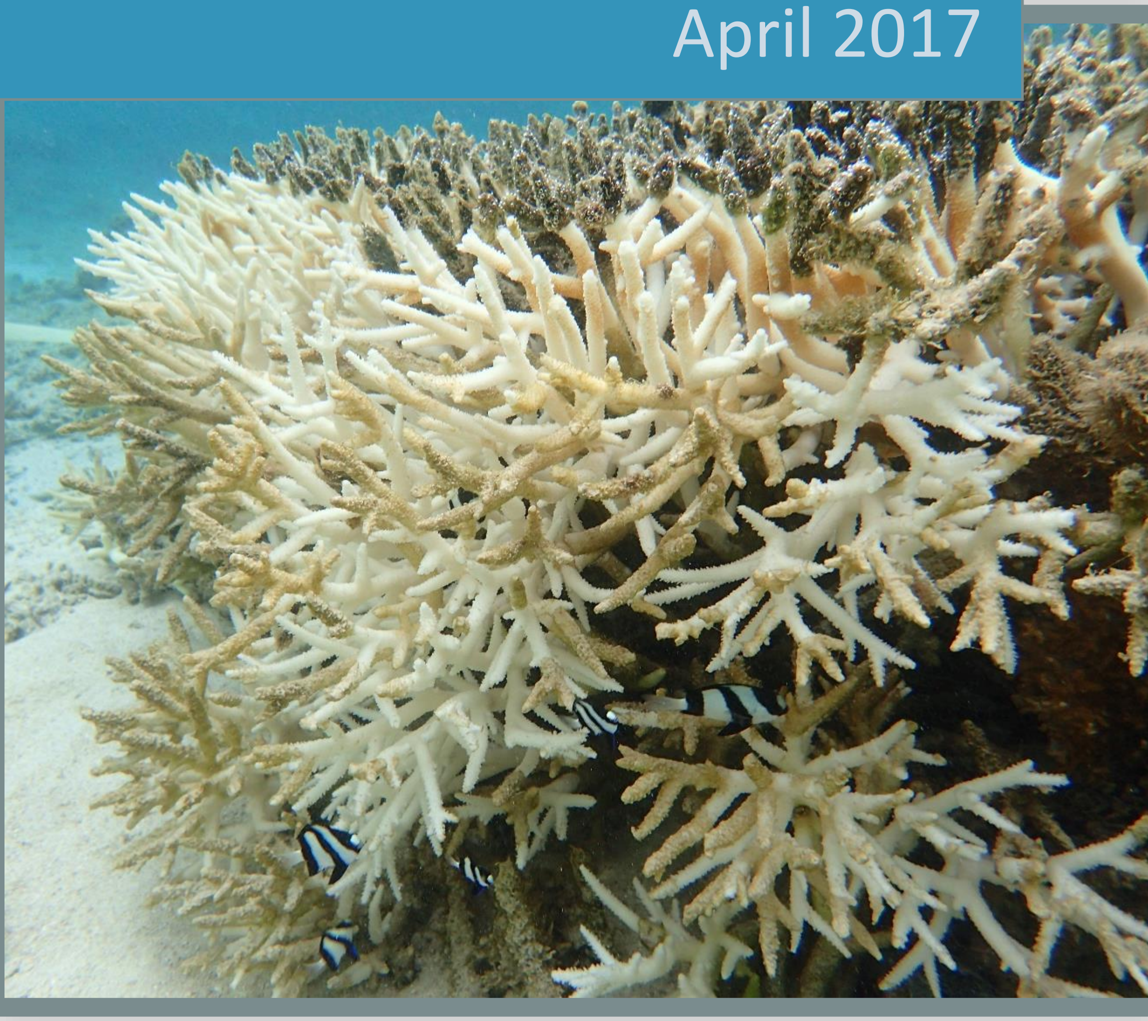
Guam Coral Bleaching Response Plan

April 2017



Overview

The Guam Coral Bleaching Response Plan was developed through the collaboration of multiple local and federal agencies, including the Bureau of Statistics and Plans (BSP) and the Guam Coastal Management Program (GCMP), the Guam Department of Agriculture's (GDOAG) Division of Aquatic and Wildlife Resources (DAWR), the Guam Environmental Protection Agency (GEPA), the University of Guam Marine Laboratory (UOGML), the National Oceanic and Atmospheric Association (NOAA), the National Park Service (NPS), Joint Region Marianas (JRM), and the U.S. Fish & Wildlife Service (USFWS).

The Guam Coral Bleaching Response Plan exists to maximize the effectiveness of activities conducted by the Guam Coral Reef Response Team and ensure efficient use of resources and human capital by providing a standardized framework for responding to coral bleaching events. Coral bleaching is largely driven by ocean warming that cannot be directly influenced at a meaningful scale by local intervention, therefore the management response to coral bleaching is especially complex and challenging.

This plan was first drafted in 2011 and finalized in 2017, although this document is intended to be a working draft that will be periodically updated and improved. This plan includes an in-depth description of Guam's early warning system for coral bleaching events, standard operating procedures for response implementation including detailed assessment protocols, and recommendations for post-bleaching management, reef recovery, and restoration approaches. This document is intended for use by coral reef managers and scientists on Guam, but may also be useful to individuals and groups in other locations impacted by coral bleaching, especially those who are interested in developing similar coral bleaching response plans.

Objectives of the Guam Coral Bleaching Response Plan:

1. Summarize the impacts of past bleaching events on Guam.
2. Provide up-to-date standard operating procedures to be followed before, during, and after coral bleaching events, including contact information for key parties; lists of agency assets and necessary supplies; and delineation of relevant local and federal policies and agency roles.
3. Develop a protocol to monitor projections of thermal stress and coral bleaching events and provide early warning of major coral bleaching events on Guam.
4. Create a framework for an optimal bleaching response, including:
    a. Measurement of the spatial extent and severity of mass coral bleaching events, including impacts to non-coral organisms;
    b. Assessment of the ecological and socioeconomic impacts of mass coral bleaching events;
    c. Identification of resilient reef areas on Guam;
    d. Formation of a plan to mitigate bleaching impacts and restore bleached ecosystems; and,
    e. Development of a pathway for communicating findings to decision makers.
5. Involve the community in monitoring the health of Guam's reefs.
6. Communicate with the local media and raise public awareness of the impacts of bleaching on Guam's reefs.

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Acknowledgments:
The Guam Coral Bleaching Response Plan is based in part on the Great Barrier Reef Marine Park Authority's (GBRMPA) Coral Bleaching Response Plan 2010-2011, as well as information provided in A Reef Manager's Guide to Coral Bleaching (Marshall and Schuttenberg 2006), produced jointly by the GRBMPA, NOAA, and The World Conservation Union (IUCN), and presented at the Response to Climate Change Workshop conducted by NOAA and GBRMPA in American Samoa (August 2007) and Guam (August 2009).

Response plans and management strategies from other coral reef jurisdictions were also referenced in the writing of this plan, including Hawaii's Rapid Response Contingency Plan for events of coral bleaching, disease, or crown-of-thorns starfish outbreaks (Aeby et al. 2008); the Florida Reef Tract Coral Bleaching Response Plan (2013) produced by the Florida Reef Resilience Program; the US Virgin Islands Reef Resilience Plan (Lewis 2011); the American Samoa Assessment and Rapid Response Plan (2013); and the Belize Coral Bleaching Response & Management Plan 2008-2013 developed by ECOMAR (Searle et al. 2014).

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Acronyms

AAFB = Andersen Airforce Base
BSP = Guam Bureau of Statistics and Plans
CNMI = Commonwealth of the Northern Marianas Islands
COTS = Crown of thorns sea star (*Acanthaster planci*)
CPC = Climate Prediction Center within NOAA's National Weather Service
CRCP = Coral Reef Conservation Program within NOAA
CREP = Coral Reef Ecosystem Program within NOAA Fisheries
CRW = NOAA Coral Reef Watch program
DAWR = Guam Department of Wildlife Resources within the Guam Department of Agriculture (GDOAG)
DHW = Degree heating week
ENSO = El Niño Southern Oscillation
EoR = Eyes of the Reef Marianas
ESRL = Earth System Research Laboratory within the Physical Sciences Division of NOAA
GBRMPA = Great Barrier Reef Marine Park Authority
GCCRMP = Guam Community Coral Reef Monitoring Program
GCMP = Guam Coastal Management Program within the Bureau of Statistics and Plans
GDOAG = Guam Department of Agriculture
GEPA = Guam Environmental Protection Agency
GLTCRMP = Guam Long-term Coral Reef Monitoring Program
GNA = Guam Natural Alliance
IPCC = Intergovernmental Panel on Climate Change
IUCN = The World Conservation Union
JRM = Joint Region Marianas
LAS = Local Action Strategy
LBSP = Land-based sources of pollution
LIT = Line intercept transect
MLLW = Mean lower low water (mean height of lowest tide recorded each day during recording period)
MMM = Maximum monthly mean
MPA = Marine protected area
MOU = Memorandum of understanding
NDBC = National Data Buoy Center of NOAA
NOAA = US National Oceanic and Atmospheric Administration
NOS = National Ocean Service within NOAA
NPS = US National Park Service
NWS = US National Weather Service within NOAA
PacIOOS = Pacific Integrated Ocean Observing System
PIFSC = Pacific Island Fisheries Science Center within NOAA Fisheries
PIT = Point intercept transect
POC = Point of contact
REA = Rapid ecological assessment
SOP = Standard operating procedure
SST = Sea surface temperature
TNC = The Nature Conservancy
UOG = University of Guam
UOGML = University of Guam (UOG) Marine Laboratory
USFWS = U.S. Fish & Wildlife Service

Background

Climate change and coral bleaching

Although coral reef ecosystems have existed for approximately 500 million years, their survival is threatened by human impacts at local, regional, and global scales. About one fifth of the planet's coral reefs have already been lost and now, more than a quarter of the remaining reefs are facing imminent degradation (Wilkinson 2006; Riegl et al. 2009). Anthropogenic greenhouse gas emissions have dire consequences for reefs, such as reduced calcification rates due to acidification (a result of carbon uptake by the ocean), outbreaks of emergent coral diseases and shifting distribution of existing diseases, and coral bleaching, which is caused by both warming seas and acidification (Riegl et al. 2009). Fifteen Pacific coral species are listed under the U.S. Endangered Species Act; two of these species (*Acropora globiceps* and *Sertiatopora aculeata*) have been confirmed in the Marianas with unconfirmed presence of a third threatened species (*Acropora retusa*) (Burdick D, pers. comm.).

Since the beginning of the 20th century, mean sea surface temperature (SST) increased by an average of 0.07°C per decade (Figure 1). Between 1971 and 2010, over 90% of the energy (heat) stored by the earth was taken up by the oceans. Most ocean warming is occurring near the surface, with an average increase of 0.11°C per decade in the shallowest 75 m of ocean waters over that period (IPCC 2014). The majority of reef-building (hermatypic) coral species depend on mutualistic relationships with symbiotic unicellular dinoflagellates, algae known as zooxanthellae, which live in the tissue of each coral polyp (genus: *Symbiodinium*). These coral species, known as the Scleractinia, obtain the majority of their nutrients from these photosynthetic algae and are able to accrete calcium carbonate to build their skeletons more rapidly than azooxanthellate corals. Scleractinian corals are restricted to relatively shallow waters, as the symbionts must receive adequate solar irradiance to supply the coral polyps with energy and oxygen (Sebens 1994).

