

An interim report of the *Comprehensive Long-term Coral Reef Monitoring at Permanent Sites on Guam* project



Including the results of an initial analysis of coral reef bleaching response survey data (2013–2017), data collected by the UOGML Reef Flat Monitoring Program (2009–2018), and a staghorn mapping and mortality assessment effort (2009–2017)

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With contributions by
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December 2018



A project funded by NOAA Coral Reef Conservation Program grant NA17NOS4820038, with previous funding provided through grants NA07NOS4260060, NA10NOS4260060, NA11NOS4820007, NA13NOS4820012, and NA15NOS4820039



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Cover: Bleached and recently killed staghorn corals (*Acropora muricata*) in Apra Harbor, Guam, in October 2017. Photo by D. Burdick. **Next page:** Bleached *Acropora abrotanoides* colonies in the shallow, high wave energy reaches of the seaward slope in Pago Bay, Guam, in September, 2017; most of the colonies in this image were killed by the severe bleaching event that affected Guam's reefs that year.

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ABOUT THIS REPORT

This interim report includes summaries of the results of an initial analysis of coral bleaching survey data collected around Guam between 2013 and 2017, UOGML Reef Flat Monitoring Program survey data collected between 2009 and 2018, and mapping and mortality assessment data collected at all of Guam's major staghorn coral communities between 2009 and 2017. Also presented in the report is background information about the *Comprehensive Long-term Coral Reef Monitoring at Permanent Sites on Guam* project and a summary of data collection activities and other program activities completed to-date.

This report was originally expected to focus primarily on the results of analyses of data collected at the seven high priority reef areas, most of which are monitored on a regular basis for the *Comprehensive Long-term Coral Reef Monitoring at Permanent Sites on Guam* project, also known as the Guam Long-term Coral Reef Monitoring Program. The high priority reef areas targeted for monitoring by the program include the Tumon Bay Marine Preserve, East Agana Bay, the Piti Bomb Holes Marine Preserve, the Achang Reef Flat Marine Preserve, Cocos-East, Fouha Bay, and Western Shoals, in Apra Harbor. However, the significant bleaching-associated impacts observed at shallow reef areas in recent years, and the results of preliminary analyses that suggested only minor changes in benthic cover at the deeper high priority reef areas, necessitated the prioritization of the analysis of the copious coral bleaching survey data collected at shallow seaward slope and reef flat survey sites located around the island.

The results of an initial analysis of coral bleaching survey data were submitted to the journal *Coral Reefs* for review in October 2018, but it was determined that the key findings described in the manuscript should also be summarized in this interim report submitted concomitantly with the final progress report for the NA15NOS4820039 grant that ended in September 2018. Also presented in this report are the initial results of an analysis of nearly a decade of monitoring data collected at reef flat sites by Dr. Laurie Raymundo, as well as a summary of the results of a staghorn coral mapping effort and a staghorn mortality assessment. The results of the analysis of reef flat monitoring and staghorn mortality assessment data were also included in the manuscript submitted to *Coral Reefs*, which is currently in review. The results of the first of the two staghorn mortality assessment efforts were also published in *Marine Ecology Progress Series* in 2017.

While a preliminary analysis of data from the high priority reef areas has been completed, further analyses are required in order to more fully examine the status and trends of reef condition at these areas. The results of a comprehensive analysis of data collected at the high priority reef areas between 2010 and 2018 will be provided in a supplemental report in the spring of 2019.

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EXECUTIVE SUMMARY

The *Comprehensive Long-term Monitoring at Permanent Sites in Guam* project, also known as the Guam Long-term Coral Reef Monitoring Program (GLTMP), involves the regular collection of data for a suite of coral reef ecosystem health parameters at high priority reef areas around Guam, as well as support for coral bleaching response and other monitoring and assessment activities carried out by the Guam Coral Reef Response Team. This project also includes the Reef Flat Monitoring Program (RFMP), an effort led-by Dr. Laurie Raymundo of the University of Guam Marine Laboratory (UOGML) to document changes in coral communities on Guam's shallow reef flats. This interim report includes a summary of GLTMP activities conducted to-date as well as the results of analyses of data collected during survey efforts supported in large part by GLTMP and RFMP staff.

Surveys led by the UOGML, and supported by GLTMP staff, were carried out around the island on multiple occasions during and between severe coral bleaching events in 2013 and 2017. The results of an analysis of sea surface temperature and accumulated heat stress data provided by NOAA Coral Reef Watch indicate that the 2013 ocean heat stress event was the most severe on record, but that the severity of this historical event was exceeded in 2017. The island-wide surveys carried out along the shallow seaward slope between 2013 and 2017 documented a 37% decline in living coral during this period. Additional mortality, including catastrophic (>90%) mortality of branching corals (mainly *Acropora* spp.) was observed after the 2017 island-wide surveys were completed. Impacts were most severe to coral communities on the eastern windward side of the islands, with an estimated 59% loss in living coral.

The loss of living coral documented at five shallow reef flat sites monitored quarterly by the Reef Flat Monitoring Program was similar to that observed at the seaward slope sites, with an average loss of 37% between 2009 and 2018. Sites with a greater proportion of the bleaching-susceptible staghorn corals experienced greater losses, with some sites exhibiting up to 80% declines in living coral. A separate staghorn coral mortality assessment effort led by Dr. Raymundo and supported by GLTMP staff was carried out island-wide in 2014/2015 following observations of catastrophic mortality observed during bleaching events in 2013 and 2014, and again in 2017 after additional mortality was observed in 2015 and 2016. The results of these assessments, which were published in Raymundo et al. (2017) and in a manuscript currently in review, indicate a 36% decline in the extent of living staghorn coral island-wide between 2013 and 2017.

32%

Decline in living coral on the shallow seaward slope island-wide 2013–2017

59%

Decline in living coral on the shallow seaward slope along east coast 2013–2017

37%

Decline in living coral at reef flat sites along west coast 2009–2018

36%

Decline in extent of living staghorn coral island-wide 2013–2017



1.1 OVERVIEW

The *Comprehensive Long-term Monitoring at Permanent Sites in Guam* project involves the regular collection of data for a suite of coral reef ecosystem health parameters at high priority reef areas around Guam, as well as support for coral bleaching response and other monitoring and assessment activities carried out by the Guam Coral Reef Response Team. As part of the project, also referred to as the Guam Long-term Coral Reef Monitoring Program (GLTMP), data are collected and managed by a small team of highly-trained field biologists from the University of Guam Marine Laboratory (UOGML) and NOAA Pacific Islands Regional Office (PIRO) Guam Field

Office, with occasional assistance by staff from the Bureau of Statistics and Plans, the Guam Environmental Protection Agency and the Department of Agriculture's Division of Aquatic and Wildlife Resources. The core GLTMP team is currently comprised of five UOGML employees, including a part-time monitoring program coordinator (MPC), a full-time monitoring technician (MT), a part-time monitoring technician (MT), and two part-time UOGML graduate students who serve as monitoring assistants (MA). Valerie Brown, a coral reef ecologist with NOAA PIRO, is also a core member of the monitoring team, providing significant input into project planning as well as leading fish survey efforts. All staff are highly skilled scientific divers trained to carry out a variety of coral reef survey methods.

Data collection at the high priority reef areas began in 2010, and since then data has been collected at a total of seven priority reef areas, with data collected from six sites on a regular basis. The high priority reef areas targeted for monitoring by the program include the Tumon Bay Marine Preserve, East Agana Bay, the Piti Bomb Holes Marine Preserve, the Achang Reef Flat Marine Preserve, Cocos-East, and Fouha Bay. Baseline surveys were carried out at Western Shoals, in Apra Harbor, in 2011 but further data collection at this site has been postponed indefinitely. The GLTMP's comprehensive approach to ecological monitoring, combined with the high density of samples within relatively large (0.1–0.2 km²) portions of the high priority reef areas, provide data critical to understanding changes in reef condition at these areas, for the development of management strategies specific to each area, and for evaluating the effectiveness of management actions in improving the condition of these high value marine ecosystems. The data collected at the high priority reef areas are also essential for evaluating the relative resilience of the reef communities to climate change impacts and for tracking changes in resilience over time. GLTMP data collection efforts at three of the five locally-managed Marine Preserves provide the only long-term monitoring data available for evaluating the effectiveness of individual preserves.

While the initial focus of the GLTMP was on the high priority reef areas, a severe mass coral bleaching event in 2013 necessitated a shift to data collection efforts that targeted the shallow reef communities that appeared to be most severely impacted by the event. The limited capacity of the small GLTMP team, and the very limited underwater data collection capacity of Government of Guam agencies, was not sufficient to carry out annual monitoring at the high priority reef areas while also implementing an island-wide, survey-intensive data collection effort aimed at documenting the extent and severity of a historic coral bleaching event. Subsequent bleaching events in 2014 and 2016, and yet another record-breaking event in 2017, required continued focus on the documentation of the extent and severity of these events as they occurred. Additional survey efforts were also carried out between bleaching events, such as the 2015 bleaching recovery assessment, which aimed to document the cumulative impact of the 2013 and 2014 bleaching events and evaluate the potential for recovery. Data collection continued at the high priority reef areas, but the limited program capacity meant that not all sites could be visited each year, nor could all survey methods be carried out during each site visit.

Recently-proposed changes (described in Section 1.5) will help the program adapt to the shifting management priorities in this period of catastrophic climate change-associated impacts.

In addition to the monitoring of high priority reef areas and coral bleaching response surveys, members of the GLTMP have also made essential contributions to the mapping, assessment and monitoring of Guam's staghorn communities; an island-wide reef resilience assessment in 2016; and a variety of other monitoring, assessment, outreach, and management-related activities. The MPC, as well as other members of the monitoring team, also provide key input into the development of management strategies, such as the recently-developed Guam Coral Bleaching Response Plan and Guam Reef Resilience Strategy, and are expected to make significant contributions to the development of a restoration strategy through participation in the new Guam Coral Reef Restoration Group.

The *Comprehensive Long-term Monitoring at Permanent Sites in Guam* project also includes continued support for the Reef Flat Monitoring Program carried out by Dr. Laurie Raymundo of the UOGML, which has tracked changes in the condition of Guam's reef flat coral communities since 2009.

