↔	↔	↑	↔
Predatory Fishes – Baseline	g.100m^{-2}	233.8	185.2	213.3	255.9	**216.3**
Predatory Fishes – 2015	g.100m^{-2}	217.6	75.73	159.4	489.9	**235.2**
Predatory Fishes – 2016	g.100m^{-2}	139.5	52.7	235.1	477.1	**233.1**
Status and Trend		↔	↔	↔	↑	↔
Herbivorous Fishes – Baseline	g.100m^{-2}	2419	3294	3819	4114	**3437**
Herbivorous Fishes – 2015	g.100m^{-2}	1506	2793	3608	2876	**2726**
Herbivorous Fishes – 2016	g.100m^{-2}	2691	5369	4835	5658	**4796**
Status and Trend		↔	↔	↑	↔	↑
Hard Corals – Baseline	% Cover	22.63	23.72	29.74	38.66	**28.84**
Hard Corals – 2015	% Cover	17.54	15.05	22.13	36.85	**23.65**
	% Cover	17.85	20.63	26.64	45.03	**28.32**
Status and Trend		↔	↔	↔	↑	↔
Fleshy Macroalgae – Baseline	% Cover	20.52	9.033	8.227	9.225	**12.3**
Fleshy Macroalgae –- 2015	% Cover	42.47	27.35	12.73	13.14	**23.07**
Fleshy Macroalgae –- 2016	% Cover	37.61	17.67	10.83	9.5	**17.51**
Status and Trend		↑↑	↔	↔	↔	↔

Reef Condition	**Critical**	**Poor**	**Fair**	**Good**	**Very Good**

Table 7–The average Reef Life Score values for each of the secondary reef condition parameters for each zone, and for the Bermuda Reef Platform Region, in the Baseline assessment and in 2015 and 2016. ↑ arrows indicate a positive change in condition. ↓arrows indicate a negative trend in condition. The number of arrows indicates the degree of statistical significance of that change (i.e. ↑ =< 0.05; ↑↑ =< 0.01; ↑↑↑ =< 0.0001). ↔ indicates no significant statistical difference between baseline and 2015. Green arrows indicate beneficial changes, red arrows indicate changes that reduce the resilience of reef assemblages.

Factor & Year	Units	Inner Lagoon	Outer Lagoon	Rim Reef	10-m Forereef	Region
Juvenile Hard Coral– Baseline	Count.m^{-2}	7.238	9.867	10.83	9.867	**9.272**
Juvenile Hard Coral– 2015	Count.m^{-2}	10.96	12.16	15.71	16.27	**13.52**
Juvenile Hard Coral– 2016	Count.m^{-2}	9.71	6.08	13.84	10.76	**10.13**
Status and Trend		↔	↔	↔	↔	↔
Coral Disease - Baseline	Prop. Colonies	0.027	0.050	0.063	0.044	**0.048**
Coral Disease – 2015	Prop. Frames	0.071	0.163	0.388	0.219	**0.210**
Coral Disease – 2016	Prop. Frames	0.021	0.048	0.123	0.169	**0.096**
Status		↔	↔	↑↑↑	↔	↔
Territorial Damselfishes – Baseline	Count.100 m^{-2}	7.9	15.27	1.767	0.55	**6.62**
Territorial Damselfishes – 2015	Count.100 m^{-2}	8.6	21.1	1.202	1.222	**8.638**
Territorial Damselfishes – 2016	Count.100 m^{-2}	14.76	24.93	0.833	0.767	**9.964**
Status and Trend		↑	↑↑↑	↔	↔	↔
Herbivorous Sea Urchins – Baseline	Count.m^{-2}	0.143	0.9	1.7	2.3	**1.282**
Herbivorous Sea Urchins –- 2015	Count.m^{-2}	0	0.2	0.2	1.1	**0.4103**
Herbivorous Sea Urchins –- 2016	Count.m^{-2}	0	0.1	0.9	1.1	**0.5676**
Status and Trend		↔	↔	↔	↓	↔
Microherbivores – Baseline	Count.m^{-2}	0.381	34.4	28.53	171.2	**60.58**
Microherbivores – 2015	Count.m^{-2}	1.829	21.31	88.45	27.84	**35.63**
Microherbivores – 2016	Count.m^{-2}	0.2286	2.24	5.867	3.147	**3.085**
Status and Trend		↔	↔	↔	↓↓↓	↓↓↓
CTB – Baseline	% Cover	36.48	58.81	46.07	49.82	46.85
CTB – 2015	% Cover	23.49	35.93	40.54	36.33	**34.93**
CTB – 2016	% Cover	34.27	46.58	43.7	35.94	**40.16**
Status and Trend		↔	↔	↔	↓	↔
Invasive Lionfish - Baseline	Count.100m^{-2}	0	0	0	0	0
Invasive Lionfish - 2015	Count.100m^{-2}	0	0	0	0	0
Invasive Lionfish - 2016	Count.100m^{-2}	0	0	0	0	0
Status and Trend		↔	↔	↔	↔	↔