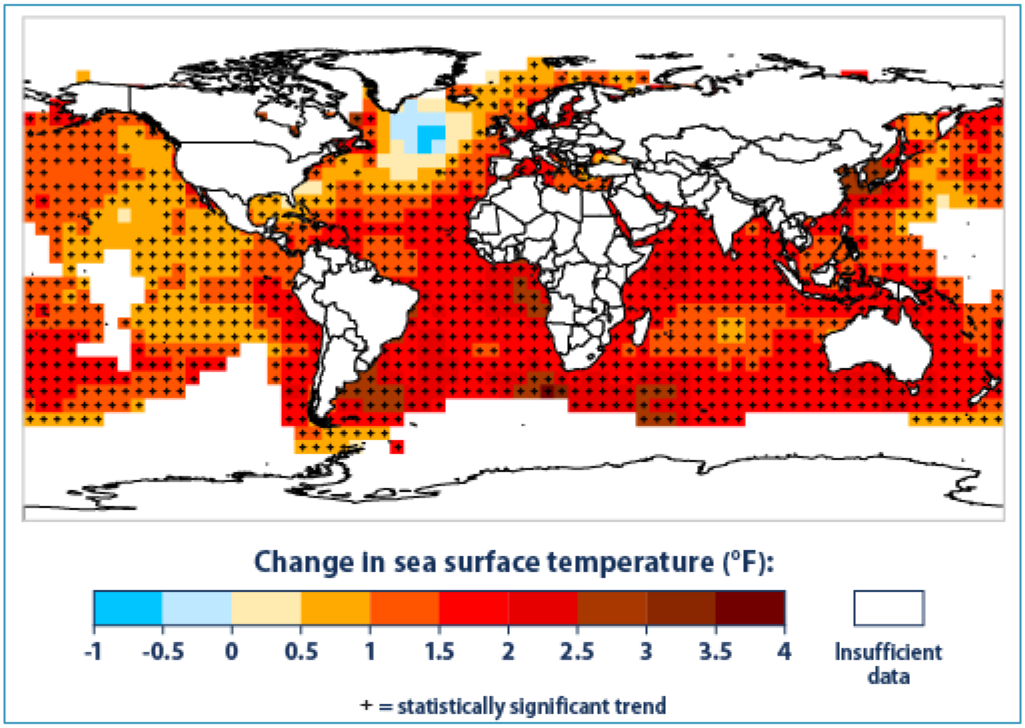


Figure 1. Change in mean SST between 1901 and 2014 (data from IPCC and NOAA); during this period, SST rose an average of 0.07°C per decade (Source: https://www3.epa.gov/climatechange/science/indicators/oceans/sea-surface-temp.html)

The current concentration of CO_2 in the atmosphere is higher than at any other time in the past 15 million years, resulting in both atmospheric and oceanic temperature increases (Bijma et al. 2013). On a geological time scale, periods of rising SST are not uncommon. However, the current rate of SST change is unprecedented. SST is predicted to increase a further

1-3°C by the end of this century; this has significant implications for the functioning of coral reefs and other coastal ecosystems and may result in more frequent and increasingly severe bleaching events (Hernandez-Delgado 2015). Rising water temperatures and more frequent high temperature anomalies impact the photosynthetic organelles of coral symbionts, making the zooxanthellae toxic to their scleractinian hosts; the polyps eject their zooxanthellae and lose their vibrant color, thus becoming "bleached" (Lesser 2007; Baker et al. 2008). Corals are highly sensitive to small changes in temperature because they typically live in habitats that are close to their upper thermal tolerances; bleaching can occur when water temperatures rise just 1°C over long-term summer SST averages (Hoegh-Guldberg 2011).

This paints a bleak future for coral reefs, as ocean warming will continue throughout this century, with the most significant warming projected for surface waters in the tropics and Northern subtropics (IPCC 2014). Coral bleaching, combined with the impacts of local stressors, is expected to be a major driver of coral reef degradation over the next half century (Marshall and Schuttenberg 2006). Although bleaching is primarily attributed to thermal stress, laboratory experiments have shown that acidification also impacts the relationship between stony corals and their dinoflagellate symbionts (Anthony et al. 2008). The degree of influence of acidification on bleaching is still unknown, however this result implies that ocean warming and acidification may have a compounding effect to increase bleaching severity in the future. Since the Industrial Revolution, there has been a 26% in acidity of ocean waters globally (IPCC 2014).

Bleaching also has indirect impacts, such as increasing coral vulnerability to disease (Mora 2009) and degrading reef habitat for fish and invertebrates (Baker et al. 2008). There is an interactive effect between coral bleaching and disease occurrence. The effect varies by genera; some species that are bleached become more susceptible to disease, while other species have been shown to become more vulnerable to bleaching after being impacted by disease (Brandt and McManus 2009). Increased SST is correlated with outbreaks of disease, possibly due to increased virulence of pathogens or decreased resistance of the corals to these infections (Brandt and McManus 2009).

Corals can die in great numbers immediately following a bleaching event, which can stretch across thousands of square kilometers of ocean, and lead to habitat phase shifts where corals are replaced by macroalgae. Although recent research has documented algal-dominated areas to occur naturally on many healthy Pacific reefs systems (Vroom et al. 2006), algal overgrowth of coral dominated areas as the result of anthropogenic activities is indicative of decreased ecosystem health, causing decreased accumulation of calcium carbonate and threatening the reef fauna that depend on the structural complexity provided by corals. The greatest threat from bleaching to coral reef ecosystems occurs when the physical structure of the reef is compromised, which results in an overall decline in species richness (number of species) (Graham et al. 2007).

Coral bleaching initially leaves reef structure intact, but this framework will collapse if the corals are unable to recover and later die. Both live coral cover and structural complexity are important for the survival of many reef-dwelling species (Coker et al. 2012). Some studies show that the long-term impacts of bleaching – which are still largely unknown, given that the first global bleaching event occurred less than two decades ago – may be more severe than expected (Wilson et al. 2006). Coral bleaching has been shown to cause declines in the abundance and diversity of reef fish, which may become more vulnerable to predation on bleached reefs, as their camouflage is ineffective against newly whitened corals (Coker et al. 2009). Reef-dwelling fish may selectively inhabit live coral over bleached or dead coral, thus further decreasing diversity of bleached reefs (Garpe and Ohman 2007). Bleaching impacts stony corals with potential effects cascading throughout trophic levels to damage entire reef systems. In the short term, coral bleaching impacts fish that directly utilize live corals for food, refuge, or nursery habitat. In the long term, populations of fish that consume coral will continue to decrease (Graham et al. 2007).

Reef resilience

"**Resilience** is defined as the ability of a system to maintain key functions and processes in the face of stresses or pressures by either resisting or adapting to change. Resilience consists of two components: **resistance**, which is the ability to absorb or resist impacts, and **recovery**, the ability to recover from them. **Coral reef resilience** refers to building resistance and recovery potential into reef ecosystems by reducing or eliminating stressors (e.g., overfishing, pollution, coastal development). The term '**reef resilience**' refers to coral reefs that are able to bounce back or recover after experiencing a stressful event such as bleaching caused by elevated temperatures."

(Source: http://www.reefresilience.org/about-resilience)

Local and regional variability exists in the thermal tolerances of zooxanthellate corals. Corals growing in waters with higher average mean temperatures are shown to have a higher tolerance to warming and lower susceptibility to coral bleaching resulting from increased SST (Glynn and D'Croz 1990). However, many coral taxa have fairly constant thermal tolerance thresholds across regions when measured at the same depth, indicating that phylogeny is a major driver of bleaching thresholds (McClanahan et al. 2004). Thermal tolerance is also influenced by the community of zooxanthellae living within a coral's tissues, and changes to this community (clade) may alter the thermal tolerance of coral colonies, as some zooxanthellae have higher thermal tolerance than others (Buddemeier and Fautin 1993). Scientists generally agree that the ability of corals to alter the composition of their symbiont communities is limited to the types of zooxanthellae acquired during the coral's pre-adult stages, although new research indicates that bleaching may drive adult corals to adopt new zooxanthellae from the surrounding waters. This may be an adaptation mechanism, if the corals acquire zooxanthellae that are more tolerant than their pre-bleaching communities (Boulotte et al. 2016).

A major concern is that the accelerating rate of environmental change could exceed the evolutionary capacity of coral reef species to adapt to these changes (Hughes et al. 2003), however some corals may be able to adapt and acclimatize to warming seas. A study of SST and coral bleaching on Australia's Great Barrier Reef showed that previous periods of thermal stress that resulted in bleaching had a "protective trajectory:" a period of short pre-stress warming above the maximum monthly mean (MMM) temperature, but below the bleaching threshold (MMM + 2^{o}C); a recovery period where temperatures fell below the MMM; and then the bleaching event, where temperatures rose above the bleaching stress threshold (Ainsworth et al. 2016). The pre-stress period, followed by recovery, allowed the corals to activate certain genes in response to non-fatal stress, which then reduced bleaching occurrence and decreased death of coral tissue during the subsequent bleaching event. This indicates that corals possess mechanisms that increase their resilience to thermal stress. However, given that SST is now steadily increasing, future bleaching events may not activate this protective mechanism if temperatures during the pre-stress phase exceed the threshold of MMM + 2^{o}C (Ainsworth et al. 2016).

Coral reef scientists and managers are attempting to develop proactive management techniques to minimize the impacts of coral bleaching events. Healthy reefs with high biodiversity and demographic connectivity to other reefs are more likely to recover from bleaching than stressed reefs, as they are better able to support coral recruitment, settlement, and growth (Marshall and Schuttenberg 2006). Current methods to directly improve the resistance of vulnerable coral communities to thermal stress (e.g., shading, cold water distribution) are highly experimental and will likely only be viable for small areas of reef. Thus the majority of management activities focus on building reef resilience by minimizing local anthropogenic threats that reduce the resiliency of reef systems, by incorporating the concept of resiliency into management plans to maximize the recovery potential of local reef systems, and by controlling potentially harmful activities at sensitive sites during coral bleaching events to minimize local stress to corals. Additional management activities include establishing coral nurseries as a way to grow healthy colonies that could be transplanted to reef sites heavily impacted by coral bleaching and other stressors. It must be noted that the cost of restoration greatly exceeds the cost of prevention, and restoration should not be counted on as the sole means by which coral reef function is sustained into the coming decades.