1.2 BACKGROUND

While Guam's reefs have been the subject of numerous studies in recent decades, until the establishment of the Guam Long-term Coral Reef Monitoring Program there had not been a continuous coral reef monitoring program that comprehensively addresses benthic habitat, water quality, and associated biological communities at high priority reef areas. This lack of baseline information limited managers' ability to evaluate natural and anthropogenic impacts to Guam's reefs and to gauge the effectiveness of management activities at the scale of individual management areas. In order to address this major gap the Government of Guam's natural resource agencies, with the assistance of the UOGML and NOAA PIRO, developed a long-term monitoring strategy aimed at addressing the management needs of local resource agencies and the objectives set by the National Coral Reef Ecosystem Monitoring Program (NCREMP). A program coordinator was hired in January 2007 to further develop and implement the monitoring strategy. A large amount of baseline data for a number of key ecosystem health parameters is now available for seven high priority reef areas that are currently the focus of a number of management actions aimed at improving reef condition. Subsequent data collection, which is ongoing at six of these reef areas, provides critical information to managers about the effectiveness of management efforts, and alerts managers to emerging threats that may not otherwise be detected.

1.3 ACTIVITIES CARRIED OUT TO-DATE

1.3.1 Regular monitoring at high priority reef areas

Data collection at the high priority reef areas began in June 2009, with initial surveys targeting the southwestern end of the Tumon Bay Marine Preserve. A more extensive data collection effort was carried out in 2010 along a portion of the Tumon Bay outer reef slope and an equivalent area along the outer reef slope in East Agana Bay. In 2011 surveys were conducted at Western Shoals, Apra Harbor, and in 2012 surveys were carried out at the Piti Bay, Tumon Bay, and East Agana Bay sites. In 2014 baseline surveys were carried out at the Achang site and at portion of the Cocos-East site, and return visits were made to the Tumon Bay, East Agana Bay, and Piti Bay sites. A new site was established in Fouha Bay in 2015, with all surveys carried out at a total of 13 permanent sampling stations in 2015. The team returned to the Tumon and East Agana sites in 2015 (and early 2016). Data collection at other long-term monitoring sites did not occur in 2016 because of the team's focus on a multi-month bleaching response effort, but data collection at the long-term sites resumed in 2017 with visits to the Tumon, East Agana, and Piti sites. Surveys at the Achang, Cocos-East, Tumon, and East Agana sites were completed in 2018. An analysis of data collected at the high priority reef areas is currently underway; the results will be presented in a report expected to be released in the spring of 2019.

1.3.2 Coral bleaching response

Researchers at the UOGML and scientists from local and federal government agencies have documented coral bleaching on Guam's reefs since the phenomenon was first reported in 1994 (Paulay and Benayahu 1999, Burdick et al. 2008). GLTMP staff and other members of the Guam Coral Reef Response Team contributed to efforts to track the impact of coral bleaching on Guam's reefs. Until recently, mass coral bleaching had not resulted in significant losses in live coral on Guam's reefs. However, in 2013 the coral reefs of Guam and other islands in the Mariana Archipelago experienced a significant bleaching event associated with anomalously high sea surface temperatures and an extended period of calm water conditions. At the time, the 2013 mass coral bleaching event registered as the most severe to have affected Guam's reefs, but within a few short years that major event would itself be overshadowed by an even more devastating event.

In order to document the extent and severity of the historic 2013 event, and to collect a dataset that would prove critical to understanding the impact of mass coral bleaching on Guam's reefs and inform predictions about the future of Guam's reefs, a large-scale data collection effort was initiated by the UOGML and other members of the Guam Coral Reef Response Team. Members of the GLTMP made significant contributions to the organization and implementation of the UOGML-led, island-wide assessment. The effort to document the 2013 event's scale and

severity generated a significant amount of quantitative coral and benthic substrate composition data, along with semi-quantitative coral community data, for 48 shallow (5 m) seaward slope sites selected randomly from around the island.

Follow-up surveys were carried out with the assistance of the MPC and other members of the monitoring team in 2015 at 16 of the original 48 bleaching response sites in order to assess the full impact of the 2013 event, as well as assess additional mortality that may have resulted from a subsequent bleaching event in 2014. As bleaching was predicted for 2016 and then observed in situ as early as July, the MPC and the full-time MT participated in bleaching response planning that year, including participating in meetings and assisting the NOAA Coral Fellow with the further development of the Guam Coral Bleaching Response Plan originally developed to a partial state by the MPC and V. Brown. Beginning in July 2016 the MT assisted the NOAA Coral Fellow with numerous qualitative and quantitative bleaching response surveys at various reef flat sites around the island, and the MPC documented bleaching observed along the seaward slope during surveys for an island-wide reef resilience assessment (discussed below).

Also in 2016, the MPC served as Co-PI with Dr. Jeffrey Maynard on a NOAA Saltonstall-Kennedy grant-funded project aimed at assessing the resilience of reef areas around island (Maynard et al. 2017). Other members of the monitoring team carried out benthic photo transect surveys in conjunction with the reef resilience assessment, which utilized Line-Point Intercept surveys for benthic cover. The benthic photo transect images obtained at the resilience assessment sites, the vast majority of which were coincident with sites surveyed during the 2013 bleaching event and/or the 2015 bleaching site re-survey effort, provided data key to understanding changes at the shallow (5 m) seaward slope sites in response to the recent bleaching events, provided a baseline of benthic community condition at deeper (12 m) reef areas prior to the severe 2017 bleaching event, and served to document the relatively low levels of bleaching observed along the seaward slope that year.

In response to the record-breaking 2017 bleaching event, GLTMP team members participated in surveys at 12 previously-surveyed sites located along the northern, western, and southern coasts. Sites along the east coast could not be accessed due to hazardous water conditions. The team also established three shallow (2 m), shore-accessible, 30 m-long permanent transects at Tanguisson Pt., on the western leeward side of the island, and in Pago Bay, on the eastern windward side of the island, at the beginning of the 2017 bleaching event. In addition, the team re-established four 50-m transects originally established in 2007 along the 10 m depth contour in Pago Bay by Dr. Peter Schuup of the Marine Lab. Baseline and multiple follow-up benthic photo transect surveys were carried out at the three sites in an effort to document changes in the benthic communities at these sites—all of which hosted a high proportion of bleaching-susceptible species—at a finer temporal scale than what could be carried out island-wide.

Data collected during and between the multiple coral bleaching events that have impacted Guam's reefs since 2013 provide the only record of the extent and severity of these historic events. These data are being used to assess the susceptibility of different coral species to bleaching, determine the environmental and human-associated drivers of any differences in bleaching impacts observed across different reef areas, and make predictions about the future composition and function of Guam's reefs under a range of climate change scenarios. GLTMP staff and collaborators have developed several journal articles based on initial analyses of the data (described below), and continue to further analyze the data to better understand the impact of ocean warming on Guam's reef ecosystems.

Bleaching survey data collected in 2013 provided the foundation of a UOGML graduate student thesis project completed in 2016, and data collected in 2013 and 2015 were also recently provided to Dr. Jeff Maynard and colleagues for a NOAA-funded study of the human and natural drivers of coral reef resilience to climate-induced coral bleaching in Guam and the identification of potential climate refugia. A manuscript that included the results of an initial analysis of coral bleaching survey data collected at shallow seaward slope sites between 2013 and 2017 was submitted to the journal *Coral Reefs* for review in October 2018. The results of an analysis of reef flat monitoring data, staghorn mortality assessment data, as well as data collected at other priority reef flat areas were also included in the manuscript, which is currently in review. Coral bleaching survey data were also submitted to NOAA Coral Reef Watch staff for inclusion in an analysis of the 2014–2017 global coral bleaching event, the results of which will be published in the same *Coral Reefs* issue.

Summaries of the results included in the recently-submitted manuscript that pertain to data collected during the island-wide shallow seaward slope surveys, staghorn coral mortality assessments, and reef flat monitoring surveys are provided in sections 2, 3, and 4, respectively, of this report.

1.3.3 Other rapid response activities

While coral bleaching response has comprised the bulk of the monitoring program's rapid response efforts, monitoring team members have also contributed to other Guam Coral Reef Response Team activities. Examples of GLTMP staff involvement in recent Guam Coral Reef Response Team activities include participating in regular team meetings, contributing to the development of response strategies, providing technical assistance in the assessment of coral reef damage caused by several vessel groundings, assisting Guam EPA with the mitigation of a vessel grounding site in Apra Harbor, and training in the deployment of an ox bile solution injection method to control *Acanthaster* populations.

1.3.4 Mapping and assessment of staghorn coral communities

Between 2009 and 2013 GLTMP staff opportunistically recorded the presence and species composition of staghorn communities around the island in an effort to generate a comprehensive, geographically-referenced inventory of these communities. The in-water observations and location data recorded using GPS receivers were used to inform the development of a spatial data layer that included all known staghorn coral communities on Guam. The staghorn corals spatial data layer and related information provided the foundation for an important study led by Dr. Laurie Raymundo of the UOGML to assess the amount of staghorn coral loss associated with the back-to-bleaching events in 2013 and 2014. The results of the study, which were published in *Marine Ecology Progress Series* (citation below), are summarized in section 3 of this report, along with the results of a follow-up staghorn mortality assessment conducted in 2017.

1.3.5 Beyond long-term monitoring and rapid response

The work of the GLTMP team extends beyond monitoring at the high priority reef areas, reef resilience assessments, coral bleaching assessments and other monitoring and assessment activities. The broad array of activities presented in the abridged list below is illustrative of the critical capacity GLTMP team members provide to reef management efforts on Guam. A more comprehensive account of GLTMP activities will be presented in a report to be released in the spring of 2019.