Reef Condition	**Critical**	**Poor**	**Fair**	**Good**	**Very Good**

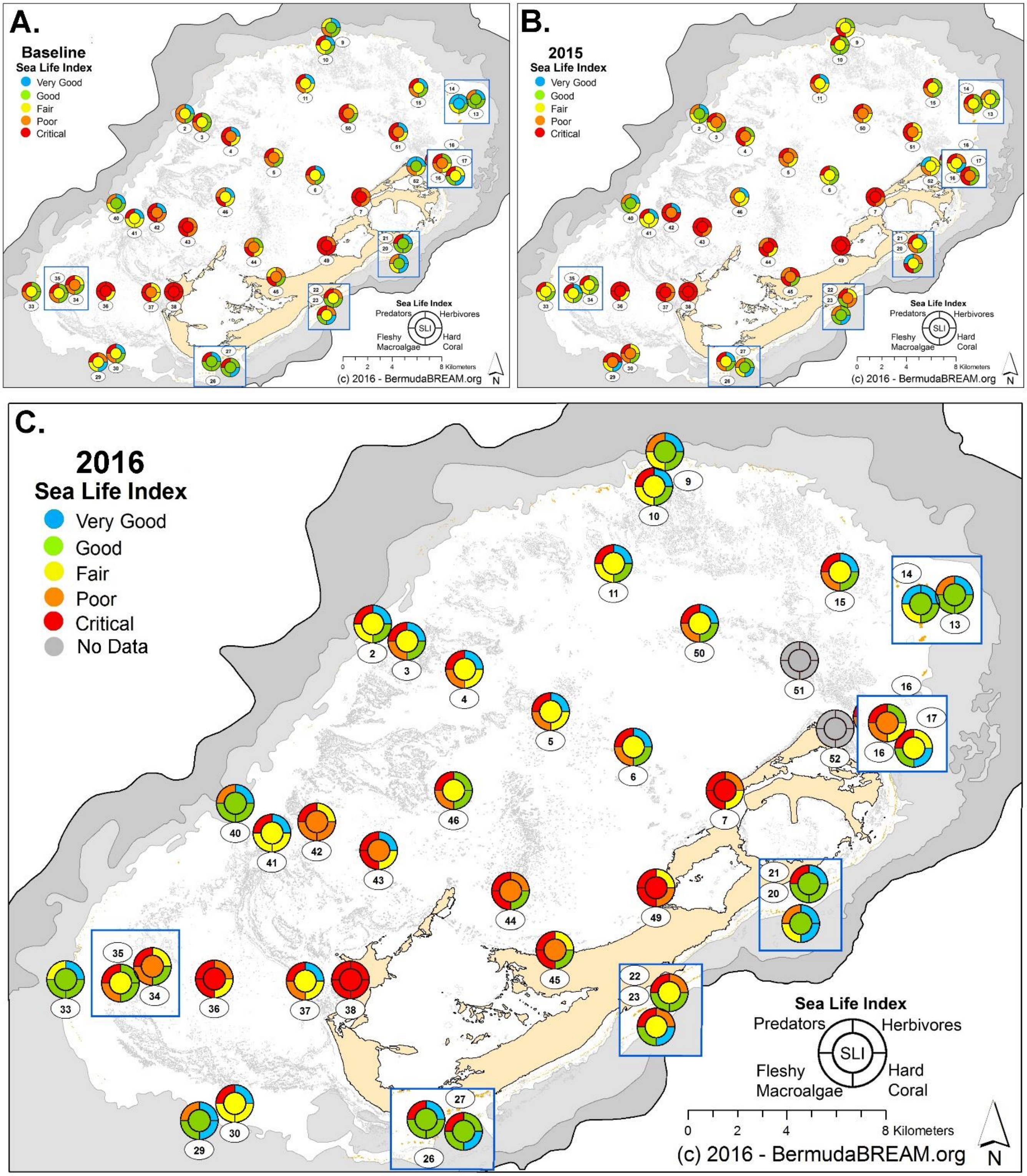


Fig. 35. Site by site values for the Sea Life Index, and component Reef Life scores across the 39 LTEM reef sites surveyed during the Baseline assessment, in 2015 and in 2016, using the GCRMN reef and fish assessment methodology. Grey circles (51 & 52) were not surveyed in 2016 only.

Table 8. The observed status and trend over time for each of the 11 measured metrics of reef condition in 2016.

Factor	Status	Trend	Action
Sea Life Index	Fair	↔	
Predatory Fishes – Biomass	Critical	↔	YES
Herbivorous Fishes – Biomass	Very Good	↑	
Hard Corals – Cover	Good	↔	
Fleshy Macroalgae – Cover	Poor	↔	YES
Juvenile Hard Corals	Fair	↔	
Coral Diseases & Bleaching – Prevalence	Fair	↔	YES
Territorial Damselfishes – Abundance	Poor	↑↑↑	YES
Herbivorous Sea Urchins – Abundance	Critical	↔	YES
Herbivorous Snails & Hermit Crabs – Abundance	Critical	↓↓↓	YES
Crustose Coralline Algae, Turfs, Bare Rock (CTB) – Cover	Good	↔	
Invasive Lionfish – Abundance	Very Good	↔	

Conclusions and Recommendations

Overall, the SLI remains Fair. This indicates that while the overall ecological condition of the Bermuda reef platform is adequate, there is room for improvement that should take place in the near future, while the ecosystem retains its resilience and capacity to recover from natural and anthropogenic impacts. The state of two of the four component factors, Predatory Fishes and Fleshy Macroalgae, indicate that human actions are the cause of the regional condition of our coral reefs.