El Niño and coral reefs

The El Niño-Southern Oscillation (ENSO), caused by shifting atmospheric pressure and oceanic circulation, is an inter-annual climatic phenomenon (occurring approximately every 2-7 years) that creates significant temperature fluctuations in the tropical surface waters of the Pacific Ocean (NOS 2016). ENSO events can have a significant impact on coral reef ecosystems due to shifts in SST, surface winds, ocean currents, sea level, nutrient availability, storm frequency and magnitude, etc. ENSO has been linked to large-scale mortality of reef-building corals due to increased SST and UV exposure, as well as decreased nutrient availability (Hoegh-Guldberg 1999). ENSO is a naturally occurring phenomenon, but there is uncertainty regarding how global warming and climate change will impact the frequency and/or magnitude of this cycle, and how that will in turn affect coral reef ecosystems.

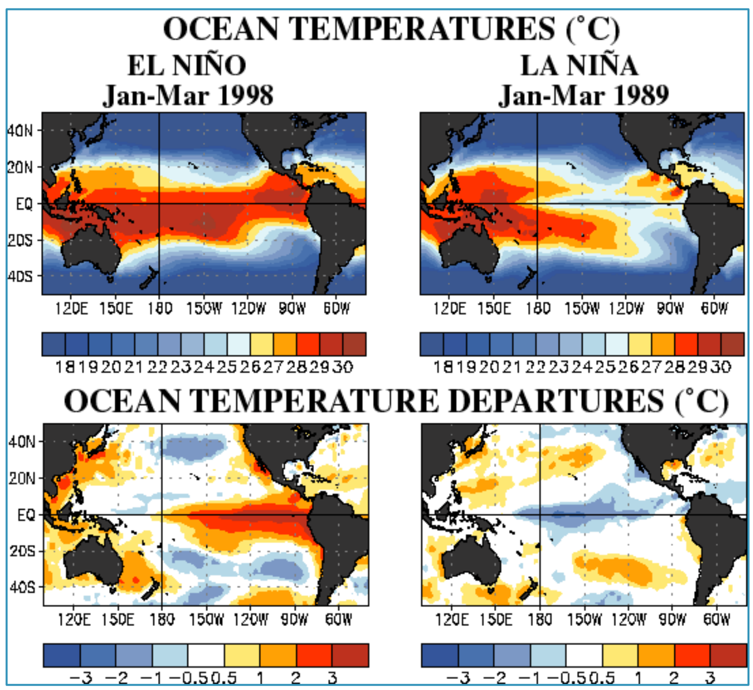
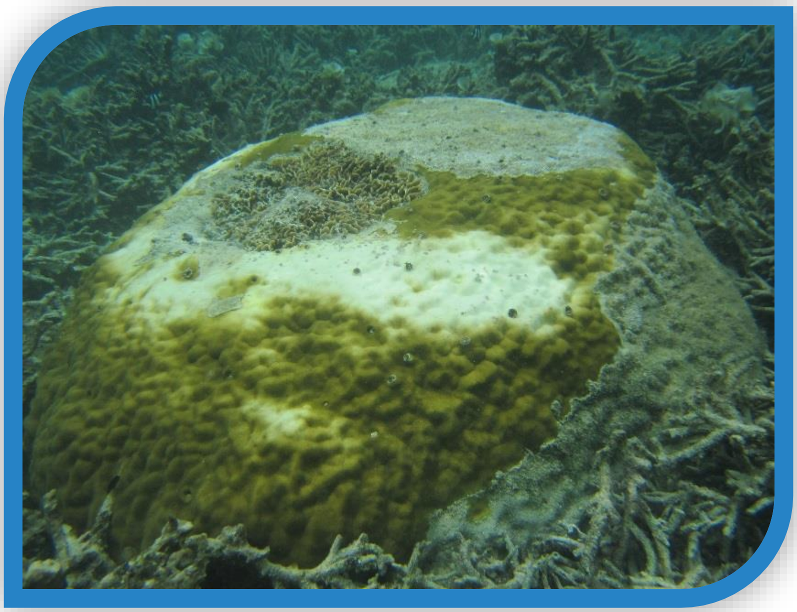


Figure 2. The El Niño phase (left) of the ENSO cycle causes elevated SSTs across the eastern tropical Pacific and is correlated with below average SST in the Guam region. The La Niña phase (right) is associated with decreased SSTs in the eastern tropical pacific region and elevated SSTs in the western tropical Pacific, including the waters surrounding Guam. (Source: http://www.cpc.noaa.gov/products/analysis_monitoring/ensocycle/ensocycle.shtml)

ENSO has two distinct phases in the Pacific Ocean: El Niño and La Niña (Figure 2). During El Niño conditions, westerly trade winds weaken and occasionally reverse in the equatorial Pacific. This causes eastward surface transport and an anomalously deep thermocline with warm SST in the central and eastern Pacific, and an abnormally shallow thermocline with cool SSTs in the western Pacific. During the La Niña phase, which often (but not always) follows an El Niño event, the westerly trade winds strengthen across the equatorial Pacific and push warm surface waters back towards the west. This condition results in an anomalously deep thermocline with increased SST in parts of the western Pacific, and a shallow thermocline with cooler than average SST in the central and eastern Pacific (McPhaden et al. 1998; McPhaden and Yu 1999). Although La Niña is known as the "cold phase" of the ENSO cycle (NOS 2016), La Niña periods are associated with elevated SST around Guam. During a La Niña event, Guam is expected to experience increased rainfall, most likely to occur between December and February (CPC 2005). Guam lies within an ENSO core region, linked to inter-annual variations of rainfall and drought-like conditions during and after El Niño events (CPC 2005). During El Niño years, there is an increased probability that tropical cyclones will form in the Guam region. ENSO events also affect local sea levels in the Guam region with the mean sea level dropping during an El Niño and rising above normal during a La Niña.

During both El Niño and La Niña events, variability in tropical wind, precipitation, and atmospheric pressure patterns in the tropical Pacific is most tightly coupled with shifts in SST from December through April. Typically, an El Niño or La Niña event will form between June and August, reach its maxima from December to April, and then dissipate in May through July of the following year. However, some extreme events have persisted for up to 4 years (CPC 2005). La Niña events generally last longer than El Niño periods (ESRL 2016). Some climatologists predict that the frequency of El Niño and La Niña events will increase as climate change accelerates (Bruno et al. 2001; Slezak 2015). The impacts of El Niño may double during the 21st century and climate change may magnify the influence of ENSO on the spatial distribution of precipitation, increasing risks from floods and droughts (Slezak 2015).



El Niño events in the past few decades have surpassed the strength of El Niño cycles over the last four centuries (Slezak 2015). Bleaching events are often correlated with ENSO, which causes increased water temperatures in the affected coral reef regions (Stone et al. 1999; Bruno et al. 2001; Baker et al. 2008). Between 1876 and 1979, only three localized coral bleaching events were documented. However, dozens of bleaching events were identified in less than three decades between 1979 and 2007 (Lesser 2007). Beginning in the early 1980s, bleaching events have occurred almost annually in at least one tropical or subtropical sea. The most severe global bleaching event to date occurred in 1998, when almost 20% of coral colonies died (global average) (IB Times UK 2015). The 1997-1998 El Niño event resulted in 20,000 human casualties and $97 billion USD in damages globally due to floods, fires, droughts, landslides, and tropical storms (Slezak 2015). The second global bleaching event was recorded during an El Niño cycle from 2009-2010 (CBS/AP 2015).

The 2015-2016 global coral bleaching event, which began in Guam and CNMI in mid-2014 (Heron et al. 2016), and continued through late 2016, is the longest on record. This El Niño was ranked as one of the top three strongest El Niño periods on record. Only the 1997-1998 event exceeded this duration, with a 12-month stint as a top three El Niño. The 2015-2016 event peaked in August/September 2015, with the SST anomaly peaking in November 2015 at 2.95°C above average, the highest recorded since 1982 (ESRL 2016). While less severe than the 1998 event overall, this bleaching impacted a greater number of reefs than any earlier event; been more severe than previous events in several areas (such the Great Barrier Reef and the Line Islands of Kiribati, were 80% of corals were killed); and caused mass bleaching of reefs that had not bleached until this event (Eakin et al. 2016). In the world's third mass bleaching event from 2015-2016 (CBS/AP 2015; Eakin et al. 2016), over one third of coral reefs were damaged by bleaching (IB Times UK 2015).

Coral bleaching on Guam

Until 2013, Guam's coral reefs were spared from the severe, widespread mortality associated with large-scale bleaching events, although localized bleaching was recorded along certain reef areas and among several genera as early as 1994. Between 1998 and 2013, Guam's reefs experienced minimal to moderate seasonal bleaching with high rates of recovery (Raymundo 2016). However, by August 2013, extensive coral bleaching was observed throughout Guam's reef flats and at deeper reef sites around the island. Guam's reefs were impacted by bleaching again by June of 2014; the coral loss resulting from this event may have been exacerbated by the lack of recovery time following bleaching in 2013. Approximately half (55% ± 10) of the island's staghorn corals (*Acropora* spp.) were lost as a result of the 2013-2014 bleaching events (Raymundo et al. 2017). Shallow corals were stressed by exposure due to extreme low tides in 2015, and shallow reef flats then experienced moderate to severe bleaching in 2016. Unfortunately, research indicates that bleaching of coral reefs, including those surrounding Guam, will become more frequent and severe in the future (van Hooidonk et al. 2013).

The first large-scale bleaching event reported in Guam since the establishment of the University of Guam Marine Laboratory (UOGML) in 1970 was an event in 1994, with another notable event reported in 1996 (Paulay and Benayahu 1999). Sixty-eight percent of taxa surveyed between October and December 1994 were reported bleached. The bleaching in 1996 was believed to have been more severe than in 1994, but a detailed record is not available. It is generally held that neither of these events resulted in significant coral mortality. Paulay and Benayahu (1999) reported that these events were not related to elevated water temperatures, but a recent examination of satellite-derived SST measurements suggests that sustained elevated water temperatures may have played a role. The temperatures recorded during the 1994 and 1996 events approximate the temperatures that have elicited coral bleaching watches and warnings issued by the NOAA Coral Reef Watch (CRW) program in recent years. The potential role of exposure to UV radiation in these bleaching events has not been properly examined as cloud cover and wave height data are not available.

A localized bleaching event that occurred in Pago Bay in 2004 was likely the result of a substantial influx of freshwater (~45 cm) from Tropical Storm Tingting. Bonito and Richmond (unpublished research, 2004) stated that a UOGML scientist observed coral bleaching on Guam every year for seven years prior to their report, but these events were localized and not accompanied by high mortality rates.

After nearly a decade without evidence of large-scale coral bleaching, bleaching was observed between September and October 2006, August and September 2007, and again in August 2008. Both the 2006 and 2007 events appear to have been associated with above average SST and coincided with bleaching watches/warnings issued by the NOAA CRW program based on satellite measurements of SST. During both events, bleaching was observed among numerous species on the reef flat and reef front to a depth of 7 m at several sites around the island (Burdick et al. 2008). Several moderately to heavily bleached *Acropora* spp. colonies were found in relatively shallow protected areas, along shallow reef fronts, and on reef margins around the island. *Millepora* spp., *Pocillopora* spp., and various other species exhibited effects from paling to moderate and heavy bleaching. Observations from the Piti Bomb Holes Marine Preserve, Pago Bay, Hilaan (Shark's Hole), Tanguisson, Ritidian, and the Achang Reef Flat Marine Preserve suggest that the 2006 bleaching event may have affected a substantial part of Guam's reef system. The widespread distribution of the 2007 bleaching event was confirmed by observations from an aerial survey carried out in August 2007 (Burdick D, pers. obs.).