- Provided data and expert input via document review, workshops, and other communications regarding the initial listing and subsequent management of ESA-listed coral species
- Participated in the development of the recently-released Guam Coral Reef Status Report (https://www.coris.noaa.gov/monitoring/status_report)
- Assisted with SECORE (SExual COral REproduction) workshops and other SECORE activities on Guam
- Assisted with a study of the genetic connectivity of Guam's staghorn populations and the importance of these coral communities as fish habitat
- Carried out coral surveys as part of the 2009, 2011, and 2017 NOAA PIFSC Marianas Reef Assessment and Monitoring Program cruises
- Carried out all field work and contributed to the development of a final report for a 2015 NOAA PIRO Moving Window Analysis of benthic communities in Fouha Bay (manuscript in prep)
- Contributed to the development of measures of success for marine resources under the Micronesia Challenge

- Carried out surveys in support of a RARE Pride project in Tepungan (Piti) Bay

1.3.6 Data management

Several datasets collected at the high priority reef areas currently reside in a relational database accessible by GLTMP members through a web-based data entry portal. The database and data entry portal were developed through a collaboration with the NOAA Coral Reef Ecosystem Division (now merged with other sections of NOAA PIFSC) and BSP. The data management system has significantly improved the management of the large amount of coral reef monitoring data generated by the GLTMP. Other datasets generated by the GLTMP, as well as data generated by the NOAA PIRO-supported Guam Community Coral Reef Monitoring Program and the UOGML Reef Flat Monitoring Program may be integrated into the data management system in the future. To facilitate broader awareness of the available data sets, metadata records developed for datasets from high priority reef areas have been posted to CoRIS. In addition, through a collaboration with PIFSC funded by the federal Big Earth Data Initiative, existing metadata records have been updated and re-formatted and additional metadata records have been developed for submission to InPort, a National Marine Fisheries Service data management program, and the National Centers for Environmental Information (NCEI). Metadata for other datasets collected supported by the GLTMP, such as coral bleaching survey data, will be developed and submitted to CoRIS, InPort, and NCEI in 2019. Full datasets are currently being prepared for archival with NCEI. While data collected by the GLTMP are available upon request, archival with NCEI will facilitate the efficient distribution of these data to a broader community of end users.

1.3.7 Outreach

GLTMP staff have also carried out numerous outreach activities in an effort to raise awareness about the status and trends in the condition of Guam's reefs. These outreach activities include online and printed articles, a website, an informational brochure, reef status reports, and numerous presentations provided to audiences of all ages. A comprehensive list of outreach activities will be presented in the spring 2019 report.

1.3.8 Conference and workshop participation

GLTMP staff also gave presentations at several local and international conferences and provided presentations or facilitation support, and were actively involved in numerous workshops and training sessions on Guam. Examples of these conferences and workshops are provided below. A comprehensive list of conferences and workshops with which GLTMP staff were involved will be presented in the spring 2019 report.

- 2013, 2015, 2016, and 2018 Guam Coral Reef Symposia
- 2014 Asia-Pacific Coral Reef Symposium, Taiwan
- 2016 International Coral Reef Symposium, Honolulu, HI
- 2016 Recreational Tour Operator workshop
- 2018 NOAA CRCP CoRIS data management workshop
- 2016 Climate Change Forecasting Workshop
- 2017 Guam Coastal Climate Change Resilience workshop
- 2018 Coral and Climate Adaptation Planning Design Tool workshop

1.3.9 Publications

Examples of reports and peer-reviewed publications (including those in prep and in review) authored or co-authored by GLTMP staff are provided below. A comprehensive list of publications will be provided in the spring 2019 report.

Raymundo, L., D. Burdick, W. Hoot, R. Miller, V. Brown, T. Reynolds, and J. Gault. In review. Successive bleaching events cause mass coral mortality in Guam, Micronesia.

Maynard, J., S. Johnson, D. Burdick, A. Jarrett, J. Gault, J. Idechong, R. Miller, G. Williams, S. Heron, and L. Raymundo. 2017. Coral reef resilience to climate change in Guam in 2016. NOAA Coral Reef Conservation Program. NOAA Technical Memorandum CRCP29. Available at https://www.coris.noaa.gov/activities/guam_coral_resilience/

Raymundo, L., D. Burdick, V. Lapacek, R. Miller, V. Brown. 2017. Anomalous temperatures and extreme tides: Guam staghorn *Acropora* succumb to a double threat. Marine Ecology Progress Series 564:47-55. Available at <https://www.int-res.com/abstracts/meps/v564/p47-55/> or upon request.

Reynolds, T., D. Burdick, P. Houk, L. Raymundo, S. Johnson. 2014. Unprecedented coral bleaching across the Mariana Archipelago. Coral Reefs 33: 499. Available at <https://link.springer.com/article/10.1007/s00338-014-1139-0>

Burdick, D., R. Miller. 2012. Comprehensive long-term monitoring at permanent sites on Guam: 2012 status report. Report submitted to the NOAA Coral Reef Conservation Program. Available at <https://repository.library.noaa.gov/view/noaa/991>

Burdick, D., V. Brown. 2011. Comprehensive long-term monitoring at permanent sites in Guam: Report of program status and presentation of preliminary baseline data and power analyses results for Tumon Bay, East Agana Bay, and Western Shoals sites. Report submitted to the NOAA Coral Reef Conservation Program. Available at <https://www.coris.noaa.gov/search/catalog/search/resource/details.page?uuid=%7B9AF65D1F-668E-4D2B-99A0-4B0D2907F1A8%7D>

Burdick, D., V. Brown, J. Asher, C. Caballes, M. Gawel, L. Goldman, A. Hall, J. Kenyon, T. Leberer, E. Lundblad, J. McIlwain, J. Miller, D. Minton, M. Nadon, N. Pioppi, L. Raymundo, B. Richards, R. Schroeder, P. Schupp, E. Smith, and B. Zgliczynski. 2008. Status of the Coral Reef Ecosystems of Guam. Bureau of Statistics and Plans, Guam Coastal Management Program. iv + 76 pp. Available at https://www.researchgate.net/publication/236590561_Status_of_the_Coral_Reef_Ecosystems_of_Guam

1.4 REEF FLAT MONITORING PROGRAM

The Reef Flat Monitoring Program (RFMP) currently involves quarterly data collection at five reef flat sites that extend along the western coast of Guam. The RFMP emerged following a study carried out by Dr. Laurie Raymundo and colleagues examining sewage nutrient eutrophication and its impact on coral disease along Guam's northwestern coast (Redding et al. 2013). At the time of the original study, seven sites were selected for assessment and monitoring of disease impacts. Two of these sites, Tanguisson and West Agaña, were nearshore to recently-upgraded sewage outfalls. The study examined whether there was any improvement in coral condition over the course of the year following the upgrade. The study concluded that all sites showed indications of sewage-based nitrogen pollution, little overall change in the concentration of nitrogen over the year of monitoring, and a positive correlation between the degree of nitrogen eutrophication and the severity of the coral disease, white syndrome, in resident corals per site. Upon completion of the study local management agencies requested that the monitoring of a subset of these sites be continued as part of the *Comprehensive Long-term Coral Reef Monitoring at Permanent Sites on Guam* project.

The RFMP has provided important, detailed information about trends in coral community health, and places particular attention on coral diseases, predators, bleaching and other coral health concerns and the relationship with water temperature and nutrients. The data generated through the RFMP provides a strong complement to the data collected at the seaward reef slope sites targeted with the GLTMP. The RFMP provides information to managers for a critical, dynamic, yet vulnerable reef zone, and is an essential component of a comprehensive coral reef monitoring strategy.

The results of a preliminary analysis of benthic cover data collected between 2009 and 2014 as part of the RFMP were presented in a 2012 progress report for the *Comprehensive Long-term Coral Reef Monitoring at Permanent Sites on Guam* project (available at https://data.nodc.noaa.gov/coris/library/NOAA/CRCP/other/grants/NA11NOS4820007/Guam_Reef_Monitoring_FinalRept.pdf). The results of further analysis of RFMP data collected between 2009 and 2018 are presented in Section 4 of this report.

1.5 ADAPTING TO A WARMING WORLD

The frequency and severity of the bleaching events and the associated major changes in benthic communities at sites around the island has necessitated a re-evaluation of GLTMP priorities. As described in a proposal for continued funding recently submitted to the NOAA Coral Reef Conservation Program, by conducting the full suite of benthic surveys at only permanent sampling stations, reducing the frequency of coral quadrat surveys, and using the CoralNet website for the first-pass analysis of images from the seaward slope terrace sites, the GLTMP team can free up the capacity necessary to establish permanent transects in the more dynamic reef front zone of the high priority reef areas, make permanent 16 of the island-wide bleaching response/recovery sites, and monitor benthic cover at these new sites on an annual or biennial basis.

Another emerging goal of the GLTMP is to actively integrate threat-reduction and reef restoration activities into GLTMP efforts when necessary and appropriate. This new goal has been proposed in recognition of the limited funding and capacity available to implement threat-reduction and reef restoration activities on Guam, and in recognition that GLTMP team members possess the technical skills required to carry out many of these activities. These activities include, but are not limited to, opportunistic *Acanthaster* control at monitoring sites; targeted *Acanthaster* control at other reef areas; continued participation in vessel grounding site response and rehabilitation; and assisting with coral nursery, coral out-planting, and other active restoration activities.

The monitoring of water quality parameters is recognized as an important component of the program, but it has become clear that the limited capacity of the GLTMP, especially in consideration of the immense effort that has been dedicated to the collection and analysis of bleaching response/recovery survey data over the last few years, is currently not sufficient for carrying out long-term monitoring of water quality parameters. With the exception of water temperature, which is recorded by loggers deployed at most of the high priority reef areas, GLTMP staff have not been able to move beyond testing and calibration of multi-parameter datasondes and actually deploy and maintain these systems on a long-term basis. In recognition of this limitation the MPC has sought out collaborations with researchers interested in collecting water quality data as part of research projects carried out at the high priority reef areas. Through these collaborations the GLTMP would lend use of the instruments, provide training, and assist with data management and analysis. The GLTMP may also be able to assist by allowing the researchers or their students/staff to join the GLTMP team on regular data collection outings using GLTMP-funded boat trips.

1.6 OUTCOMES AND BENEFITS

The results of data analyses are summarized in periodic reports, included those listed above, which are made available to the government agencies and the general public. Datasets collected through GLTMP efforts are provided upon request to resource agencies, research teams, and others, and once archived with NCEI will reach an even larger community of end-users. Anecdotal reports and the results of preliminary analyses of data obtained through GLTMP activities are also regularly presented to resource agency staff at relevant multi-partner meetings and workshops, and communicated via email, telephone conversations, and in-person in an effort to provide up-to-date information on the status of Guam's rapidly-changing reef ecosystem.

The GLTMP continues to contribute to local coral reef monitoring and management capacity through the continued employment of program staff. Thus far, the program has provided part-time employment for a total of 11 graduate students from the University of Guam Marine Laboratory. Participation in the GLTMP has provided these individuals with a wide range of experiences, and a level and quality of participation in sampling design, protocol development, procurement, data collection, and data analysis that most have not previously experienced. As described in more detail in Section 1.3.5, monitoring team members, particularly the MPC and the two MTs, play important roles in reef management efforts on Guam that extend well beyond the collection of data at monitoring sites.