Predatory Fishes remain in Critical condition across the platform, due to overfishing. Large sharks were not seen in any survey, and large grouper species are sparsely distributed across the platform. Mid-sized predatory fishes, which were not the focus of commercial fisheries effort until the 1980s, are also in low population densities. The latest Fisheries statistics (Bermuda Government 2017) have also found that the catch of these important commercial fish stocks is on the decline. These fishes play a critical role in maintaining the condition of Bermuda's coral reefs by controlling the abundance of potentially damaging fishes such as damselfishes and smaller parrotfish species. To allow predatory fish stocks to remain in a critical condition endangers both the state of our reefs and our national economy. *We recommend that the restoration of these fish stocks and enhanced protection along with improved management to prevent future declines should be a national priority.*

Herbivorous Fishes were found to be in Very Good condition across the region, and were seen to be in higher densities in the Outer Lagoon, Rim and 10-m Forereef zones in 2016 relative to 2015 and the Baseline surveys. The Very Good condition of Herbivorous Fishes concurs with the earlier conclusions by Luckhurst and O'Farrell (2014) and O'Farrell et al (2015) that parrotfishes and surgeonfishes have recovered in abundance and biomass since the total ban on the use of fish traps in April 1990. One possible reason for the significant increase in herbivorous fishes within the Outer Lagoon, which is composed of patch reefs, pinnacle reefs and faros, may be due to the difference in weather conditions between 2015 and 2016 experienced by the survey team. In 2015, many of the surveys were carried out when winds exceeded 15-kts, while surveys in 2016 were carried out when winds generally were less than 15-kts. It may be that parrotfishes chose to graze in deeper water habitats along the flanks of lagoonal pinnacle reefs and rim reefs in 2015 to avoid the turbulent water conditions. Calmer water in 2016 would mean parrotfishes could graze on the tops of patch and rim reefs without encountering turbulence in 2016.

Hard Corals remain in Good condition in 2016, with little change from 2015 or the Baseline surveys. Hard Corals appear to be occupying a higher percent of the 10-m Forereef surface than we observed in 2015. Such a dramatic increase seems unlikely to be caused by the rapid coral growth or the recruitment of new corals. Instead, the observation of increased coral cover at the 10m Forereef zone may be due to improvements we made in image analysis. We increased the number of points surveyed per frame from 25 to 100, although randomized points should provide statistically identical answers regardless of point number.

Fleshy Macroalgae remains in Poor condition in 2016, and was seen to be significantly higher in the Inner Lagoon zone. This could be due to the calmer weather observed in 2016, or due to increased nutrients as either produced from the dredging of the North and South shipping channels in 2016 or from some unidentified terrestrial source. On the 10-m Forereef, fleshy macroalgae decreased. Ecologically, it is possible that a decrease in macroalga cover occurred in 2016, due to observed increases in herbivorous fish biomass in the 10-m Forereef. *We recommend action to determine whether macroalgae continues to increase in cover within the Inner Lagoon, and the causes for its increase.*

Juvenile Hard Corals were observed to be statistically unchanging over the survey periods. This is positive news, as declines in juvenile coral abundance may lead to declines in adult hard coral in later years. It also provides an indication that data collected regarding the status of herbivorous snails and hermit crabs is valid, as both types of data are collected from the same quadrats.

Coral Disease was seen to be Poor in both the Rim and 10-m Forereef, with highly significant increases in disease prevalence observed within the Rim. *We recommend that further study of the dynamics and changes in coral disease in Bermuda be carried out as soon as possible.*

Territorial Damselfish are in Poor (i.e. high) abundance in 2016, and have increased substantially and significantly since both the Baseline surveys and 2015. Their biomass has doubled in Lagoon since Baseline!!! This is a ticking time bomb that needs to be addressed by improving stocks of meso-predatory fishes. *We recommend that the relationship between territorial damselfishes, the coral they harm, and the meso-predators that keep territorial damselfishes in check be assessed further. It may also be useful to close fishing on a very small number of lagoonal patch reefs for 2 to 4 years, to see if a reduction in human fishing pressure allows the recovery of meso-predatory fishes, and a subsequent reduction in the abundance of coral-damaging territorial damselfishes.*

Herbivorous Sea Urchins were observed to remain in Critical condition in 2016, with an additional decline in abundance on the 10-m Forereef. It may be that predation has increased on this now rare group of sea urchins. *We recommend adding sea urchin predators to the fish assessments in future surveys. In addition, echinoderms including sea urchins often are very patchily distributed on the scales of 100-m to 10-km. Large-scale drift surveys across the Rim and 10-m Forereef zones, which document the location and extent of high-density patches of sea urchins is advised.*

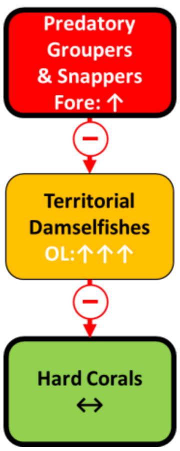
Microherbivorous Snails and Hermit Crabs also were seen to be in Critical (low) condition and to have declines substantially and in a highly significant manner in 2016 relative to Baseline surveys. The microherbivores probably play a very important role in maintaining CTB habitat, which is in turn critical for the recruitment of new hard coral juveniles. Either an increase in predation or an increase in mortality due to disease or pollution may have caused the widespread and substantial decline in the abundance of these small plant-eating organisms. *We strongly recommend that focused follow-up surveys of the important Microherbivore group be undertaken as soon as possible across the Rim and 10-m Forereef zones.*

CTB was also observed to decline on 10-m Forereef. Reef cover can change from Crustose Coralline Algae, Turf and Bare space to Hard Corals, Macroalgae, or to other biota including sponges, soft corals and other sessile invertebrate organisms. Different factors drive the change to each of these other forms of biotic cover, and the mechanisms of change for each kind of biota are sometimes controversial or ambiguous. For instance, the loss of CTB to Fleshy Macroalgae may be due to either a decrease in herbivory or to an increase in nutrient concentrations (recently reviewed in Adam et al 2015). The loss of microherbivores, or the increase in other benthic categories may be the cause of the loss of this critical microhabitat. Since Hard Corals were observed to increase in 2016, the reduction in CTB may be expected to be a natural consequence of this change in biotic cover, and would be a beneficial change to the 10-m Forereef habitat.