Impacts of the 2006 and 2007 bleaching events on Guam's reefs are difficult to assess, as limited reef access and resources resulted in only a handful of observations and little quantitative data. A survey of *Pocillopora verrucosa* colonies at Anae Island, off Guam's southwest coast, showed that 67% of colonies at 1-3 m depth were paled, partially bleached, or fully bleached by September 2006 (Chau, unpublished data). Of 36 tagged *P. verrucosa* colonies, all appeared to have partially or fully recovered after more than three months. In contrast, about 60% of all coral species surveyed in October 2006 along a single transect on the reef margin in the Tumon Bay Marine Preserve exhibited partial or full mortality (Brown 2007). Surveys of an *Acropora*-dominated coral community in Tumon Bay in August 2007 indicated that approximately 60% of the total live coral and greater than 90% of the *Acropora* spp. along five 25 m transects exhibited paling or partial bleaching (Brown and Burdick, unpublished data). Because this nearly monotypic, *Acropora*-dominated coral community is not common on Guam, observed bleaching rates are not representative of island-wide occurrence. A qualitative survey of the north side of Cetti Bay indicated that at least eight scleractinian genera were affected by bleaching to a depth of about 7 m in 2007 (Brown, unpublished data).

The bleaching events in 2006 and 2007, combined with impacts of outbreaks of *Acanthaster planci,* the crown of thorns sea star (COTS), and several vessel groundings, triggered the formation of an interagency coral reef response team on Guam. The response team, first formalized via a memorandum of understanding (MOU) signed in 2009 and reauthorized by a subsequent MOU in 2016 (Appendix I), includes the Guam Department of Agriculture (GDOAG) Division of Aquatic and Wildlife Resources (DAWR); the Guam Environmental Protection Agency (GEPA); the Bureau of Statistics and Plans (BSP) and the Guam Coastal Management Program (GCMP); the University of Guam (UOG); NOAA; the National Park Service (NPS); Joint Region Marianas (JRM); and the US Fish & Wildlife Service (USFWS).

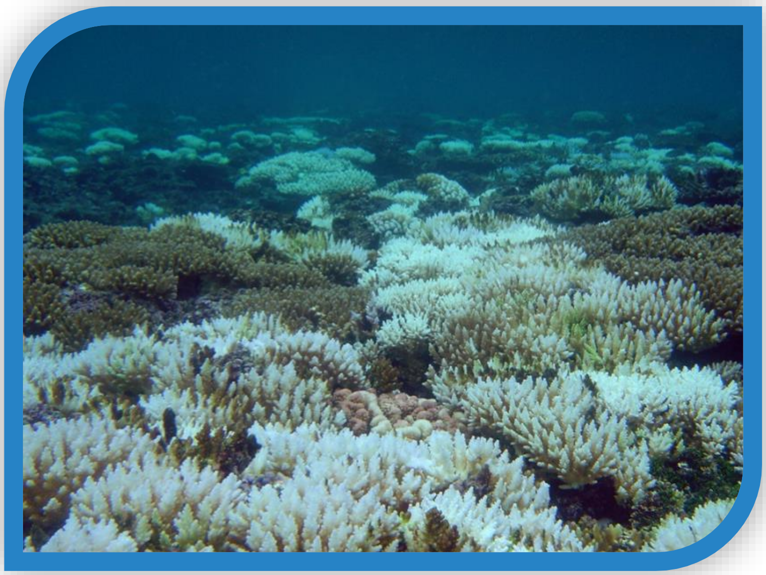
Table 1. NOAA CRW's defined bleaching thermal stress levels for its 5 km bleaching alerts, based on HotSpot intensity and degree heating weeks (DHW)
(Source: http://coralreefwatch.noaa.gov/satellite/bleaching5km/index_5km_baa_max_r07d.php)

Stress level	Definition	Potential bleaching intensity
No stress	HotSpot $\leq$ 0	No bleaching
Bleaching watch	0 < HotSpot < 1	
Bleaching warning	1 $\leq$ HotSpot and 0 < DHW < 4	Possible bleaching
Bleaching alert level 1	1 $\leq$ HotSpot and 4 $\leq$ DHW < 8	Bleaching likely
Bleaching alert level 2	1 $\leq$ HotSpot and 8 $\leq$ DHW	Mortality likely

On July 9, 2013, NOAA's CRW program released an alert raising the bleaching risk level to Bleaching Watch status for Guam and CNMI (Table 1). Guam's response team began monitoring local reef conditions, according to the protocols of a draft bleaching response plan written in 2011. The CRW Outlook projected that Guam would reach Bleaching Alert Level 1 during the event, so the response team began to prepare for possible bleaching by compiling observations and anecdotal reports and mobilizing the community to report signs of bleaching. The team then divided the island into quadrants and began informal surveys of sites around Guam. Initially, the focus was on collecting qualitative data such as species impacted, depths of observed bleaching, and bleaching severity.

In August 2013, scientists on Guam recorded the first observations of bleaching, following observations in the Saipan lagoon earlier that month. During the first half of August, biologists documented patchy paling or bleaching at several sites, including Piti Bay, Cocos Lagoon, Tumon Bay, Fadian, and Pago Bay (behind the UOGML). The extent and severity of bleaching was not yet considered serious, but it triggered the response team to begin monitoring the spatial extent of the impacts and plan for a potential widespread bleaching event (Brown V, pers. comm.). By mid-to late August, Saipan was elevated to a Bleaching Warning, while Pagan and some of the northern islands were raised to Alert Level 1.

By the end of August 2013 on Guam, there was mild to occasionally moderate paling among some of the species most vulnerable to bleaching, some partial bleaching recorded at depths of up to 7 m, and a few examples of fully bleached corals, based on observations at West Agana Bay, Marbo Cave, Sharks Hole, and Tanguisson beach. Along the inner reef flat of West Agana Bay, colonies of *Acropora cf. pulchra* were moderately to severely bleached. A coral disease resembling white syndrome was detected among several bushy *Acropora* spp. on the reef fronts near Sharks Hole and in West Agana Bay (Burdick D, pers. obs.). Along Guam's east side, bleaching of mild to moderate severity was observed along approximately 1 km of coastline. Shallow reefs had more severe impacts than deeper reefs, although bleaching of the reef flats and lagoons occurred after initial bleaching of the reef fronts. At reefs near Ipan, Inarajan, and Fadian, some Favids and bushy *Acropora* spp. were bleached in the shallows, with some bleached *Montipora* spp. found at depths up to 15 m (Houk P, pers. obs.).



Local experts agreed that bleaching was now widespread across the island's reefs but patchy, impacting a variety of corals including the following genera: *Acropora, Montipora, Porites, Pavona, Galaxea, and Millepora*, in addition to two species of anemone. Generally, bleaching was not affecting all colonies of a species at any site. Most of the bleaching was documented in shallow water, but some was also noted at depths of 12-15 m behind the UOGML. By this point, bleaching had been recorded at Tumon Bay, East Agana Bay, Piti Bay, Umatec Bay, Cocos Lagoon, Pago Bay, and Fadian (Brown V, pers. comm.).

Based on the spatial extent of the bleaching, the response team decided to conduct broad-scale surveys across Guam's reefs to evaluate bleaching extent and severity, species impacted, and mortality, while building a photo bank of impacted corals. By early September, mortality due to bleaching was noted in Saipan among staghorn *Acropora*, *Pocillopora damicornis*, and *Isopora palifera* (Brown V, pers comm.). On Guam, there was moderate to severe bleaching of *Acropora* stands on shallow reef flats. Fairly widespread paling and some partial to full-colony bleaching of *Acropora, Montipora,* and *Pocillopora* was recorded on the reef flats, reef margins, and outer reef slopes to depths of 6-8 m (Burdick D, pers. obs.). Aerial surveys revealed island-wide bleaching on the reef fronts and reef slopes (Miller R, pers. comm.). At this point there was no coral mortality that could be attributed to bleaching, but there was evidence of white syndrome, a coral disease associated with warming ocean temperatures (Burdick D, pers. obs.). Ten percent of *Goniopora fruticose* colonies that were being monitored at Luminao Reef off Cabras Island on Guam's west side showed impacts from both bleaching and black band disease (Raymundo L, pers. obs.).

Warm, calm conditions continued to increase shallow water temperatures through early to mid-September. Guam's eastern coast is generally rougher than the western leeward side, but unusually quiet winds (approximately 2 m/sec slower than average) led to little water movement above shallow reefs on both sides of the island, further heating the coastal waters. Most east coast sites had patchy paling and bleaching across a range of coral species, with bleached *Montipora* spp. observed at depths of 15 m (Houk P, pers. obs.). A swell temporarily resulted in rough conditions along Guam's southwest coast that may have increased the concentration of nutrients in the water column and contributed to paling of reefs in this area. Storms in late September contributed to increased freshwater inputs and runoff, raising concerns of coral mortality in areas such as Pago Bay (Brown V, pers. obs.). On September 24, the CRW Outlook increased Guam's status to Alert Level 1. During the 2013 bleaching event, SST exceeded the mean monthly temperature by 0.5°C to 1.6°C for four months and 85% of Guam's coral taxa bleached (Raymundo 2016). The most severe bleaching (greatest percent coral cover bleached) occurred on the island's southeast coast (Reynolds T, unpublished data).

The response team agreed to survey sites according to the photo transect method used in Palau during the 2010 bleaching event (van Woesik et al. 2012). Sites selected included those surveyed during a rapid ecological assessment (REA) conducted in 2011 by NOAA Fisheries and several additional sites along northern reefs, for a total of 48 sites (16 per geographic quadrant) (Williams et al. 2012). Specific roles were assigned to team members and others involved in the surveys, to complete tasks such as camera operation, transect deployment, and benthic invertebrate surveys. Initial photographic surveys were not successful and it was determined that camera operators needed additional training in camera use and calibration. Observers swam transects and conducted semi-quantitative surveys to characterize bleaching severity and extent per colony as low (<10% of colony affected), medium (10-50% of colony affected), or high (>50% colony affected). The 48 sites were surveyed over a three-month period from October to December.

In 2014, coral bleaching occurred on Guam between June and July (Raymundo 2016), which commenced the current global bleaching event. This was unusual as Guam does not generally experience ocean warming during an El Niño phase (Eakin et al. 2016); Guam is more likely to experience bleaching during the La Niña phase of an ENSO event. The most severe bleaching occurred along shallow near-shore reef flats, with the most extensive bleaching and mortality occurring among *Acropora* spp. (Raymundo et al. 2017). The CRW Outlook reported a Bleaching Watch for Guam at this time based on their 50km products, so the severity of the bleaching that occurred was unexpected. The CRW 5km products released later that year indicated that Guam experienced Level 1 and Level 2 bleaching conditions during this time. No extensive surveys of the 2014 event were conducted as managers did not expect bleaching to occur during this time. During both the 2013 and 2014 bleaching events, high SST combined with extreme low tides increased the vulnerability of Guam's reefs to bleaching. Approximately 15.5 hectares of *Acropora* spp. was lost due to bleaching in 2013 and 2014 (Raymundo et al. 2017). In 2015, following two successive years of coral bleaching, 16 of the 48 sites surveyed in 2013 were resurveyed using photo transects; four sites were randomly selected from each quadrant of the island. In addition to surveying for impacts of bleaching and recovery, observers looked for evidence of coral disease; no outbreaks were recorded. Qualitatively, there was some evidence of recovery, including coral recruitment and resheeting (when new tissue grows over dead coral in the same colony) (Raymundo L, pers. comm.).