2.1 INTRODUCTION

Members of the Guam Coral Reef Response Team, including GLTMP staff, Dr. Raymundo of the UOGML, UOGML graduate students, Valerie Brown with NOAA PIRO, Guam EPA staff, and Whitney Hoot with BSP, carried out multiple data collection efforts aimed at assessing the impact of thermal stress events on Guam's reefs communities between 2013 and 2017. Surveys targeted a randomized selection of seaward slope sites island-wide, priority reef flat sites, and all known major staghorn coral communities. GLTMP staff were primarily involved in data collection efforts

targeting the seaward slope communities, but the MPC also provided significant contributions to the assessment of staghorn coral communities (addressed Section 3), and some staff support was provided for surveys at priority reef flat sites.

The results of an analysis of coral bleaching survey and staghorn mortality assessment data were included in a manuscript that was recently submitted for publication in a special edition of the journal *Coral Reefs* focused on the 2014–2017 global coral bleaching event (Raymundo et al. In review). Because GLTMP staff played significant roles in the collection and analysis of data collected at the island-wide seaward slope sites, and the MPC made significant contributions to the development of the manuscript itself, a summary of the study's findings are presented in this section. The results of the analysis of data collected at priority reef flat site surveys, which were supported by GLTMP staff but led by Whitney Hoot of BSP, are not presented here but will be made available upon publication of the article or in a report issued by BSP. The impacts of the bleaching events on coral communities at the RFMP sites surveyed quarterly by Dr. Raymundo since 2009 are described in Section 4 below.

2.2 METHODS

2.2.2 Benthic cover and bleaching prevalence surveys

Benthic photo transect surveys were carried out at 48 shallow (~5 m) seaward slope sites located around the island during the 2013 bleaching event and at 12 seaward slope (5 m and 12 m depths) sites located along the western and northern coasts during the 2017 bleaching event (Figure 1). Benthic photo transect surveys were also carried out in 2015 at 17 of the 48 shallow seaward slope sites surveyed in 2013, as well as at 20 seaward slope sites (5 and 12 m depths, including 17 of the sites surveyed in 2013) in conjunction with a NOAA S-K grant-funded reef resilience assessment for which the MPC served as Co-PI. The benthic photo transect surveys were carried out along three 25 (later 30) meter-long transects placed end-to-end across the target depth contour. Coral diversity and bleaching condition were also semi-quantitatively assessed for corals occurring in the vicinity of surveyed transects in 2013 and 2017, and coral colony size and condition surveys were carried out in 2015. Macroinvertebrate belt transects were also carried out at the 48 sites in 2013, and reef fish surveys were carried out by V. Brown at the 17 sites in 2015, but these data have not yet been analyzed and will not be discussed in this report.

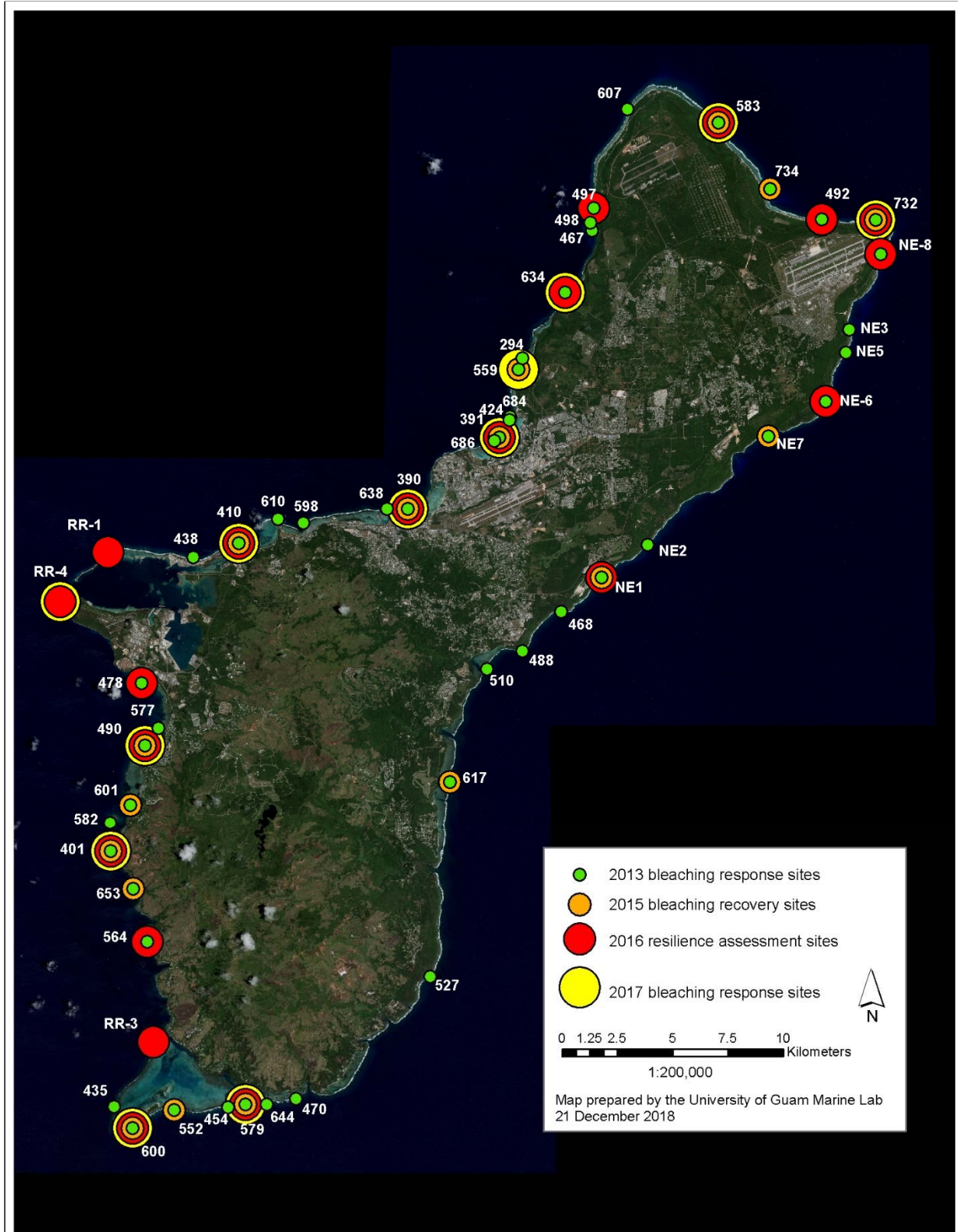


Figure 1. Location of coral bleaching response and reef resilience assessment sites surveyed between 2013 and 2017.

2.2.3 Environmental data analysis

Valerie Brown and the MPC obtained satellite-derived sea surface temperature (SST) and degree heating weeks (DHW) data, as well as bleaching alerts and predictions, from the NOAA Coral Reef Watch website (<https://coralreefwatch.noaa.gov/satellite/index.php>) in order to assess thermal conditions in the waters around Guam during periods of coral bleaching. Ms. Brown also monitored temperature and wave data from wave buoys near Ipan, eastern Guam, and Ritidian, in northern Guam, via the PacIOOS website (<https://www.pacioos.hawaii.edu>). Reef flat temperatures were monitored at three RFMP sites using loggers maintained by Dr. Raymundo since 2009.

2.3 RESULTS AND DISCUSSION

2.3.1 Environmental conditions

Sea surface temperatures and accumulated heat stress (degree heating weeks) acquired from NOAA coral Reef Watch are provided for each year between 2013 and 2017 in Figure 2. Descriptions of environmental conditions for each year are provided below.

An analysis of satellite-derived SST and DHW data indicates that thermal stress conditions during the 2013 bleaching event were, at the time, the most severe since satellite measurements began. The predicted coral bleaching threshold for Guam (30°C) was exceeded for most of the period between June and October, with SST reaching a peak of 31.5°C in August. Accumulated heat stress reached a peak of 12 DHW in early October and did not fully dissipate until late December.

In May 2014, less than six months after temperatures dissipated in 2013, satellite-derived SST exceeded the bleaching threshold. A maximum SST of 31°C was recorded in June, and although satellite-derived temperatures remained between 29°C and 30°C through December temperatures recorded by in situ loggers exceeded 31°C on several occasions between June and September. Accumulated heat stress reached a peak of 9 DHW in mid-September and dissipated by mid-December.

Thermal stress in 2015 was low compared to the two previous years, reaching a peak of 30.8°C in late July and with accumulated heat stress never exceeding 1 DHW. While thermal stress in 2015 was limited, the onset of a strong El Nino event resulted in a 0.35 m decrease in sea level between late 2014 and 2015. The ENSO-associated extreme low tide events caused the

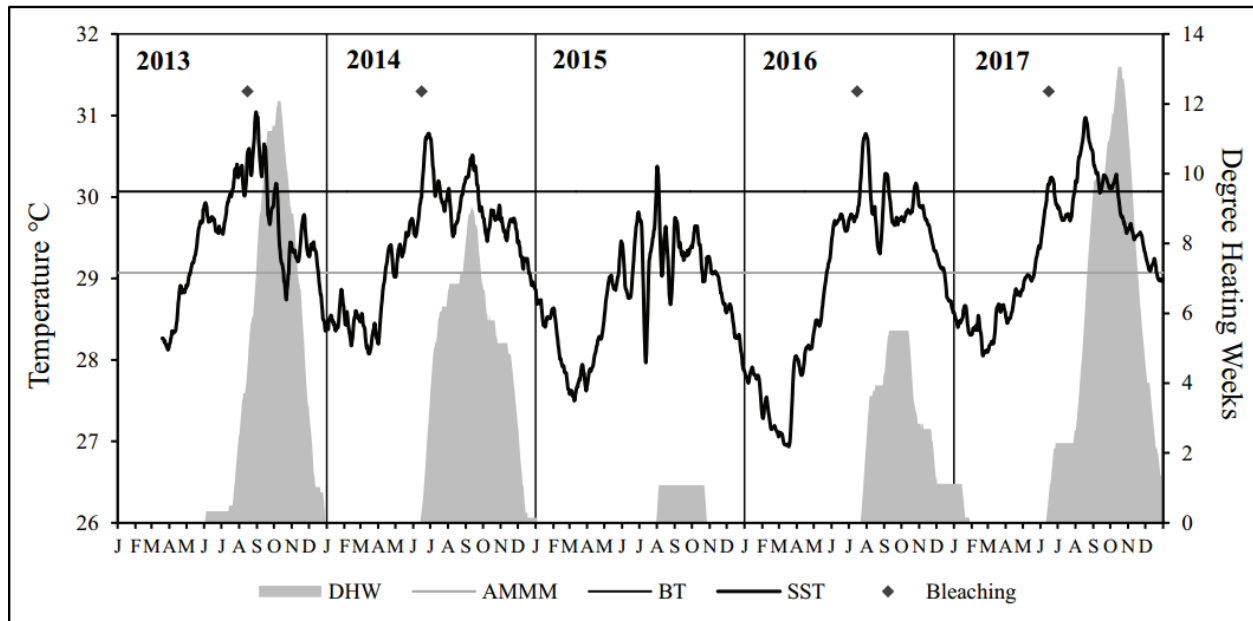


Figure 2. Sea surface temperature from the NOAA CRW virtual station for Guam plotted against annual maximum monthly mean SST (AMMM), bleaching threshold (BT), and degree heating weeks between 2013 and 2017. Figure reproduced from Raymundo et al. (In review).

repeated subaerial exposure of shallow reef flat communities, which resulted in significant mortality to the upper extent of coral growth across much of Guam’s reef flats.