Invasive Lionfish were not observed in any transect across the 37 sites in 2016. In contrast, in 2012 lionfish were observed in over 25% of reef sites across the Mesoamerican region when using the same survey methods (Healthy Reefs Initiative 2012). In Belize, no lionfish were observed across 16 sites at 10-

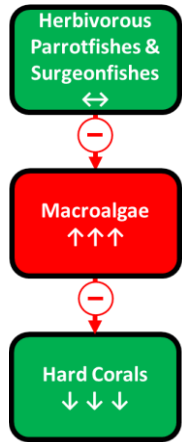
m depth using the same methodology in 2009, while in 2012 the same team recorded lionfish at 14 of 16 sites. The ecological rarity of these meso-predators in Bermuda relative to other Caribbean countries, specifically in the shallow water habitats assessed in this survey, where juvenile parrotfish are known to recruit and have their strongest ecological impact is very positive news. In addition, Eddy et al (2016) determined that juvenile parrotfishes are not a major component of the diet of Bermuda lionfish. Additional analysis of the BREAM LTEM data of juvenile parrotfish abundance may further illustrate the lack of ecological impact by lionfish across the shallow reef platform.

Predictions of Future Reef Zone Trends based on Food Web Dynamics

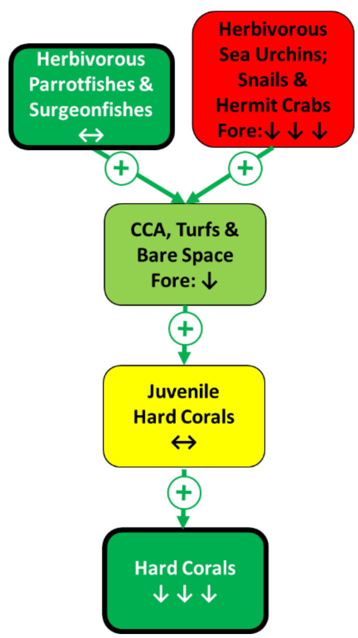


Increases in Predatory Groupers and Snappers can be predicted to cause a decline in Territorial Damselfish, and a resultant increase in Hard Coral cover. Conversely, declines in the biomass of Predatory Fishes will release Territorial Damselfishes from predation in lagoonal reef zones, and may cause the long-term decline in coral cover.

In the Inner Lagoon, Predatory Fishes were Critical, and Territorial Damselfishes were Fair, but increasing. Hard Corals in the Inner lagoon are Fair now, and may decrease in the future without some control of the Damselfishes. In the Outer Lagoon, Predatory Fishes were Critical, and Territorial Damselfishes were Poor, but increasing. Hard Corals are Good now, and may decrease in the future if the impact of damselfishes is not reduced. In the Rim Reef, Predatory Fishes were Critical, and Territorial Damselfishes were Very Good, but did not change. Hard Corals are Good now, and expected to remain the same in the future. In the 10-m Forereef, Predatory Fishes were Poor, and Territorial Damselfishes were Very Good, but did not change. Hard Corals are Very Good now, and expected to remain the same in the future.



Herbivorous Fishes consume fleshy Macroalgae, which otherwise can overgrow Hard Corals, or in other ways cause Hard Coral cover to decline. In the Inner Lagoon, Herbivorous Fishes were Fair, and Fleshy Macroalgae were Critical, but substantially increasing. Hard Corals are Fair now, and may substantially decrease in the future. In the Outer Lagoon, Herbivorous Fishes were Very Good, and Fleshy Macroalgae were Poor, but did not change. Hard Corals are Good now, and expected to remain the same in the future. In the Rim Reef, Herbivorous Fishes were Very Good, and Fleshy Macroalgae were Fair, but did not change. Hard Corals are Good now, and expected to remain the same in the future. In the 10-m Forereef, Herbivorous Fishes were Very Good, and Fleshy Macroalgae were Fair, but did not change. Hard Corals are Very Good now, and expected to remain the same in the future.



The Herbivorous Fishes and Invertebrates as a group graze the reef surface and prevent Fleshy Macroalgae and thick Turf algae from dominating space. This promotes the cover of CCA and Bare Space. Juvenile Hard Corals recruit preferentially to CCA and Bare Space. High abundance of Juvenile Hard Corals is required to sustain adult Hard Coral populations in the future. In the Inner Lagoon, Herbivorous Fishes were Fair, Herbivorous Sea Urchins were Critical, and Microherbivores were Critical. This can be predicted to cause CTB at present to decrease, which will cause Juvenile Hard Corals to decline and Hard Corals to also decline in the future. In the Outer Lagoon, Herbivorous Fishes were Very Good, Herbivorous Sea Urchins were Critical, and Microherbivores were Critical. This can be predicted to cause CTB at present to remain the same, which will cause Juvenile Hard Corals to remain the same and Hard Corals to remain the same in the future. In the Rim Reef, Herbivorous Fishes were Very Good, Herbivorous Sea Urchins were Critical, and Microherbivores were Poor. This can be predicted to cause CTB at present to remain the same, which will cause Juvenile Hard Corals to remain the same and Hard Corals to remain the same in the future. In the 10-m Forereef, Herbivorous Fishes were Very Good, Herbivorous Sea Urchins were Poor, and Microherbivores were Critical. This can be predicted to cause CTB at present to substantially increase, which would cause Juvenile Hard Corals to increase and Hard Corals to increase in the future.