Early warning system

Guam's early warning system involves monitoring projections and forecasts combined with local in situ monitoring and observations. The purpose of the early warning system is to detect and predict the conditions that lead to coral bleaching and provide a window to prepare for response before bleaching occurs. The combination of clear, calm weather, extreme low tides, and elevated SST likely contributed to the severe bleaching that Guam's reefs experienced in 2013, which supports the need to monitor all components of the early warning system. **A designated member(s) of the Guam Coral Reef Response Team will monitor the following components of the early warning system and report back to the team and other stakeholders as needed.**

Components of the early warning system:

I. Projections and forecasts
   a. NOAA Coral Reef Watch products
   b. Climate/ENSO projections
   c. Weather forecasts
   d. Tidal forecasts

II. Local monitoring and observations
   a. SST and water level instruments
   b. Aerial surveys
   c. Eyes of the Reef reports

III. Validating projections

Projections and forecasts

<u>NOAA Coral Reef Watch products</u>

The NOAA CRW program provides coral bleaching alerts based on satellite data (measurements of nightly SST), used to predict reefs at risk of thermal stress and bleaching. CRW provides products at two resolutions, 5 km (daily updates) and 50 km (twice weekly updates). The high-resolution 5 km products, first released in February 2015, are expected to be more accurate than the 50 km products because of increased data density, quality, resolution, and understanding of climate patterns (CRW 2016). CRW provides this high-resolution data on SST, SST anomaly, SST trend, HotSpot, and degree heating weeks (DHW) (see sidebar), accessible in data tables and on maps. In addition to viewing current daily values and archived historical data and maps, CRW provides animations depicting changes in variables over the most recent 30 and 90-day periods.

The data is organized into 212 regional virtual stations, which have been designed to present the information at a jurisdictional or subregional level. This allows reef managers to assess conditions throughout their administrative areas and gain an understanding of regional impacts, rather than evaluating each 5 km pixel separately (CRW 2016). There are 11 stations in Micronesia, including separate stations for Guam and the Commonwealth of the Northern Mariana Islands (CNMI). Interactive functions on the CRW website allow the user to view multi-year graphs and see changes in SST and DHW over two year periods for each virtual station.

CRW data

SST anomaly: The difference between today's SST and the long-term average SST; positive numbers (corresponding with warm colors on the map) mean the current temperature is warmer than average and negative numbers (cool colors) indicate that the current temperature is cooler than average

SST trend: Change in SST over the past 7 days; cool colors correspond with decreased SST, warm colors indicate increased SST, and green means SST did not change significantly over the past week

SST bleaching threshold: 1°C above the highest summertime average SST

HotSpot: Depicts areas where the current SST is above the SST bleaching threshold; HotSpot value of 1°C or higher means there is thermal stress that may cause bleaching at the present time

Degree Heating Week (DHW): Shows accumulated thermal stress over the past 12 weeks (not only how high the temperature is, but also how long it has been elevated); significant bleaching typically occurs at 4°C DHW and mass bleaching and mortality is likely at 8°C DHW or greater (shown in warm colors)

(Source: https://coralreefwatch.noaa.gov/satellite/bleaching5km/index.php)

The daily 5-km Bleaching Alert Area product (updated daily at 13:30 EST) shows locations where thermal stress is currently at defined bleaching threshold levels (Table 1). This tool shows the highest stress thermal level that each pixel has been exposed to over the previous one to seven days. Areas with elevated stress levels are depicted in warm colors on the maps (Figure 3). CRW maintains a free email service that alerts users to changes in thermal stress levels at selected virtual stations (to sign up: http://coralreefwatch-satops.noaa.gov). Users can choose to receive alerts for all stations or only those within their region of interest. **Members of the Coral Reef Response Team should regularly monitor these email alerts, with one or more persons designated to receive these alerts via email.**

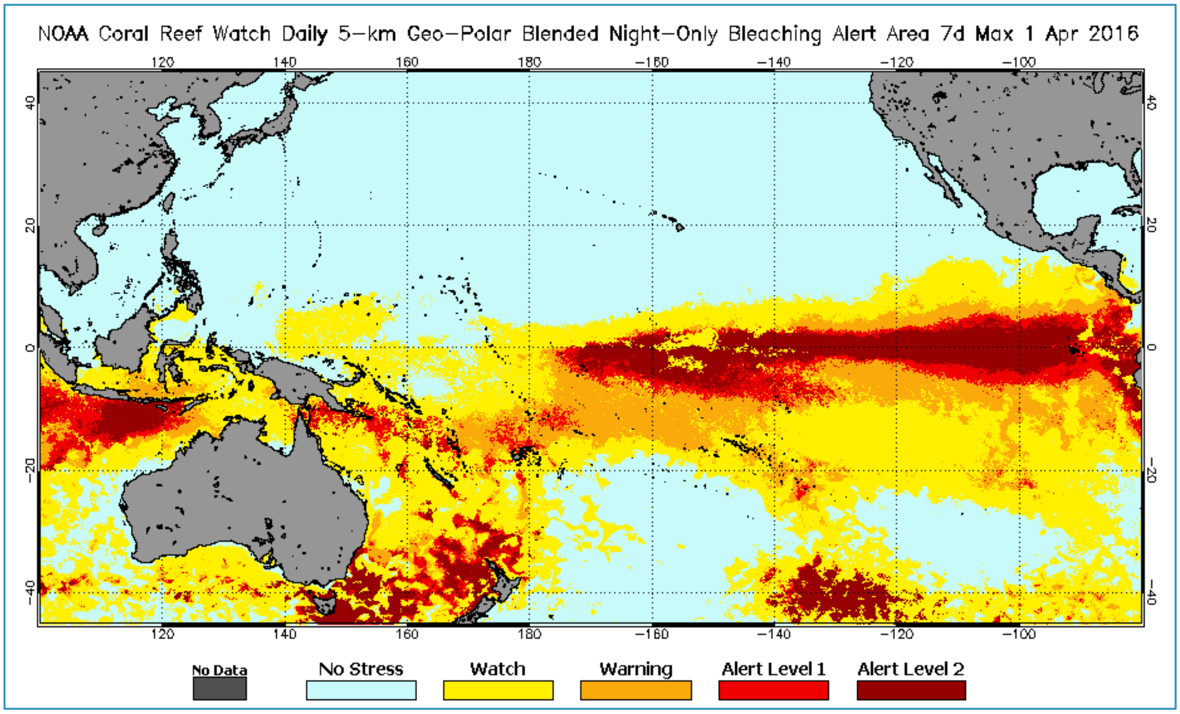


Figure 3. NOAA CRW daily 5 km bleaching alert map; warm colors indicate elevated thermal stress (Source: https://coralreefwatch.noaa.gov/satellite/index.php)

CRW also provides a 5 km four-month coral bleaching thermal stress outlook based on the SST forecast from the National Weather Service (NWS) and calculated with projections of DHW and HotSpot levels. The outlook (updated weekly on Tuesday mornings, EST) predicts the chance of coral bleaching thermal stress occurring in the upcoming four months, which is the usual length of one bleaching cycle. CRW provides bleaching outlooks calculated using two methodologies, both of which are available in weekly or four-month ranges. The first method, which produces the 60% and 90% chance graphs, uses 28 weekly measurements of SST (4 per day) to determine a probabilistic outlook for up to 270 days in the future. The percentage of each of these 28 measurements projected to reach a certain thermal stress level over the specified period is determined in order to assess the probability of each 5x5 km pixel reaching that stress level, then the 28 SST measurements are ranked according to severity. For the 90% chance maps, the top 90% of the 28 measurements (according to severity) are included in the calculation. For each pixel, at least one of the SST measurements in the top 90% correlated with the stress level depicted; the other measurements in the top 90% were correlated with an equal or higher stress level. The same method is used for the 60% chance maps. Thus, the 60% chance maps are more conservative. The second outlook method presents the probability, from 0-100%, that a pixel will reach a certain thermal stress level, based on the percentage of the 28 SST measurements projected to reach that level (Eakin et al. 2012; CRW 2016).

The most accessible element of the CRW site is the bleaching thermal stress gauges (Figure 4) and time series product, which provides summary data specific to a selected regional virtual station, including data for each 5 km pixel within the station. The bleaching outlooks for each virtual station are based on the 60% likelihood calculations. Guam's thermal stress gauge and time series graphs can be accessed here:
http://coralreefwatch.noaa.gov/vs/gauges/guam.php

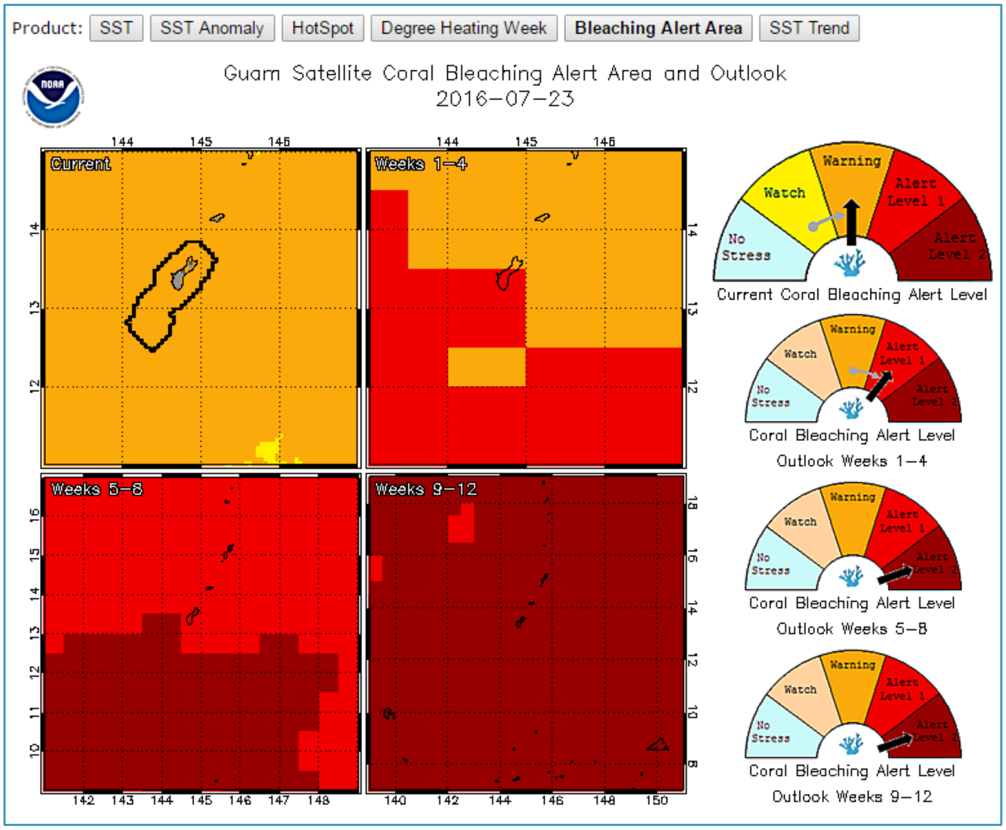


Figure 4. NOAA CRW thermal stress gauge for Guam
(Source: http://coralreefwatch.noaa.gov/vs/gauges/guam.php)

As of May 2016, NOAA describes its 50 km products as operational, while its 5 km products are still listed as experimental. Until the high-resolution products are deemed fully operational, they should be monitored in conjunction with the 50 km products. A tutorial for the 50 km products is available here:
http://coralreefwatch.noaa.gov/satellite/education/tutorial/crw15_intro_products.php

Notably, in 2014, bleaching occurred when Guam was still in bleaching watch status according to the 50 km data. Although the 5 km products were not available during the 2014 event, data released subsequently revealed that the 5 km products would have shown Guam in a higher alert status when the bleaching began in early summer 2014. CRW is currently developing a forecasting tool to predict future outbreaks of coral disease, which may be useful to the Coral Reef Response Team in the future (CRW 2016).