Thermal stress conditions in 2016 were moderately severe, with the 30°C bleaching threshold first exceeded in July and a maximum SST of 30.9°C recorded in late July. Accumulated heat stress peaked at 5.5 DHW between September and October and didn’t fully dissipate until the end of January 2017. Water temperature at reef flat sites greatly exceeded the offshore satellite-derived SST measurements, with a maximum of 35.6°C recorded from a logger deployed in Tumon Bay.

Thermal stress conditions in 2017 were more severe than the record-breaking conditions of 2013, with satellite-derived and buoy temperatures both exceeding 31°C in August and accumulated heat stress reaching 13 DHW in mid-October. Maximum water temperatures of between 34°C and 35°C were recorded from reef flat sites in Tumon Bay and Agat between June and August.

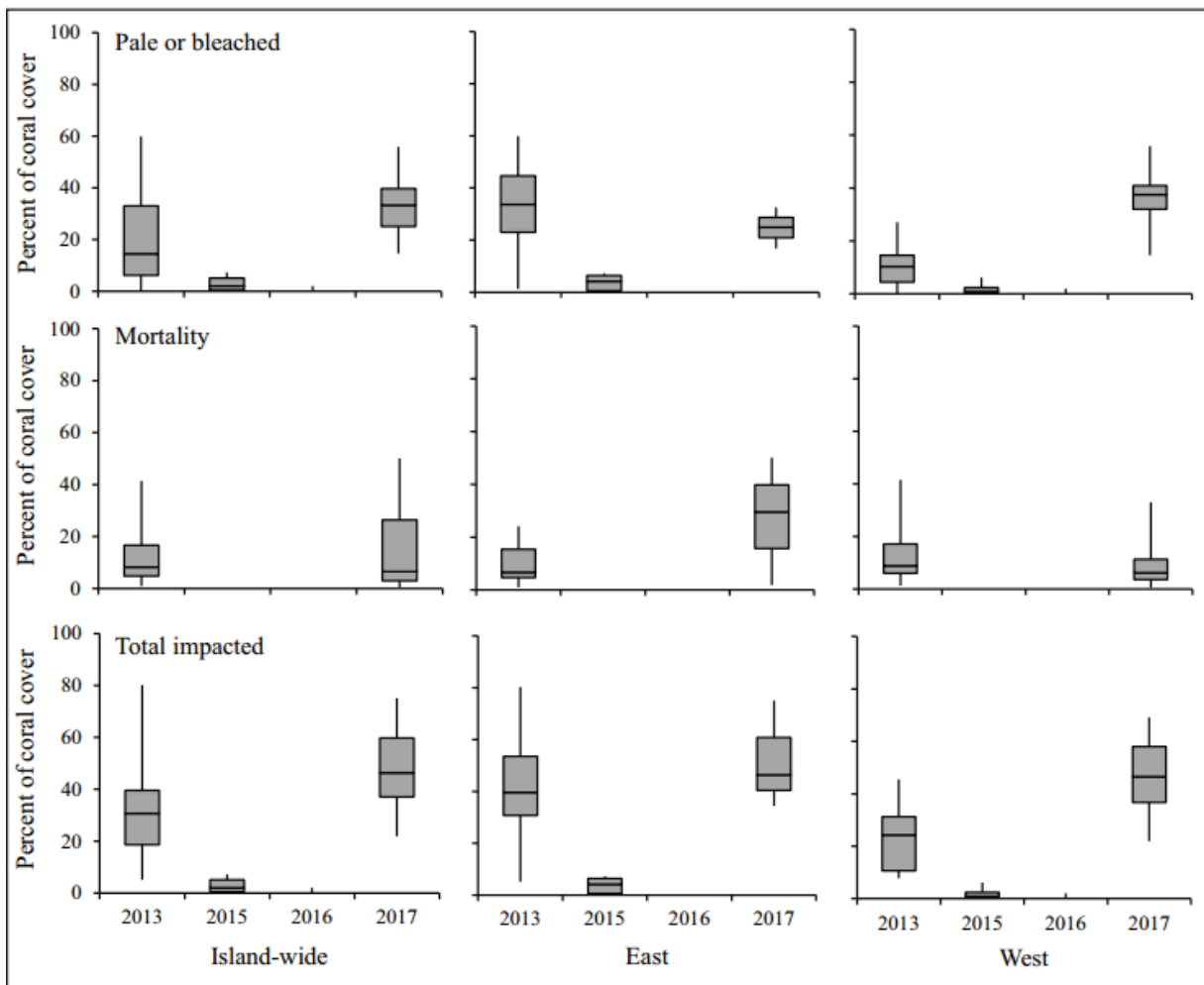


Figure 3. Percentage of bleaching-impacted coral cover from shallow (5 m) seaward slope benthic photo transect surveys between 2013 and 2017 for all sites island-wide, eastern windward sites, and western leeward sites. Figure reproduced from Raymundo et al. (In review).

2.3.2 Bleaching prevalence at shallow seaward slope sites

Nearly a third ($32 \pm 19\%$) of coral cover at the shallow seaward slope sites was impacted by bleaching in 2013, with an average of $11 \pm 9\%$ of coral cover exhibiting bleaching-associated mortality. While the amount of bleaching-associated mortality was similar for the eastern windward sites ($10 \pm 7\%$) and the western leeward sites ($12 \pm 10\%$), the percentage of pale or bleached coral cover was significantly greater for eastern sites ($31 \pm 17\%$) than for western sites ($11 \pm 7\%$)(Figure 3). An analysis of the 2013 dataset by Travis Reynolds, a former graduate student of Dr. Raymundo, suggests that this difference was driven in large part by the greater proportion of bleaching-susceptible coral taxa in eastern windward coral communities (Reynolds 2016).

While thermal conditions associated with coral bleaching were observed in 2014, seaward slope surveys were not carried out due to the lack of warning of the unusually early onset of bleaching conditions, which were not detected at the time by the older 50-km NOAA Coral Reef Watch product, and because of limited capacity. However, significant bleaching, including bleaching-associated mortality, was observed at several reef flat sites. Consistent with the low levels of thermal stress in 2015, shallow seaward slope communities exhibited low levels of bleaching ($3 \pm 3\%$ of coral cover was pale or bleached), with no observed bleaching mortality. The mean percentage of pale or bleached coral at shallow seaward slope sites in 2016 was even lower than in 2015 ($0.1 \pm 0.5\%$), although it should be noted that significant bleaching was recorded at reef flat sites during this same period. The percentage of bleaching-impacted coral cover at seaward slope sites in 2017 was even greater than in 2013, with an island-wide mean of $48 \pm 17\%$ impacted coral cover, including $15 \pm 17\%$ of coral cover that exhibited bleaching-associated mortality. Semi-quantitative surveys of coral communities revealed that 92% of all surveyed coral taxa and 98% of coral genera exhibited paling, bleaching, or bleaching-associated mortality.

2.3.3 Changes in benthic cover at shallow seaward slope sites

The percentage of living coral cover at shallow seaward slope sites island-wide declined by approximately one-third between 2013 and 2017 (from $25 \pm 13\%$ to $17 \pm 9\%$)(Figure 4); this decline is likely attributed in large part to mortality associated with the multiple thermal stress events recorded during this period. The decline in mean island-wide coral cover was driven primarily by a nearly 60% decline (from $29 \pm 13\%$ to $12 \pm 1\%$) at the eastern sites, whereas no significant difference in coral cover was observed at western sites during this period. However, it should be noted that the small number of eastern seaward slope sites surveyed in 2017 may not be representative of the full extent of the windward side of the island.