Recommendations for Action

The recommendations made in the sections above are summarized below:

7. The restoration of grouper and snapper stocks and enhanced protection along with improved management to prevent future declines should be a national priority.
8. Determine whether macroalgae continues to increase in cover within the Inner Lagoon, and the causes for its increase.
9. Further study of the dynamics and changes in coral disease in Bermuda should be carried out as soon as possible.
10. The relationship between territorial damselfishes, the coral they harm, and the meso-predators that keep territorial damselfishes in check be assessed further. It may also be useful to close fishing on a very small number of lagoonal patch reefs for 2 to 4 years, to see if a reduction in human fishing pressure allows the recovery of meso-predatory fishes, and a subsequent reduction in the abundance of coral-damaging territorial damselfishes.
11. Add sea urchin predators to the fish assessments in future surveys. In addition, echinoderms including sea urchins often are very patchily distributed on the scales of 100-m to 10-km. Large-scale drift surveys across the Rim and 10-m Forereef zones, which document the location and extent of high-density patches of sea urchins is advised.
12. Focused follow-up surveys of the important Microherbivore group be undertaken as soon as possible across the Rim and 10-m Forereef zones.

Additional Recommended Management Actions or Changes to Policy

In addition to the recommendations above, we still recommend that current or new management options are implemented to pursue the following management strategies:

A: Support the Monitoring of Coral Reefs and Fishes

This report represents the national assessment of the condition of Bermuda's coral reefs and fishes, as part of the international Global Coral Reef Monitoring Network assessment of reefs across the Caribbean. The project was partially funded by two non-government grants by the Bermuda Zoological Society and the XL-Catlin End-to-End Marine Research Grant. However, the project was only possible through the donation of a substantial amount of time and resources by the BREAM programme and the Murdoch and Gosling families.

The Bermuda Government has committed to the protection and management of Bermuda's coral reefs and marine resources through the creation of policy and via its commitments to several local and international conventions, including the Bermuda Biodiversity Action Plan, the Convention on Biological Diversity, the Convention of Migratory Species, and the Convention of Wetlands of International Importance.

As such, future monitoring of the status and condition of fishes and coral reefs should be supported and funded, at least to some extent, by the Bermuda Government.

B. Support the Development of an Environmental Decision-Making Protocol

Changes in each factor assessed within this BREAM LTEM project should function as indicators that are directly linked to specific management and conservation actions. It would be preferable that Government and Non-Government stakeholders assisted in the development of an Environmental Decision-Making Protocol (EDMP)that defined what actions were available and appropriate responses to changes in the abundance or distribution or status of each of the critical reef health indicators we assess in this report. The development of an EDMP would accelerate the rate at which resource managers and conservationist could respond to problematic changes in the condition of our reefs or fish stocks, and would provide nationally accepted goals for marine environmental health and resilience.

C: Restoration of Predatory Fish Populations

7. Enhance the stocks of groupers by introducing a limited ban on the capture and sale of Black groupers during their spawning period (as we currently do with spiny lobster), based on evidence of the timing of their maximum aggregation at spawning sites.
8. Consider bag and size limits on grey snappers, schoolmaster snappers, yellowtail snappers, graysbys and coneys.
9. Expand our knowledge of juvenile predatory fish habitats, which are generally within the lagoon (patch reefs), along the shore (nearshore), and within enclosed bays (inshore). Many species of offshore reef fish, including predatory fish species, start life by settling as juvenile fish to coastal habitats, only to move offshore as they mature.
10. Reduce coastal development and pollution impacts to the marine environment, as many juvenile reef fishes are found the inshore and nearshore waters first before they move to outer reef areas.
11. Design coastal structures such as docks and breakwaters with rough surfaces or attachments so that they provide additional habitat for juvenile and adult fishes.

D. Expand Marine Spatial Protected Areas

Protected areas act as a marine resource “banks” and provide “interest” in the form of continuously available fishes for commercial and recreational harvest, through the spill-over effect, and enhanced reproductive output. We recommend the expansion in the distribution of protected areas that span the reef platform from inshore bays, along lagoonal chains of reefs, out to the forereef. These areas are juvenile habitats that are current threatened due to a lack of smaller predatory fishes and high damselfish densities. Networks of protected reefs allow fish to transition from zone to zone throughout their life cycle.

E. Expand the Fishing License Programme

Recently the Fishing License programme was expanded to include recreational spear fishers. We recommend that all recreational fishers require a licence. This would include both those fishing from the shore and those using marine craft. Access to fishing activity should not be financially onerous to those with low income, however. No-cost licences to locals who use hand lines within their parish of residence could be provided so that the financially challenged retain access to fishing activities.

F. Recommendations for Environmental Organizations

Many of the recommended actions within this report are also within the range of issues addressed by local environmental organizations. We hope that these recommendations are adopted by local stakeholders. We offer our services in providing the members of local non-government organizations with lectures and information that supports the sharing of information on how to better manage and improve the condition of Bermuda’s coral reefs.

New Government Policies

We also support the following changes to the Bermuda Government marine management strategies and policies that took place in 2016 and 2017:

1. Moved the timing of protection of the red hind grounds from May 1 to Aug 31 to April 15 to Aug 14, as the red hinds were seen to be aggregating early in 2013 and 2014.
2. Extended closure of the Black Grouper aggregation areas until December 1st
3. Changed bag limit of red hind to 10 per day for recreational fishermen, and 50 per day in April for commercial fishermen.
4. Sewage management for boat owners.