Climate/ENSO projections

Seasonal climate predictions should be reviewed by the Coral Reef Response Team by April each year to evaluate bleaching risk in the upcoming summer months. ENSO cycles should be closely monitored. La Niña events are likely to result in above average SSTs around Guam, while El Niño events are correlated with below average water levels and extreme low tides in this region.

The Multivariate ENSO Index (MEI), generated by NOAA's Earth System Research Laboratory (ESRL), measures air pressure and temperature, winds, SST, and cloud cover to evaluate ENSO conditions. The MEI, updated once per month, is intended for research purposes, not real-time climate monitoring, and should be used cautiously and in conjunction with other components of the early warning system when predicting bleaching (ESRL 2016). The MEI is a global index and does not describe ENSO conditions by region. Available here: http://www.esrl.noaa.gov/psd/enso/mei

Ranking of monthly ENSO conditions since 1950 available at: http://www.esrl.noaa.gov/psd/enso/mei/rank.html

NOAA's Climate Prediction Center (CPC), within the National Weather Service, provides weekly ENSO updates, published online every Monday. A climate diagnostics bulletin is uploaded on the second Thursday of each month. These reports describe the current strength and status of ENSO conditions, shifts in SST, wind, radiation, and precipitation anomalies, and an outlook of future ENSO conditions. Weekly and monthly ENSO advisories available here: http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/enso_advisory

Weather forecasts

The US National Weather Service (NWS), a division of NOAA, publishes weather summaries and 7-day forecasts. **Short and mid-term weather forecasts produced by the NWS should be checked regularly during the summer months, particularly when the conditions listed below last for three days or longer.** This data is useful in predicting the conditions that lead to elevated sea surface temperatures and thus coral bleaching on Guam, which include:

- Calm, clear weather – low winds, little cloud cover
- Above average summer temperatures
- Below average rainfall

NOAA NWS 7-day forecasts for Guam (provides current conditions and forecasts for temperature, cloud cover, precipitation, and wind) available at: http://forecast.weather.gov/MapClick.php?zoneid=GUZ001

NOAA NWS marine forecast for coastal waters of Guam and the Marianas (provides current conditions and forecasts for wind speed, wind direction, wind wave height, and swell height) available at: http://www.prh.noaa.gov/guam/marine.php

Tidal forecasts

Tidal forecasts should also be monitored to predict conditions that may increase the risk of thermal stress that causes coral bleaching. Coral bleaching may be more likely during periods of repeated daytime extreme low tide conditions, especially during summer months. Near-shore water temperature, particularly on shallow reef flats, can become anomalously high, while exposure to air causes additional stress for coral communities. The flow of heated water from the reef flat over the reef margin (particularly through channels) and reef front may cause coral bleaching in these zones as well.

NOAA tidal predictions for Apra Harbor, Guam are available at: https://tidesandcurrents.noaa.gov/noaatidepredictions/NOAATidesFacade.jsp?Stationid=1630000

Annual tide charts for Guam are produced by the UOGML and available at: http://www.guammarinelab.com/tidecharts.html

Local monitoring and observations

SST and water level instruments

Numerous sources of *in situ* measurements of local SST for Guam (Figure 5) are available including instruments owned by the NOAA National Ocean Service (NOS) and the Pacific Integrated Ocean Observing System (PacIOOS), as well as temperature loggers deployed by NPS and UOGML researchers (Table 2). In situ water level measurements are also relevant for coral bleaching response, as extreme low tides are correlated with coral heat stress, exposure, and bleaching. **Telemetric data from in situ instruments should be consistently monitored, in conjunction with monitoring of local weather conditions and forecasts.** After a bleaching event, non-telemetric data should be reviewed to evaluate localized water temperature patterns and compare them to recorded bleaching impacts recorded. This may help us identify resilient taxa and reef areas that do not bleach even when exposed to anomalously high temperatures. This data may also contribute to validation of projections and forecasts. **Before a bleaching event, scientists and managers with existing in situ loggers will be asked to check their deployed instruments and ensure that they are functioning, then maintain them throughout the event. The response team will deploy additional instruments if needed.**

NOAA NOS provides real-time telemetric data on SST, air temperature and pressure, and water level from permanent instruments in Apra Harbor (Station APRP7-1630000). SST is measured 2 meters below mean lower low water (MLLW), which NOAA defines as the mean height of the lowest recorded daily tide each day throughout the recording period. Archived SST data is available online from September 2008 to present, including a table of real-time data from the previous 45 days and summaries of data from the present month, prior months, and prior years. NOS reports telemetric data on atmospheric pressure and water level in Pago Bay (Station PGBP7-1631428), however SST is not measured at this station. These data are found on the NOAA National Data Buoy Center (NDBC) website (see below):

Apra Harbor (Station APRP7): http://www.ndbc.noaa.gov/station_page.php?station=aprp7

Pago Bay (no SST) (Station PGBP7): http://www.ndbc.noaa.gov/station_page.php?station=pgbp7

PacIOOS collected data in Cetti Bay from June 2010 through Jan 2011 using a nearshore sensor (Station NS09). Archived data on SST, water level, chlorophyll concentration, turbidity, and salinity are available for download from the PacIOOS website. PacIOOS currently collects data on these same parameters using a nearshore sensor in Pago Bay (Station NS15). This instrument does not report real-time data; as of April 2017, the most recent available data is from December 2016, found here:

Cetti Bay (Station NS09) and Pago Bay (Station NS15):
http://oos.soest.hawaii.edu/pacioos/focus/waterquality/wq_marianas.php

PacIOOS measures SST in Ipan at a depth of 0.46 meters below the water line with a telemetric moored Waverider buoy (Station 52200); SST data is available from September 2004 to present. Real-time and archived data are available on the NOAA NDBC website. PacIOOS also maintains a Waverider Buoy at Ritidian Point (Station 52202) that measures SST at a depth of 0.46 meters below the water line. No real-time data is available; historical data from this instrument is available for 2012 through December 2015 on the NOAA NDBC website (see below):

Ipan (Station 52200): http://www.ndbc.noaa.gov/station_page.php?station=52200

Ritidian Point (Station 52202): http://www.ndbc.noaa.gov/station_page.php?station=52202

NPS has deployed three sets of loggers near Adelup, Asan Beach (Piti), and Agat Cemetery to measure temperature, light intensity, and water level (pressure). (There is a fourth set positioned at the NPS shop to measure baseline temperature and light, in addition to atmospheric pressure, which is needed to calculate water level). The instruments are positioned next to permanent reef flat transects at two sites (five 30 meter transects at each site), where NPS uses citizen scientists to conduct CoralWatch (coral bleaching) monitoring and Guam Community Coral Reef Monitoring Program benthic monitoring.

Several temperature loggers have been installed at sites around the island by UOGML researchers for various projects in recent years. Dr. Tom Schils has three water quality sensors deployed along a depth gradient in Apra Harbor and two sensors at Andersen Air Force Base (AAFB). These instruments collect data on temperature, salinity, dissolved oxygen, chlorophyll concentration, turbidity, and pH. Data from the sensors in Apra Harbor are uploaded approximately every 2-3 months; data collection from the sites at AAFB is more sporadic due to weather conditions. These data have been collected on behalf of the Department of Navy to support baseline marine resources monitoring to inform the development of the JRM Marine Resources Management Plan. Dr. Schils also has some temperature, turbidity, and light data from Apra Harbor sites that predates these current sensors.

Dr. Laurie Raymundo at the UOGML maintains four non-telemetric temperature loggers on the reef flats at Luminao, Piti, Tumon Bay, and Haputo; these instruments have been active since 2009, although there are some gaps in the data period due to instrument malfunction and loss.

The Guam Long-term Coral Reef Monitoring Program (GLTCRMP) has collected temperature data at several of its permanent sites since 2010 during reef surveys. Additionally, there are six active temperature loggers monitored by the GLTCRMP (Table 2) in addition to data from five loggers that are no longer active (Table 3). All 11 instruments are Onset TidbiT v2 Temp Loggers. The GLTCRMP also has two multi-parameter data sondes (YSI 6920 V2-2 Multiparameter Water Quality Sondes) that will be deployed in 2017, which will be able to measure turbidity, dissolved oxygen, pH, conductivity, temperature, and depth. The sondes will likely be deployed at reef sites in Piti and Achang.

Table 2. Index of active in situ SST and water level instruments on Guam's reefs as of December 2016. Telemetric instruments that provide real-time or near real-time data are underlined.