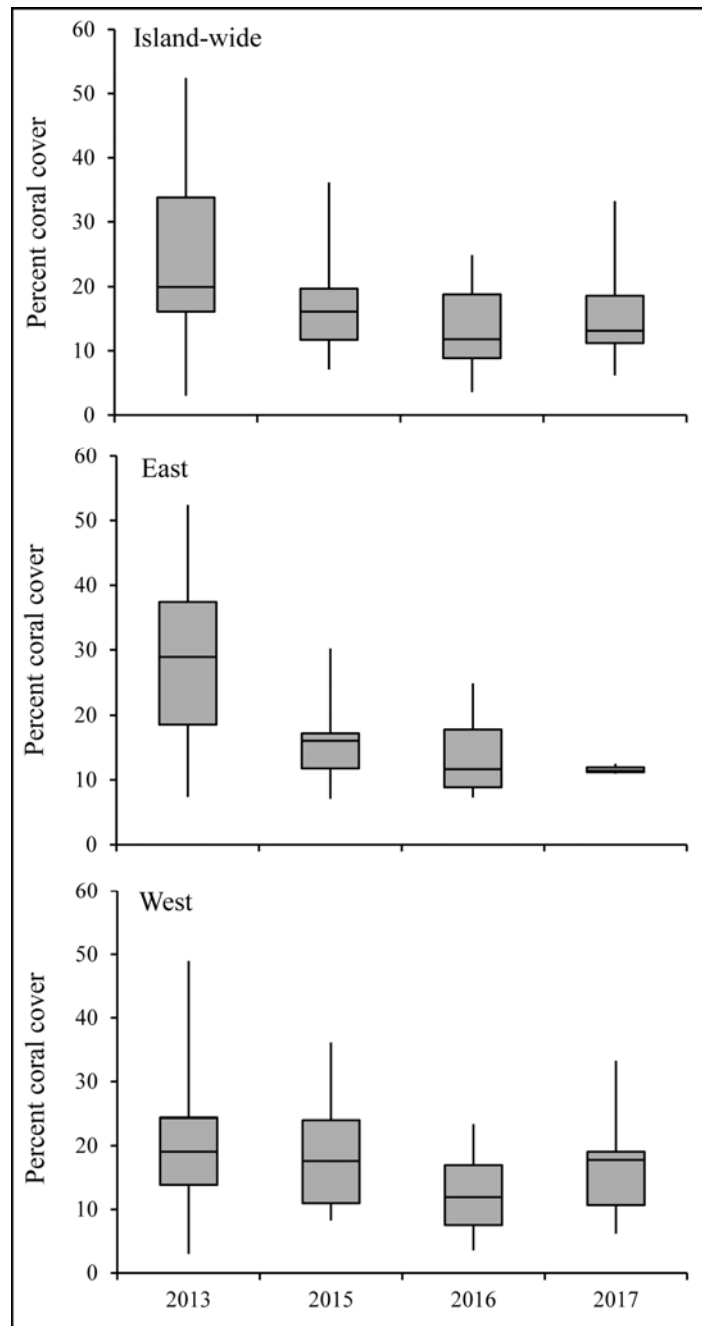


Figure 4. Change in percent coral cover from shallow (5 m) seaward slope benthic photo transect surveys between 2013 and 2017 for all sites island-wide, eastern windward sites, and western leeward sites. Figure reproduced from Raymundo et al. (In review).



3.1 INTRODUCTION

Arborescent *Acropora* species, known commonly as staghorn corals, provide important habitat for fishes and invertebrates on tropical coral reefs. Staghorn corals also happen to be among the coral species considered most vulnerable to the effects of climate change, particularly to thermal stress events, which are expected to increase in frequency and severity as sea surface temperatures continue to rise. Prompted by the apparent decline in Guam's staghorn coral communities in recent decades and the increasing threat of climate change, members of the

GLTMP, in collaboration with UOGML researchers and the National Park Service (NPS), opportunistically mapped the majority of Guam's staghorn coral thickets between 2009 and 2013. This baseline inventory of Guam's staghorn thickets is critical for understanding the contribution of these unique coral communities to Guam's coral reef ecosystem and in assessing changes in their extent and condition over time.

The staghorn mapping effort quickly proved essential, as the resulting spatial data provided the foundation of a 2014/2015 staghorn mortality assessment led by Dr. Laurie Raymundo of the UOGML, and supported by the MPC. This initial island-wide mortality assessment was prompted by observations of catastrophic mortality at several of Guam's staghorn coral communities in association with bleaching events in 2013 and 2014, as well as mortality associated with subaerial exposure during a period of ENSO-related extreme low tides in 2014/2015. The results of the assessment were published in Raymundo et al. (2017). A second mortality assessment was carried out in 2017 following observations of additional mortality associated with a bleaching event in 2016. The cumulative results of the 2015 and 2017 assessments were included in Raymundo et al. (In review), along with the results of analysis of coral bleaching surveys carried out island-wide along the shallow seaward slope survey and data collected by the RFMP.

3.2 METHODS

Shallow reef areas around Guam where staghorn coral thickets were known or expected to occur were investigated opportunistically between 2009 and 2013 by GLTMP team members and an NPS intern, who swam across the reef flats and recorded the locations of thickets using mapping-grade GPS receivers, obtained images of the thickets using digital cameras, and, in some cases, recorded observations of coral condition. In a closely related collaboration between the Bureau of Statistics and Plans and UOGML researchers, an observer was towed behind a small boat to more efficiently cover large expanses of Cocos Lagoon and Apra Harbor. The GPS data, in combination with high-resolution satellite imagery, were used within a Geographic Information System to create polygon features delineating the estimated extent of staghorn thickets.

Between November 2014 and February 2015 the MPC assisted Dr. Raymundo with a semi-quantitative assessment of the extent and mortality of all known staghorn *Acropora* populations (n=21) around Guam (Figure 5). The location and pre-bleaching extent of the staghorn communities were derived from the spatial data layer resulting from the above-mentioned mapping effort. Surveys involved the visual estimation of percent mortality, which was multiplied by the pre-bleaching areal extent to arrive at post-bleaching areal extent and calculations of net staghorn coral loss. Follow-up surveys of the same 21 populations were carried out between February and May 2017 (prior to bleaching that year) in response to additional mortality observed following the 2015 surveys. The follow-up surveys employed a more quantitative

approach in which coral condition was assessed at 16 points within replicate quadrats placed on staghorn thickets or colonies.

3.3. RESULTS AND DISCUSSION

Prior to the 2013 bleaching event, staghorn coral populations, which were primarily dominated by *Acropora cf. pulchra*, were estimated to have covered a total of approximately 0.33 km² of reef area around Guam (Figure 5). Most staghorn populations occurred on shallow reef flat platforms along the western coast, but some small thickets occurred in Apra Harbor, Cocos Lagoon, and Puguia Patch Reef (Double Reef). Cumulative staghorn coral mortality from elevated SSTs and extreme low tides between 2013 and 2015 was estimated at 53±10% by Raymundo et al. (2017). One large population in Agat, southwestern Guam, suffered 100% mortality, while eight other populations experienced 70% or greater mortality. Staghorn populations re-assessed in 2017 exhibited reductions in live cover ranging from 29% to 100% compared to pre-2013 populations (Figure 6). Four of the surveyed populations were devoid of any living tissue, three showed persistent mortality of more than 70% of the pre-2014 population, while seven populations had coral cover values of 50% or greater.

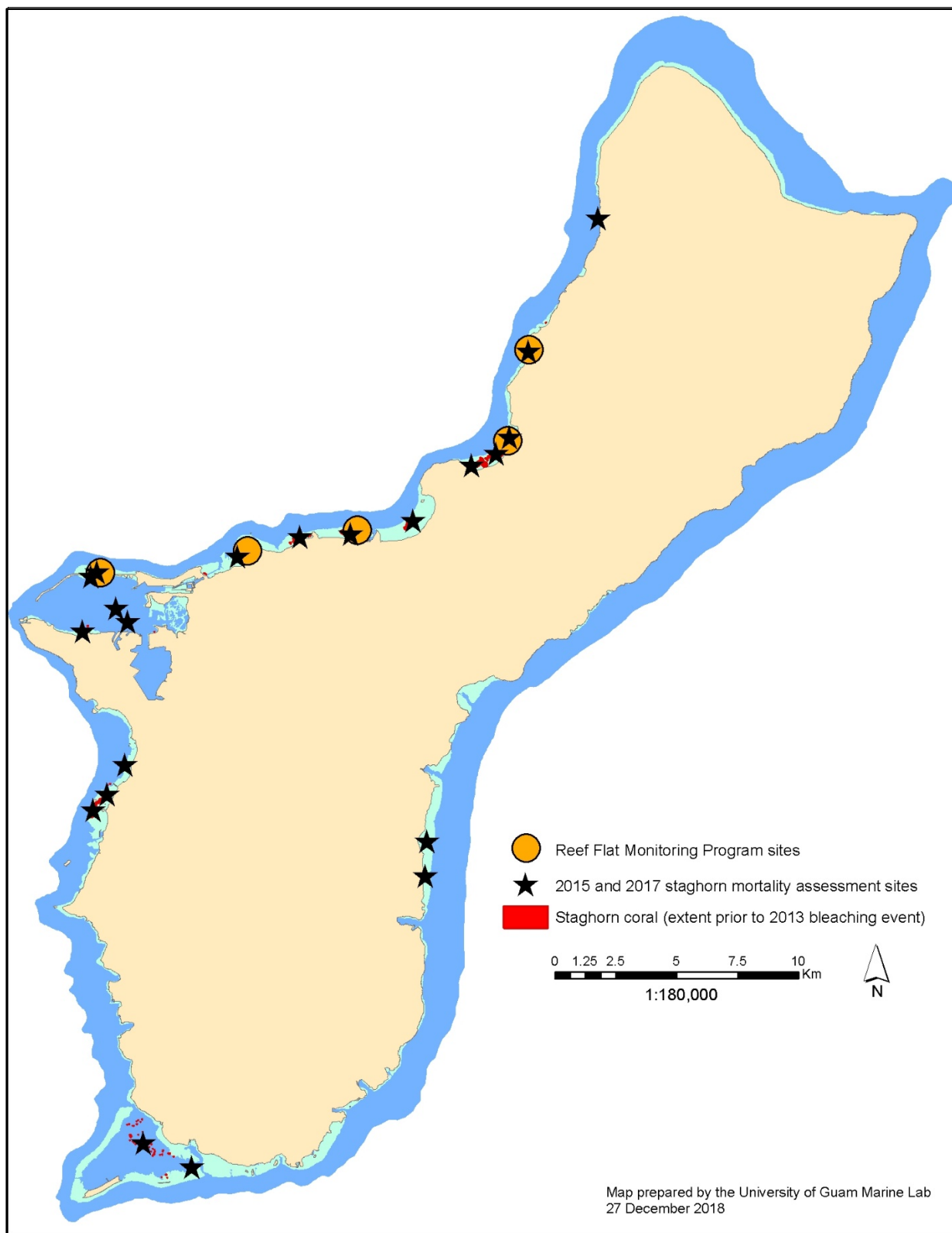


Figure 5. Location of staghorn mortality assessment sites and Reef Flat Monitoring Program sites.