References

ArcGIS 9.2 Desktop Help. http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=welcome

Adam TC, Burkepile DE, Ruttenberg BI, Paddack MJ. (2015) Herbivory and the resilience of Caribbean coral reefs: knowledge gaps and implications for management. Marine Ecology Progress Series;520:1-20.

Arnold SN, Steneck RS, Mumby PJ.(2010) Running the gauntlet: inhibitory effects of algal turfs on the processes of coral recruitment. Marine Ecology Progress Series. 414:91-105.

Bardach JE. (1959) The summer standing crop of fish on a shallow Bermuda reef. Limnology and Oceanography:77-85.

Beijbom O, Edmunds PJ, Roelfsema C, Smith J, Kline DI, Neal B, Dunlap MJ, Moriarty V, Fan T-Y, Tan C-J, Chan S, Treibitz T, Gamst A, Mitchell BG, Kriegman D (2015) Towards automated annotation of benthic survey images: variability of human experts and operational modes of automation. PLOS One.

Bermuda Government (2017) Environmental Statistics Compendium 2017. Bermuda Government, Department of Statistics. https://www.gov.bm/sites/default/files/Environmental-Statistics-Compendium-2017.pdf Accessed 24/01/2018

Birrell CL, McCook LJ, Willis BL (2005) Effects of algal turfs and sediment on coral settlement. Marine Pollution Bulletin. 51(1):408-14.

Coates KA, Fourqurean JW, Kenworthy WJ, Logan A, Manuel SA, Smith SR. (2013) Introduction to Bermuda: geology, oceanography and climate. In: Coral Reefs of the United Kingdom Overseas Territories (pp. 115-133). Springer Netherlands.

Cróquer A, Weil E. (2009) Spatial variability in distribution and prevalence of Caribbean scleractinian coral and octocoral diseases. II. Genera-level analysis. Diseases of aquatic organisms.83(3):209-22.

Donahay PL, Liss PS, Duce RA, Kester DR, Hanson AK, Villareal T, Tindale NW, Gifford DJ. (1991) The role of episodic atmospheric nutrient inputs in the chemical and biological dynamics of oceanic ecosystems. Oceanography. 4(2):62-70.

Eddy C, Pitt J, Morris Jr JA, Smith S, Goodbody-Gringley G, Bernal D. (2016) Diet of invasive lionfish (Pterois volitans and P. miles) in Bermuda. Marine Ecology Progress Series. 2016 Oct 25;558:193-206.

Flower J, Ortiz JC, Chollett I, Abdullah S, Castro-Sanguino C, Hock K, Lam V, Mumby PJ. (2017) Interpreting coral reef monitoring data: A guide for improved management decisions. Ecological Indicators 72:848-69.

Fourqurean JW, Manuel SA, Coates KA, Kenworthy WJ, Boyer JN (2015) Water quality, isoscapes and stoichioscapes of seagrasses indicate general P limitation and unique N cycling in shallow water benthos of Bermuda. Biogeosciences. 12(20):6235-49.

GCRMN Caribbean Monitoring Steering Committee (2016) GCRMN-Caribbean Guidelines For Coral Reef Biophysical Monitoring. Seventh Meeting of the Scientific and Technical Advisory Committee (STAC) to the Protocol Concerning Specially Protected Areas and Wildlife (SPAW) in the Wider Caribbean Region Miami, Florida, 2 - 4 November 2016 18 pp.
Available at http://www.car-spaw-rac.org/?The-GCRMN-Caribbean-guidelines,639 Accessed: Jan 23, 2017.

Harborne AR, Rogers A, Bozec YM, Mumby PJ (2017) Multiple Stressors and the Functioning of Coral Reefs. Annual Review of Marine Science.9:445-68.

Hughes TP (1994) Catastrophes, phase shifts, and large-scale degradation of a Caribbean coral reef. Science 265: 1547-1551.

Idjadi JA, Haring RN, Precht WF (2010) Recovery of the sea urchin *Diadema antillarum* promotes scleractinian coral growth and survivorship on shallow Jamaican reefs. Marine Ecology Progress Series 403: 91-100.

Jameson SC, Erdmann MV, Karr JR, Potts KW (2001) Charting a course toward diagnostic monitoring: a continuing review of coral reef attributes and a research strategy for creating coral reef indexes of biotic integrity. Bulletin of Marine Science. 69(2):701-44.

Jackson JB, Donovan MK, Cramer KL, Lam VV. Status and trends of Caribbean coral reefs. Gland: Global Coral Reef Monitoring Network, IUCN.
Available at: http://cmsdata.iucn.org/downloads/caribbean_coral_reefs___status_report_1970_2012. pdf. 2014 Accessed January 23, 2018

Lang JC (ed.) (2003) Status of Coral Reefs in the western Atlantic: Results of initial Surveys, Atlantic and Gulf Rapid Reef Assessment (AGRRA) Program. Atoll Research Bulletin 496

Lessios HA (2016) The great Diadema antillarum die-off: 30 years later. Annual Review of Marine Science: 8:267-83.

Luckhurst BE, O'Farrell S. (2014) Rapid recovery of parrotfish (Scaridae) and surgeonfish (Acanthuridae) populations following the fish pot ban in Bermuda. InProc Gulf Caribb Fish Inst (66):301-306.

Marks KW, Klomp, KD. (2003) Fish biomass conversion equations. Pp. 625-628 in J.C. Lang (ed.), Status of Coral Reefs in the western Atlantic: Results of initial Surveys, Atlantic and Gulf Rapid Reef Assessment (AGRRA) Program. Atoll Research Bulletin 496

McField M R,Kramer P (2007) Healthy Reefs for Healthy People: A Guide to Indicators of Reef Health and Social Well-being in the Meso-American Reef Region. With contributions by M. Gorrez and M. McPherson. The Smithsonian Institution, Belize City, Belize: 208 pp.