Active in situ SST and water level sensors on Guam						
No.	**Location**	**Depth**	**Lat, Lon**	**Measurements**	**Duration**	**Agency/POC**
1	<u>Apra Harbor (Station APRP7)</u>	2 m below MLLW	13.444, 144.657	SST, air temp, atmospheric pressure, water level	9/2008 to present	NOAA NOS
2	<u>Pago Bay (Station PGBP7)</u>	N/A	13.428, 144.796	Atmospheric pressure, water level (no SST)	10/2008 to present	NOAA NOS
3	<u>Ipan (Station 52200)</u>	0.46 m below water line	13.354, 144.788	SST	9/2004 to present	PacIOOS
4	Pago Bay (Station NS15)	~1.5 m	13.42082, 144.7859	SST, water level, chlorophyll, turbidity, salinity	7/2012 to present	PacIOOS
5	Asan Beach (near War in Pacific flag poles)	~1 m	13.476139, 144.706639	SST, light, water level	4/29/2016 to present	NPS (Allison Miller)
6	Asan Beach (Adelup)	~1 m	13.477918, 144.723586	SST, light, water level	4/29/2016 to present	NPS (Allison Miller)
7	Agat Cemetery	~1 m		SST, light, water level		NPS (Allison Miller)
8	Apra Harbor (Anchor Reef) (N02-Float 6)	~5.5 m	13.449446, 144.667145	SST, salinity, dissolved O2, pH, chlorophyll, turbidity	1/2015 to present	UOG (Tom Schils)
9	Apra Harbor (Middle Shoals) (N06-Float 2)	~ 7 m	13.449585, 144.657291	SST, salinity, dissolved O2, pH, chlorophyll, turbidity	1/2015 to present	UOG (Tom Schils)
10	Apra Harbor (Orote Point) (N10-Float 4)	~8.5 m	13.449467, 144.624658	SST, salinity, dissolved O2, pH, chlorophyll, turbidity	1/2015 to present	UOG (Tom Schils)
11	AAFB (Urunao) (A01-Float 4)	~8.5 m	13.619336, 144.834492	SST, salinity, dissolved O2, pH, chlorophyll, turbidity		UOG (Tom Schils)
12	AAFB (Tarague) (A05-Float 1)		13.62704, 144.897684	SST, salinity, dissolved O2, pH, chlorophyll, turbidity	(Not yet deployed)	UOG (Tom Schils)
13	AAFB (Lafac Point/Pati Point) (A10-Float 1)		13.566973, 144.941078	SST, salinity, dissolved O2, pH, chlorophyll, turbidity		UOG (Tom Schils)

14	Luminao	1-1.5 m	13.46531667, 144.6466	SST	2009 - present	UOG (Laurie Raymundo)
15	Piti	2 m	13.47308333, 144.70435	SST	2009 - present	UOG (Laurie Raymundo)
16	Tumon Bay (near Outrigger)	1-1.5 m	13.51681667, 144.8023167	SST	2009 - present	UOG (Laurie Raymundo)
17	Haputo	1-1.5 m	13.57775, 144.8303667	SST	2009 - present	UOG (Laurie Raymundo)
18	East Agana Bay (EAB-6)	13.5 m	13.484863, 144.759294	Temperature	9/2014 - present	GLTCRMP (Dave Burdick)
19	East Agana Bay (EAB-10)	9 m	13.48678, 144.763303	Temperature	9/2014 - present	GLTCRMP (Dave Burdick)
20	East Agana Bay (EAB-12)	10 m	13.490523, 144.765836	Temperature	9/2014 - present	GLTCRMP (Dave Burdick)
21	Tumon Bay (TUM-8)	13.5 m	13.512194, 144.792858	Temperature	9/2014 - present	GLTCRMP (Dave Burdick)
22	Tumon Bay (TUM-46)	10.4 m	13.514726, 144.797149	Temperature	9/2014 - present	GLTCRMP (Dave Burdick)
23	Fouha Bay (FOU-8)	7.3 m	13.30539, 144.653966	Temperature	6/2015 - present	GLTCRMP (Dave Burdick)

Table 3. Index of inactive temperature loggers deployed by the Guam Long-term Coral Reef Monitoring Program. All instruments listed below are Onset TidbiT v2 Temp Loggers.

Inactive temperature loggers previously deployed by the GLTCRMP						
No.	**Location**	**Depth**	**Lat, Lon**	**Measurements**	**Duration**	**Agency/POC**
1	Piti (PIT-10)	9.4 m	13.471938, 144.69198	Temperature	11/2014 - 11/2015	GLTCRMP (Dave Burdick)
2	Piti (PIT-14)	11.6 m	13.474848, 144.695302	Temperature	9/2014 - 9/2015	GLTCRMP (Dave Burdick)
3	Tumon Bay (TUM-60)	9 m	13.51677795, 144.7972689	Temperature	9/2014 - 7/2015	GLTCRMP (Dave Burdick)
4	Achang (ACH-6)	10.4 m	13.241546, 144.705465	Temperature	10/2014 - 10/2015	GLTCRMP (Dave Burdick)
5	Achang (ACH-18)	11 m	13.24192, 144.711387	Temperature	10/2014 - 10/2015	GLTCRMP (Dave Burdick)

The NOAA Coral Reef Ecosystem Program (CREP) has been collecting water temperature data on Guam since 2003 (Table 4). CREP deploys subsurface temperature recorders for a period of 2-3 years; data is collected when the units are recovered, thus no real-time data is available. As of April 2017, CREP has 15 instruments deployed on Guam's reefs (Table 5); these units were deployed in 2014 and will be replaced (and the data collected) in 2017. To access historical data, contact Jeanette Clark, NOAA Pacific Island Fisheries Science Center (PIFSC) (jeanette.clark@noaa.gov). See Appendix II for CREP data sharing recommendations.

Table 4. Archived subsurface temperature data collected by NOAA CREP

Historical data from NOAA CREP temperature instruments on Guam						
Site name	**Location**	**Lat**	**Lon**	**Depth (m)**	**Date deployed**	**Data collection end**
GUA_OCEAN_001	Tumon Bay (Northern section, near reef crest)	13.519017	144.79778	0.33	9/24/2003	5/28/2004

GUA_OCEAN_002	Tumon Bay (Btwn Gun Beach & Two Lovers)	13.528973	144.80049	11.79	10/5/2005	1/3/2009
GUA_OCEAN_003	Tumon Bay (Btwn Gun Beach & Two Lovers)	13.528996	144.80048	0.16	10/6/2005	3/6/2009
GUA_OCEAN_004	Btwn Ritidian Point and Pati Point	13.632366	144.893	9.51	10/5/2005	1/13/2014
GUA_OCEAN_005	Achang Bay (Near Achang reef flat)	13.242175	144.70391	5.12	10/9/2005	3/26/2012
GUA_OCEAN_006	Andersen (SE of Pati Point)	13.603111	144.92353	13.03	5/4/2014	9/10/2013
GUA_OCEAN_020	Tumon Bay (Btwn Gun Beach & Two Lovers)	13.529073	144.80048	13.40	5/8/2011	6/21/2013

Table 5. NOAA CREP temperature sensors currently deployed on Guam (non-telemetric); data will be uploaded in 2017 after instruments are recovered and replaced

Active NOAA CREP temperature instruments on Guam						
Site ID	**REA Site ID**	**Location**	**Lat**	**Lon**	**Depth (m)**	**Date Deployed**
GUA_OCEAN_009		Piti bomb holes	13.47553133	144.6991525	1.2	4/4/2014
GUA_OCEAN_020	GUA-020	Tumon Bay (Btwn Gun Beach & Two Lovers)	13.52902045	144.8004694	12.5	5/8/2011
GUA_OCEAN_014	GUA-20	Tumon Bay (Btwn Gun Beach & Two Lovers)	13.52891835	144.8001805	25	3/25/2014
GUA_OCEAN_015	GUA-20	Tumon Bay (Btwn Gun Beach & Two Lovers)	13.52881794	144.8013136	5.2	3/25/2014
GUA_OCEAN_020	GUA-20	Tumon Bay (Btwn Gun Beach & Two Lovers)	13.52893721	144.8003622	15.2	3/25/2014
GUA_OCEAN_005	GUA-21	Achang Bay (Near Achang reef flat)	13.24217076	144.7038846	5.5	3/26/2014
GUA_OCEAN_012	GUA-21	Achang Bay (Near Achang reef flat)	13.24343157	144.700538	1	3/26/2014
GUA_OCEAN_013	GUA-21	Achang Bay (Near Achang reef flat)	13.2408564	144.7044653	25.6	3/26/2014
GUA_OCEAN_021	GUA-21	Achang Bay (Near Achang reef flat)	13.24126317	144.7044194	14.9	3/25/2014
GUA_OCEAN_010	GUA-22	North of Mangilao golf course	13.47370709	144.8660013	25	3/29/2014
GUA_OCEAN_011	GUA-22	North of Mangilao golf course	13.47596627	144.8635619	6.4	3/29/2014

GUA_OCEAN_022	GUA-22	North of Mangilao golf course	13.47515599	144.8648544	15.8	3/29/2014
GUA_OCEAN_006	GUA-23	AAFB/Pati Point	13.60329836	144.9236406	15.5	3/29/2014
GUA_OCEAN_007	GUA-23	AAFB/Pati Point	13.60391392	144.9239717	24.4	3/30/2014
GUA_OCEAN_008	GUA-23	AAFB/Pati Point	13.60226931	144.9233726	5.5	3/30/2014

Archived oceanographic and biological data collected by NOAA and other US government agencies can be accessed here: http://catalog.data.gov/dataset
Users can filter by location and search for certain data topics, such as climate, oceans, and ecosystems.

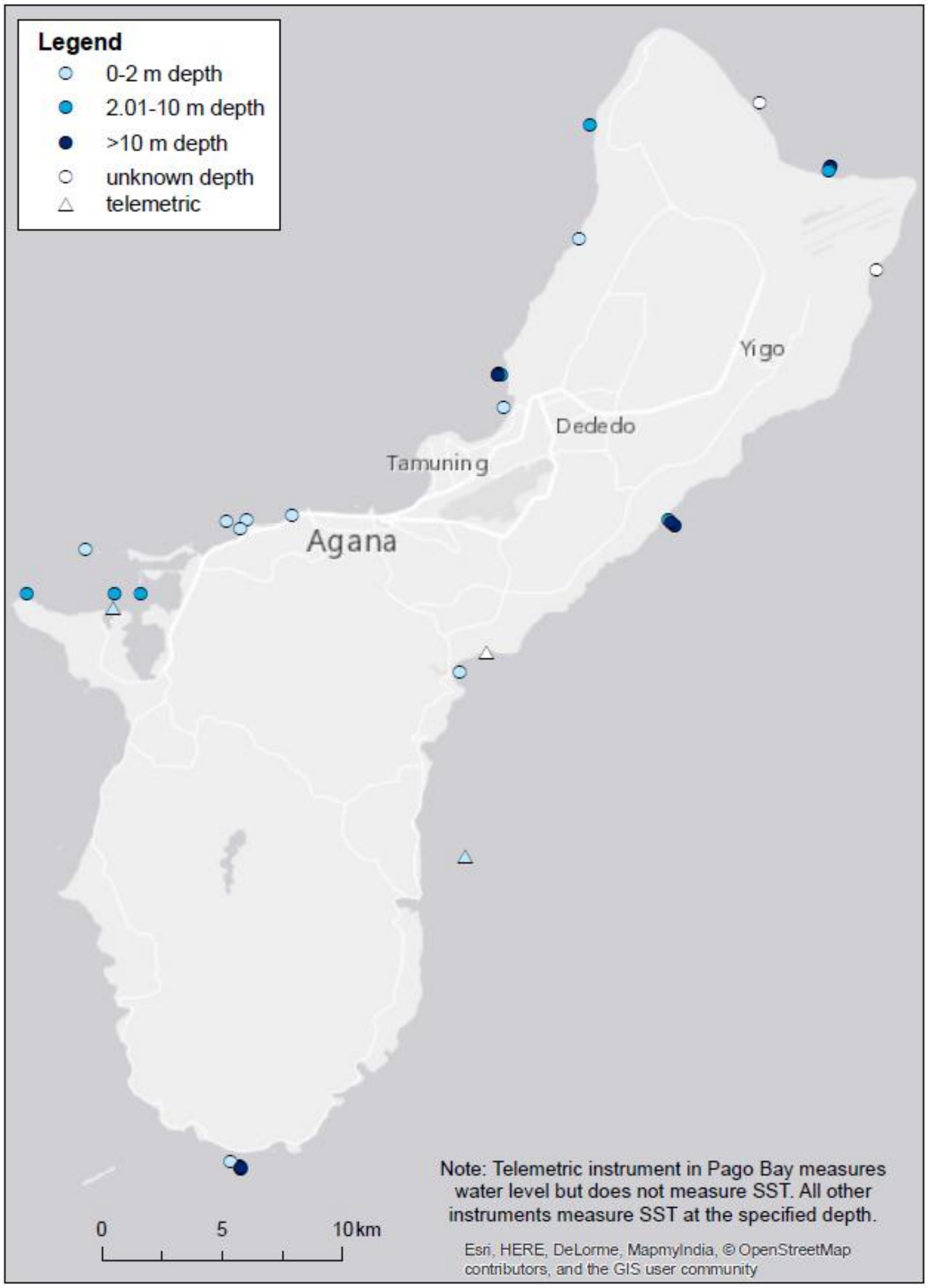
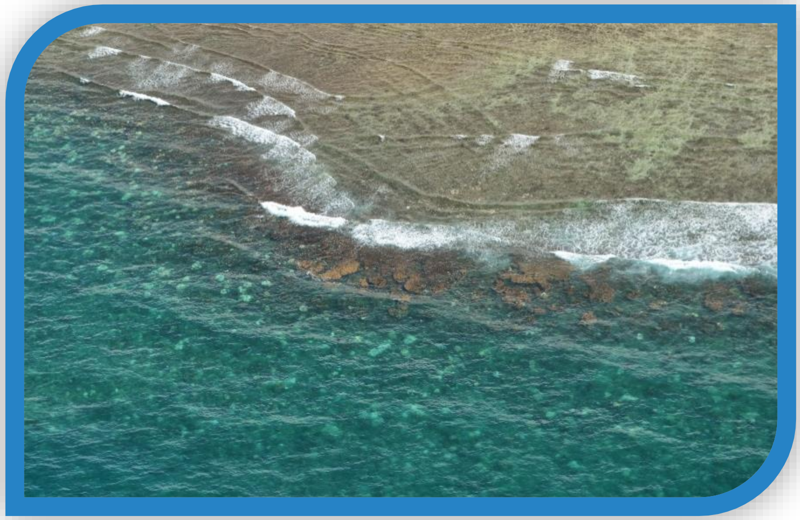