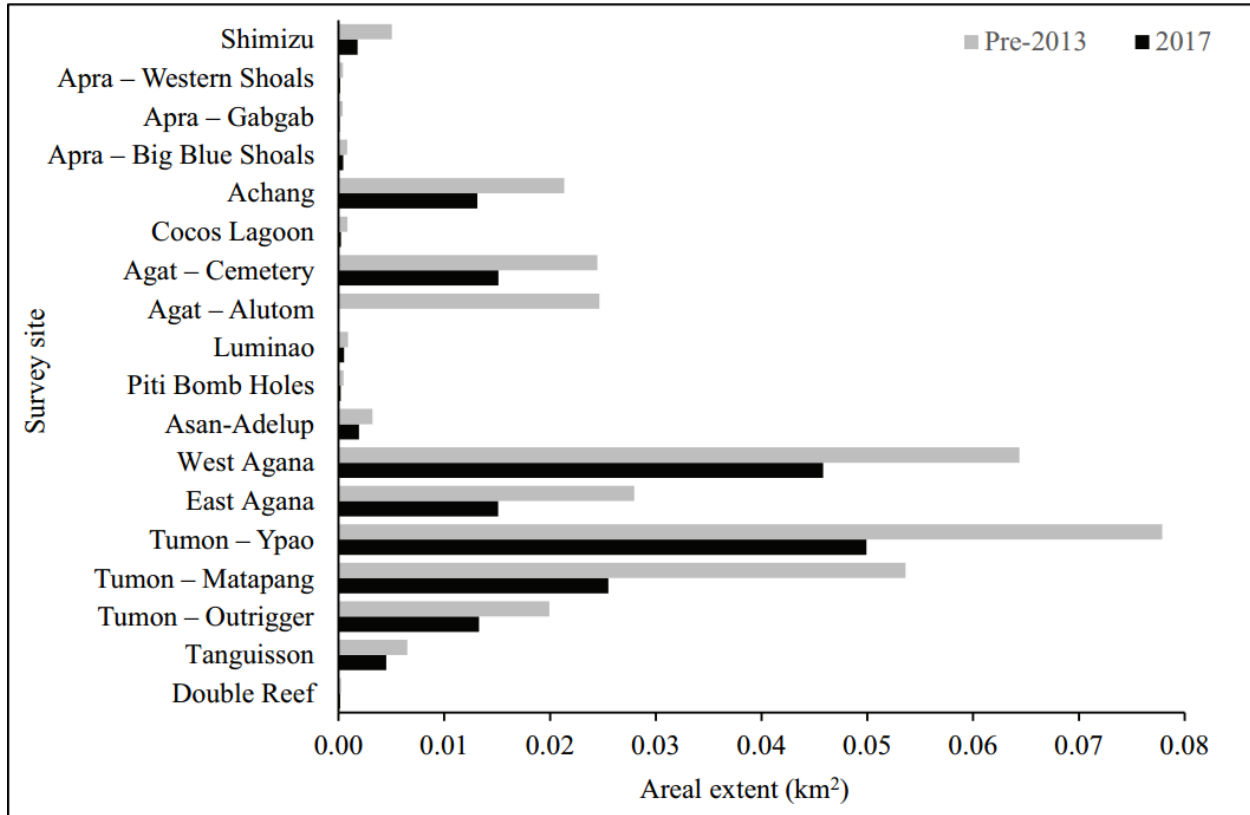
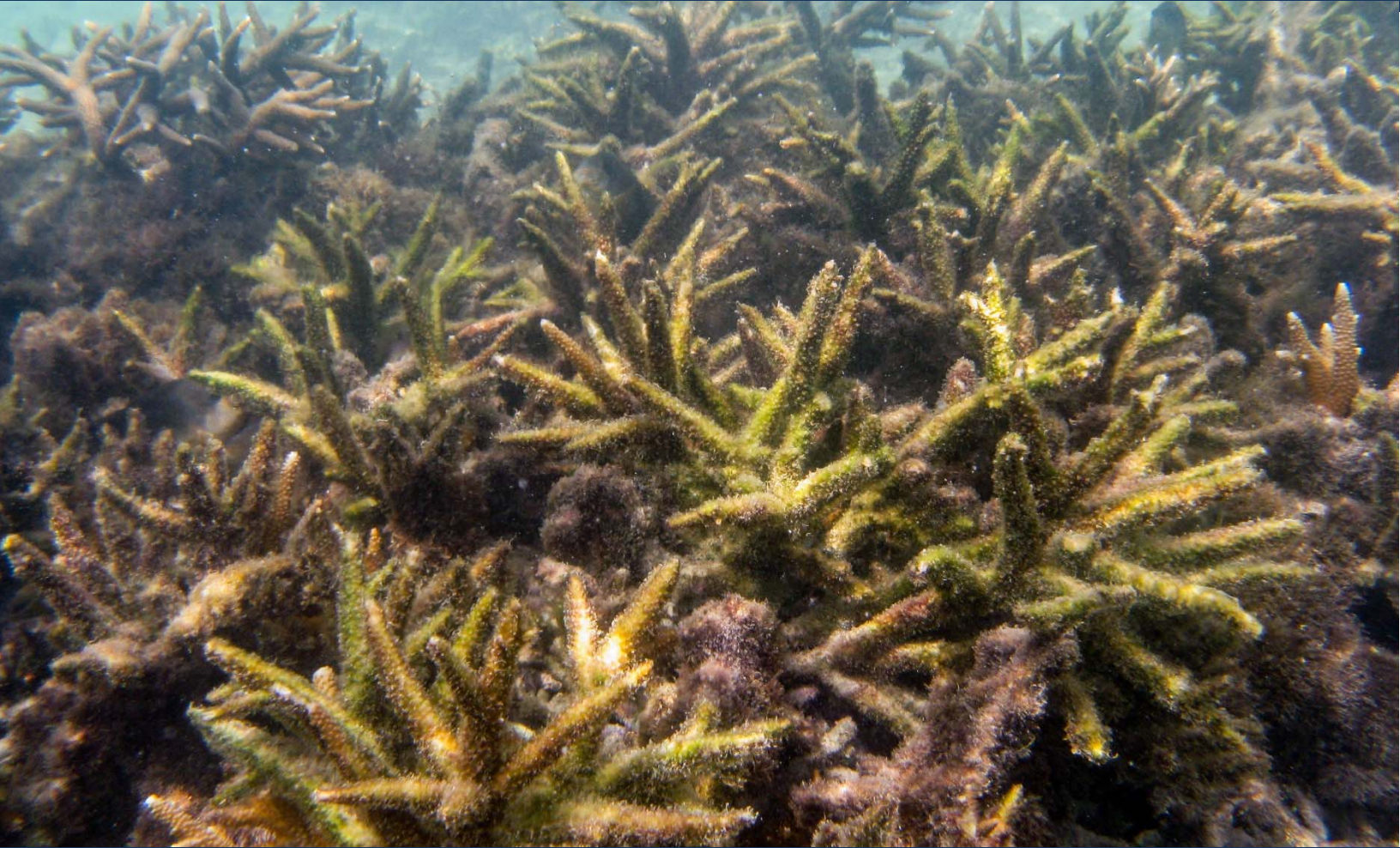


Figure 6. Change in estimated areal extent of 18 surveyed staghorn *Acropora* populations around Guam. The graph depicts the areal extent of the sites surveyed prior to 2014 compared to the estimated percent lost by 2017. Figure reproduced from Raymundo et al. (In review).



4.1 INTRODUCTION

As described in Section 1.4 above, the Reef Flat Monitoring Program (RFMP) involves quarterly visits to five sites along the northwestern coast. This project emerged from a 2009 study examining sewage nutrient eutrophication and its impact on coral disease along Guam's northwestern coast (Redding et al. 2013). Upon completion of the study, local management agencies requested that the monitoring of a subset of these sites be continued as part of Guam's Long-term Coral Reef Monitoring Program. Due to funding limitations, one site (Adelup), was

dropped, as it hosted a coral community very similar to that in West Agaña. A second site (Haputo, the northernmost site) was later discontinued due to limited access related to U.S. military activities at a nearby firing range. Five sites have thus been monitored regularly since 2009. The RFMP has provided important, detailed information about trends in coral community health, and places particular attention on coral diseases, predators, bleaching and other coral health concerns and the relationship with water temperature and nutrients. The data generated through the RFMP provides a strong complement to the data collected at the seaward reef slope sites targeted with the GLTMP. The RFMP provides information to managers for a critical, dynamic, yet vulnerable reef zone, and is an essential component of a comprehensive coral reef monitoring strategy.

4.2 METHODS

Monitoring is scheduled to take place quarterly at five sites, including Tumon, Tanguisson, West Agaña, Piti, and Luminao (Figure 5). Weather conditions sometimes prevent access to certain sites, but, in general, most sites are visited at least three times per year. Three 20-meter permanent transects were established at each site in 2009. Transect markers have been lost during storms at certain sites, but new ones were established within the same coral community patch during the next census. A line intercept transect method is used to collect data on benthic composition; benthic categories include live hard coral, old dead coral, recently-killed coral, rubble, pavement, soft coral, sand, silt, macroalgae, cyanobacteria, and crustose coralline algae. A one-meter belt transect is used to survey coral health impacts. All colonies within the belt are identified to species and visually inspected for the following: coral disease (white syndrome, black band, brown band, skeletal eroding band, growth anomalies, cyanobacterial mat), predation, competitive overgrowths, bleaching, and partial mortality of unknown cause (after Raymundo et al. 2009). A colony size estimation was incorporated into the survey regime in 2011; maximum diameter for each colony was binned into the following categories: 1–10 cm; 11–30 cm; 31–60 cm; 60–100cm; 101–200 cm; >201 cm. Hobo pendant temperature loggers (Onset Corp. ©) have been deployed at the Tumon, Piti and Luminao sites since 2009.

4.3 RESULTS AND DISCUSSION

The RFMP captured several significant events that impacted Guam’s coral reefs since 2009. Mean change in percent live hard coral and dead coral (summed values of old dead and recently killed coral) are presented in Figure 7. The year 2009 marked the end of an extended crown-of-thorns seastar (COTS) outbreak which impacted reefs along Guam’s entire coast and explained the larger proportion of dead coral across sites in this year. A series of bleaching and extreme low tide events that began in 2013 resulted in significant coral loss (details presented in Table 1; summarized in Raymundo et al. In review).

On average, coral cover at monitored reef flat sites on the west coast of Guam hovered around 30% coral cover until 2014, when coral cover at all sites began a gradual decline due to repeated mortality events. The RFMP documented coral loss averaging 27% across the five sites over a 10-year period encompassing the COTS outbreak, repeated bleaching episodes, and an ENSO-related year-long extreme tide event. However, total coral decline within individual sites varied greatly, with sites supporting extensive staghorn *Acropora* populations showing the greatest loss (Tanguisson, Tumon and West Agaña; average of 46% decline) and sites dominated by *Porites* showing significantly less loss (Piti and Luminao; average of 4% decline). At present, dead coral represents the greatest proportion of benthic cover type across all five sites. Recovery patterns should be discernible in future monitoring visits, barring additional severe bleaching events.