McManus JW, Polsenberg JF (2004) Coral–algal phase shifts on coral reefs: ecological and environmental aspects. Progress in Oceanography 60(2):263-79.

Murdoch TJT, Murdoch JMH (2016) Baseline condition of the coral reefs and fishes across three depth zones of the forereef of Bermuda. BREAM: Bermuda Reef Ecosystem Analysis and Monitoring Programme Report, Bermuda Zoological Society, Flatts Bermuda. BBP-2016-237.

Murdoch TJT (2017) Status and Trends of Bermuda Reefs and Fishes: 2015 Report Card. BREAM: Bermuda Reef Ecosystem Analysis and Monitoring Programme Report, Bermuda Zoological Society, Flatts Bermuda. BBP-2017-256.

O'Farrell S, Harborne AR, Bozec YM, Luckhurst BE, Mumby PJ.(2015) Protection of functionally important parrotfishes increases their biomass but fails to deliver enhanced recruitment. Marine Ecology Progress Series 522:245-54.

Piontek S (2016) Final Report St Eustatius 2016 Global Coral Reef Monitoring Network. Dutch Caribbean Biodiversity Database. pp:15

http://www.dcbd.nl/document/final-report-steustatius-2016-global-coral-reef-monitoring-network

Smith SR (1988) Recovery of a disturbed reef in Bermuda: in fluence of reef structure and herbivorous grazers on algal and sessile invertebrate recruitment. In: Proceedings of the 6th International Coral Reef Symposium: 2. Townsville, pp 267–272

Smith SR, de Putron S, Murdoch TJ, Pitt JM, Nagelkerken I (2013) Biology and ecology of corals and fishes on the Bermuda Platform. InCoral Reefs of the United Kingdom Overseas Territories. pp. 135-151). Springer Netherlands.

Smith SR, Sarkis S, Murdoch TJ, Weil E, Croquer A, Bates NR, Johnson RJ, de Putron S, Andersson AJ (2013) Threats to coral reefs of Bermuda. InCoral reefs of the United Kingdom overseas territories. pp. 173-188). Springer Netherlands.

Stewart HL, Carpenter RC (2003) The effects of morphology and water flow on photosynthesis of marine macroalgae. Ecology. 84(11):2999-3012.

van Beukering P, Sarkis S, van der Putten L, Papyrakis E (2015) Bermuda' s balancing act: The economic dependence of cruise and air tourism on healthy coral reefs. Ecosystem Services. 11:76-86.

Weil E, Cróquer A. (2009) Spatial variability in distribution and prevalence of Caribbean scleractinian coral and octocoral diseases. I. Community-level analysis. Diseases of aquatic organisms. 83(3):195-208.

Wilkinson CR (1999) Global and local threats to coral reef functioning and existence: review and predictions. Marine and Freshwater Research. 50(8):867-78.

Appendix 1: Site Locations and Linkages

Funding	ID	Lat	Long	Name	Depth	Linkage
LTEM	1	32.427916	-64.869009	Devils	20-m	1
LTEM	2	32.426445	-64.867328	Devils	10-m	1
Catlin	3	32.420172	-64.852499	Devils	Rim	1
LTEM	4	32.409898	-64.827749	Devils	OL	1
LTEM	5	32.394442	-64.790582	Crescent	OL	1
LTEM	6	32.381549	-64.754926	Baileys	IL	1
LTEM	7	32.365644	-64.715355	WhaleBay	IL	1
LTEM	8	32.491596	-64.741539	Conch	20-m	8
LTEM	9	32.48952	-64.74134	Conch	10-m	8
Catlin	10	32.476784	-64.745957	Conch	Rim	8
LTEM	11	32.448686	-64.763414	Grid	OL	8
LTEM	12	32.434972	-64.610169	Kitchen	20-m	12
LTEM	13	32.436383	-64.625783	Kitchen	10-m	12
Catlin	14	32.435685	-64.628792	Kitchen	Rim	12
LTEM	15	32.445463	-64.665775	Kitchen	OL	12
LTEM	16	32.392644	-64.65198	SeaVentu	10-m	16
Catlin	17	32.390225	-64.649019	SeaVentu	Rim	16
LTEM	18	32.38467	-64.646838	SeaVentu	20-m	16
LTEM	19	32.318762	-64.672866	Kate	20-m	19
LTEM	20	32.325391	-64.686693	Kate	10-m	19
Catlin	21	32.330728	-64.685434	Kate	Rim	19
Catlin	22	32.289543	-64.750341	HungryBa	Rim	22
LTEM	23	32.294149	-64.748222	HungryBa	10-m	22
LTEM	24	32.271956	-64.751086	HungryBa	20-m	22
LTEM	25	32.228189	-64.833227	Sonesta	20-m	25
LTEM	26	32.243418	-64.824544	Sonesta	10-m	25
Catlin	27	32.244607	-64.828966	Sonesta	Rim	25
LTEM	28	32.215963	-64.932713	Chaddock	20-m	28
LTEM	29	32.24471	-64.941626	Chaddock	10-m	28
Catlin	30	32.250996	-64.926417	Chaddock	Rim	28
LTEM	31	32.272182	-64.911783	Chaddock	OL	28
LTEM	32	32.30105	-65.003984	Chub Hea	20-m	32
LTEM	33	32.296218	-64.999295	Chub Hea	10-m	32
Catlin	34	32.299619	-64.979019	Chub Hea	Rim	32
LTEM	35	32.302568	-64.972384	Chubby Ca	OL	32
LTEM	36	32.296594	-64.935322	Exclamati	OL	32
LTEM	37	32.295756	-64.896164	Elys Flat	IL	32
LTEM	38	32.29623	-64.876637	Elys Fringi	IL	32
LTEM	39	32.364608	-64.927382	WBC	20-m	39
LTEM	40	32.360761	-64.926373	WBC	10-m	39
Catlin	41	32.349933	-64.910555	WBC	Rim	39
LTEM	42	32.354074	-64.891257	Dockyard	OL	39
LTEM	43	32.343541	-64.8646	Dockyard	OL	39
LTEM	44	32.328876	-64.807758	Brackish	IL	39
LTEM	45	32.307251	-64.788638	Hallett	IL	39
LTEM	46	32.390913	-64.865328	Central	OL	46
LTEM	47	32.369354	-64.827585	Central	OL	46
LTEM	48	32.356768	-64.782168	Central	IL	46
LTEM	49	32.330002	-64.745065	ShellyBay	IL	46
LTEM	50	32.426804	-64.726335	3HS	OL	12
LTEM	51	32.413166	-64.683275	FtStCath	OL	51
LTEM	52	32.388205	-64.667919	FtStCath	Rim	51

Appendix 2: GCRMN – Field Method Logistics

Two Diver Procedure
Divers 1 & 2 enter water together
Diver 1 carries out Task 1 (Fish Transects), leaving the first 5 transects in place.
Diver 2 carries out Task 2 across all 5 transects from 1 to 5
Diver 2 carries out Task 3 across all 5 transects from 5 to 1
Diver 1 winds in the 5 transects after they have been assessed by Diver 2
Divers 1& 2 return to boat together

Gear
Transect lines (30m) – numbered at both ends, marked at 2-m intervals on even numbers.
Digital camera with flash, with 2 aluminium bars:

A.105 cm "Long" for large benthic cover photoquadrats (60 cm image height),
B. 45 cm (Short) for small recruit quadrats (25 cm image height)

Fish data slate w data sheets & pencils

Diver allocation of gear
Diver 1: 5 transect lines, fish data slate w 5 data sheets
Diver 2: photo gear

GCRMN Data Component List

Task 1 Fish Transects
5 transects – measuring 30m length.
All large mobile fish present (of all species) are counted within a belt transect (30m length x 4m width), with the survey time limited to approximately 6 minutes per transect. Once assessed, the transects are reassessed at 30m length x 2m width for damselfish, sea urchins, smaller benthic fishes

Task 2. Photo-quadrats: Benthic Cover, Disease, Mobile Invertebrates
80 benthic photographs collected at each site (5 transect lines x 16 photographs per line).
Standardized quadrat area: 0.9m x 0.6m
Photographs are taken along each of the 5 transect lines set for counting fish
16 images captured per transect line at alternating meter marks (i.e. 0, 2,4,6… …26,28,30)

Task 3. 25cm^2 quadrats: Coral Recruitment
Coral recruits: >1 cm^2 to <4.0 cm^2
6 quadrats surveyed along 5 fish transects (N = 30 total)
Quadrats placed at 2-meter intervals; with lower corner of quadrat at 0, 6, 12, 18, 24, 30 m.

Appendix 3: Fish Survey Data Sheet Template

Diver:			**Date:**			**Time:**	
Location:					**Trans:**		
	Fish	**5**	**10**	**20**	**30**	**40**	**>40**
Damsel	Bicolored						
	Beaugregory / Cocoa						
	Threespot (Yellow Eye)						
Parrotfish	Princess						
	Queen						
	Redband						
	Redtail						
	Stoplight						
	Striped						
	Yellowtail						
Surgeon	Blue Tang						
	Doctorfish (D bars)						
	Ocean Surgeonfish						
Silver	Bream						
	Pinfish						
	Porgy						
	Chub						
Predator	Barracuda						
	Blue Striped Grunt						
	Creole/Barber						
	Hogfish						
	Jacks (all)						
	Trumpetfish						
Seabass	Black Grouper						
	Coney (2 dot lip tail)						
	Graysby (3 dots dorsal)						
	Red Hind (No dots)						
	Barred Hamlet						
	Other						
Snapper	Gray Snapper						
	Lane Snapper						
	Yellowtail Snapper						
Plankton	Sargent Major						
	Bluehead Wrasse						
	Creole Wrasse						
	Black Durgeon						
: (	Lionfish						
:)	Sea Urchin						

This report should be cited as:
Murdoch TJT (2018) Status and Trends of Bermuda Reefs and Fishes: 2016 Report Card. BREAM: Bermuda Reef Ecosystem Analysis and Monitoring Programme Report, Bermuda Zoological Society, Flatt's. Bermuda. Bermuda Biodiversity Project #266.

Raw data and statistical analyses can be viewed at: www.bermudaBREAM.org

Contact:
Thaddeus Murdoch, Ph.D.
Chief Scientist
Bermuda Reef Ecosystem Analysis and Monitoring (B.R.E.A.M.) Programme
P.O. Box 513 Warwick, WKBX, BERMUDA
http://www.bermudabream.org
Tel: +441.505.8424; email:tmurdoch@bermudabream.org

Support provided by: Murdoch Marine Ltd. Bermuda Zoological Society; XL Catlin – End to End Marine Research Grant

This is Contribution #266, Bermuda Biodiversity Project (BBP), Bermuda Aquarium, Museum and Zoo, Department of Environment & Natural Resources.