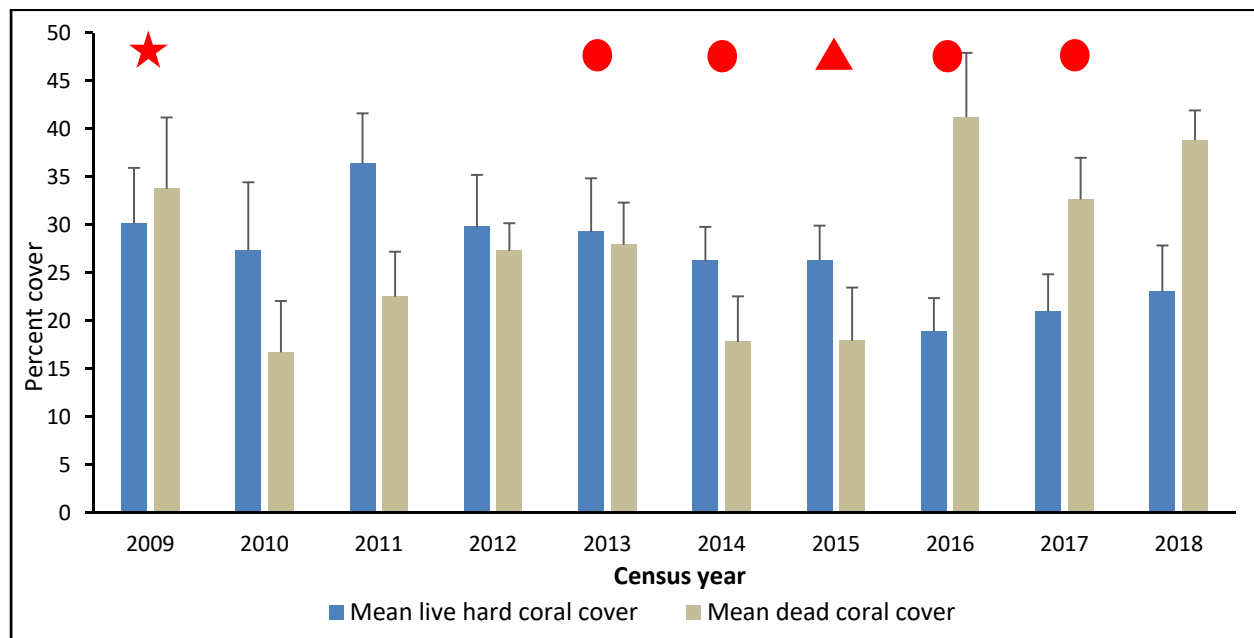


Figure 7. Change in average (Mean ± SE) percent live hard coral (LHC) cover and dead coral (DC) cover across five sites monitored by the Reef Flat Monitoring Program from 2009 to 2018. Events which resulted in significant coral loss are indicated by red shapes above the respective years when the events took place, including a crown of thorns outbreak (star), coral bleaching (circles), and extreme low tides (triangle).

Prevalence of bleaching and white syndrome are presented in Figure 8. White syndromes (WS) were the most prevalent diseases recorded from Guam, and were present at all sites during all census periods. However, prevalence was consistently much higher at the *Porites*-dominated sites (Luminao and Piti) than at the *Acropora*-dominated sites (Tumon, Tanguisson, and West Agaña). While this group of syndromes affects many species, and is currently thought to be caused by more than one infectious bacterium, *Porites* is known to be a dominant host genus on Guam (Myers and Raymundo 2009). In *Porites*, the disease can be highly prevalent but appears to be chronic and sublethal to the colony. In contrast, it can also manifest as a highly infectious and rapidly progressing disease in an acute outbreak form, which is more lethal to whole colonies. Outbreaks of WS have occurred in *Acropora* populations in Tanguisson and Tumon in 2017 and in *Pocillopora damicornis* in 2018 (data not shown in Fig. 8).

Bleaching prevalence was generally low except during seasonal periods of elevated sea surface temperatures. While there appears to be no obvious link between bleaching and white syndrome over what were considered normal seasonal fluctuations, WS outbreaks were seen during or immediately after bleaching events between 2016 and 2017 in Tanguisson and Tumon. This suggests there may be a link between these two phenomena impacting coral health, and further investigation and monitoring are warranted.

Table 1. Summary of change in live hard coral cover at five sites monitored by the Reef Flat Monitoring Program between 2009 and 2018. The net change and total change values for West Agaña were calculated using data from 2014 to 2018, due to storm-related loss of two transects in 2013; the 2014-2018 values represent change across the new transects.

Year	Tanguisson	% Change	Tumon	% Change	West Agaña	% Change	Piti	% Change	Luminao	% Change
2009	24.0		49.9		14.8		33.1		28.9	
2010	14.0	-10.0	48.3	-1.6	9.6	-5.2	29.3	-3.8	35.6	6.7
2011	24.8	10.8	43.8	-4.5	22.9	13.3	42.8	13.5	47.8	12.2
2012	17.7	-7.1	45.6	1.8	17.7	-5.3	36.2	-6.6	31.8	-16.0
2013	26.4	8.7	49.4	3.8	16.8	-0.9	22.8	-13.4	31.2	-0.6
2014	13.8	-12.6	34.0	-15.4	24.7	na	31.8	9.0	27.1	-4.1
2015	13.6	-0.2	34.3	0.3	23.4	-1.3	29.9	-1.9	30.3	3.2
2016	10.0	-3.6	16.9	-17.4	14.0	-9.4	27.3	-2.6	26.5	-3.8
2017	10.0	0.0	25.9	9.0	13.9	-0.1	24.3	-3.0	30.8	4.3
2018	8.3	-1.7	31.8	5.9	15.9	2.0	32.9	8.6	26.6	-4.2
Net Change per Site		-15.7		-18.1		-6.8		-0.2		-2.3
Total Change per Site		-65.4		-36.3		-35.7		-0.6		-8.0
Mean % change across sites		-27.4 +/- 11.5								

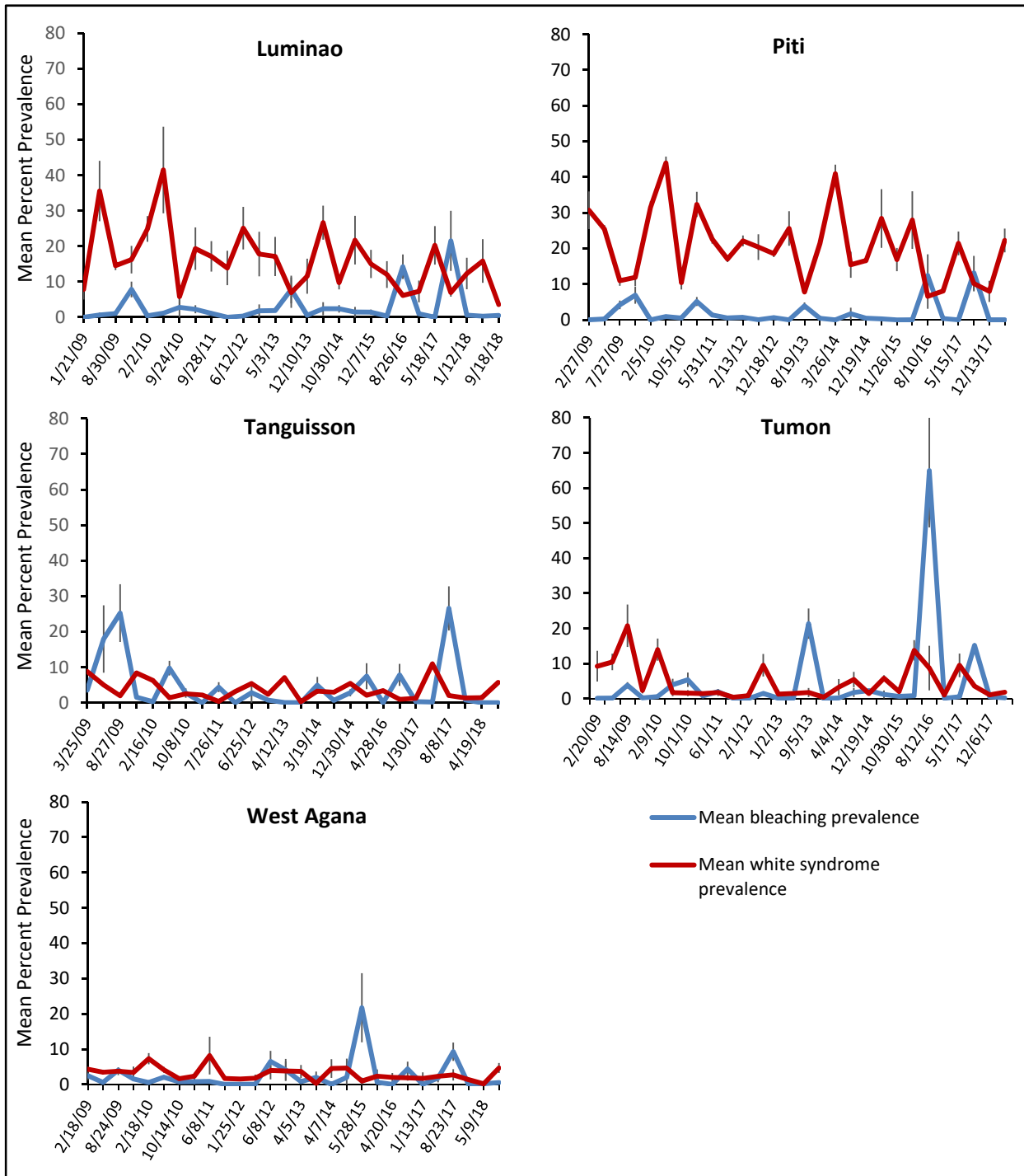


Figure 8. Mean (+/-SE) bleaching and white syndrome prevalence for each site monitored by the Reef Flat Monitoring Program. Values are based on assessments of n=3 transects per site. Data from quarterly sampling from 2009 to 2018.

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