Figure 5. Active SST loggers on Guam's reefs (as of May 2016)

Aerial surveys



The objective of the aerial monitoring component of the early warning system is to detect the early stages of coral bleaching events over a wide geographic area. Aerial monitoring is carried out by the DAWR biologist responsible for conducting aerial fishery, turtle, and cetacean surveys, which occur twice per month from approximately February to September (one weekday and one weekend day, both randomly selected). Guam's entire coastline is covered during each survey, excluding the perimeter of AAFB. While the primary responsibility of the DAWR biologist is to enumerate fishers and marine megafauna, the biologist should be able to note possible instances of coral bleaching in the shallow waters surrounding the island without detracting from their primary responsibility. When bleaching is severe, an entire reef may appear white from above the surface, which can easily be seen from a plane (Oliver et al. 2004).

The interagency MOU signed in March 2016, which formalizes activities of the Guam Coral Reef Response Team, includes a commitment from GDOAG to provide access to collect data before and after bleaching events during DAWR aerial surveys when possible. In order to maximize the efficacy of these surveys for the early warning system, the DAWR biologist should receive some training on identifying and recording coral bleaching, if needed, when it is not feasible to include an additional passenger on the survey. **Typically, DAWR uses a 2-seater plane, which does not allow for additional passengers. However, if at least two weeks advance notice is provided, a larger plane can be arranged, which allows for a coral specialist to assist with the aerial survey and collect photographs and written/voice recorded data specifically related to bleaching. In years when bleaching is projected, the response team should request that DAWR book a larger plane for all surveys through September as early in the year as possible.**

DAWR is not currently conducting aerial surveys between October and January, which limits the aerial data that could be collected later in the year, when previous bleaching events (e.g. 2013) have peaked. Due to funding limitations, chartering a plane is not considered feasible. Local government partners may be able to pursue funding for unmanned aerial vehicle (drone) surveys, although there are complex logistical and legal concerns to consider.

Eyes of the Reef reports

Given the limited time and resources of response team members, community-based reporting is a vital component of the early warning system. With proper training, engaged participants can significantly increase Guam's capacity to identify and respond to bleaching events.

The Eyes of the Reef Marianas (EoR) program was launched in December 2015. EoR Marianas, based on Hawaii's Eyes of the Reef initiative, was established to provide residents of Guam with a mechanism for reporting observed reef impacts. Participants are encouraged to attend a two-hour classroom-based training session, in which they learn how to identify reef impacts (such as coral bleaching and disease) and report these sightings through the online EoR reporting form; however, anyone can report a reef impact through the EoR website. Participants are asked to submit photographs and GPS coordinates with their reports when possible. The EoR online reporting form is available here: http://eormarianas.org/make-a-report

As of April 2017, over 130 participants had completed EoR training. EoR staff plan to train additional instructors to lead EoR training sessions, refine training materials, create a mobile app for reporting impacts in the field, and develop online tutorials for individuals who do not attend a training session, or for those who wish to refresh their knowledge. In order to increase EoR participation, the following groups may be targeted for outreach:

- Divers and snorkelers, accessed via dive companies and tour operators
- Students at UOG and Guam Community College (GCC)
- Local high school students and student groups
- Non-profit and community-based organizations
- Military recreation and service group leaders

The EoR model is designed for participants who are already recreational reef users, such as divers, snorkelers, swimmers, boaters, fishers, and stand up paddle boarders. EoR reports may serve as the first indication of widespread bleaching, as this program has the potential to get many ‘eyes on the reef’ to alert scientists and managers to isolated incidents of bleaching before they are detected through regular scientific surveys and monitoring activities. **A designated member (or members) of the response team should regularly monitor reports submitted through the EoR online reporting form, which is hosted on Google Drive. Reports should be promptly corroborated through in-water visual verification and the submitter should be contacted.** This creates the opportunity to improve the quality of EoR reports by providing feedback to participants and also reassures them that their reports are meaningful.

NPS Youth Reef Health Monitoring

As a way of recording and measuring coral bleaching events, War in the Pacific National Historical Park staff and high school volunteers are conducting quarterly monitoring events on specific reef flat coral patches within the NPS Asan and Agat beach units. All participants are invited to complete a three-step volunteer program either for personal benefit or to meet Guam high school service learning requirements. First volunteers attend “Dry Day” training where they learn basic coral biology, basic reef ecology, and reef health monitoring methods (University of Queensland Coral Watch, www.coralwatch.org). Once their “Dry Day” training is completed, the trained high school students are able to assist NPS staff during a “Monitoring Day”. In-water monitoring days are conducted approximately every three months with the assistance of the NPS non-profit partner organization, Pacific Historic Parks. On these days the trained volunteers conduct snorkel surveys using the Coral Watch Health Chart at one of three (Adelup, Piti, or Agat) permanent reef flat monitoring sites. At this time the volunteers apply the methods they learned during the Dry Day session in the field while snorkeling. Upon the completion of a Monitoring Day data collection excursion, volunteers attend the last step of the volunteering program, “Data Day.” Data Days volunteers are taught how to log the data they collect into the Coral Watch website.

As this project obtains information on coral bleaching occurrence and frequency, results may be used to better manage reef resources on Guam. Parties interested in the data collected from these surveys should visit the Coral Watch (University of Queensland Coral Watch, www.coralwatch.org) online database.

Validating projections

Predicted versus actual bleaching occurrence should be compared to test the accuracy of thermal stress and coral bleaching projections for Guam. During bleaching events, the response team should compile forecasts and descriptions of ambient conditions, then correlate these with thermal stress responses observed at reef sites around the island. **Eyes of the Reef reports, combined with scientific surveys, will provide a bleaching timeline that can be contrasted with alerts and forecasts.** The regular tracking of this information will allow for better interpretation of existing forecasting systems and may be used to refine tools that can more accurately predict relationships between climatic and weather events and coral bleaching. Information gained at the local level should be disseminated to the appropriate federal government agencies or programs, including NOAA CRW and the National Weather Service.

Use of NOAA CRW products significantly reduces the input of local resources that would be required to analyze remotely-sensed and/or in situ measurements of SST, but continuous feedback from local data collection is required to validate these products so they remain relevant to local resource management efforts. **In order to verify accuracy of CRW products, particularly the experimental 5 km alerts and outlooks, the Coral Reef Response Team should provide the program with detailed reports of coral bleaching activity observed on Guam.** CRW has requested bleaching observations (including reports of "no bleaching") from 2014 onward. Forms and instructions for submitting bleaching reports to CRW are available here: http://coralreefwatch.noaa.gov/satellite/research/coral_bleaching_report.php

CRW may be interested in receiving SST data collected by in situ instruments in addition to the water temperature data requested on their bleaching report forms. An independent effort by local agencies should be made to validate the accuracy of the NOAA CRW products, whether through observation or more intense study. For instance, bleaching of staghorn *Acropora* spp. and other vulnerable taxa has been observed on the reef flats of Guam shortly prior to, or shortly after, issuance of CRW bleaching alerts. This suggests that the bleaching threshold of certain coral communities on Guam may be lower than predicted by the CRW models used to issue alerts and create outlooks.

Standard operating procedures

Response initiation triggers

Response initiation is based on specific decision criteria that trigger response activities. Consistent monitoring of the early warning system through interpretation of projections, analysis of local measurements, and verification of bleaching reports will allow managers and scientists to employ an appropriate level of response based on the expected extent and severity of a likely bleaching event. The decision to launch a major bleaching assessment effort is based on the geographic spread of bleaching, the observed depth of bleaching impacts, the number of species impacted, and severity of the bleaching (Table 6). Although specific triggers and their outcomes are outlined below, decisions may often be ad hoc as bleaching event trajectory and resource availability will vary. The flow chart below (Figure 6) serves as a decision tree for response management.

Table 6. Classification of bleaching severity (Adapted from Marshall and Schuttenberg 2006)

Bleaching severity	Site level	Colony level
No bleaching	No bleaching or paling	No bleaching or paling
Mild	Occasional pale/bleached colonies, but most not bleached (1-10% of coral cover bleached)	Partial bleaching (1-10% of colony is bleached or up to half of colony is pale)
Moderate	Frequent bleaching (10-50% of all colonies observed are pale or bleached)	Up to half of colony (10-50%) is bleached or up to entire colony is pale
Severe	Very frequent bleaching (51%-90% of all colonies are bleached)	More than half of colony (51-90%) is bleached
Very severe	Reef is almost completely white (less than 10% of all colonies are not bleached)	Colony is fully bleached or almost fully bleached (> 90% bleached)
Dead		Dead/recently dead

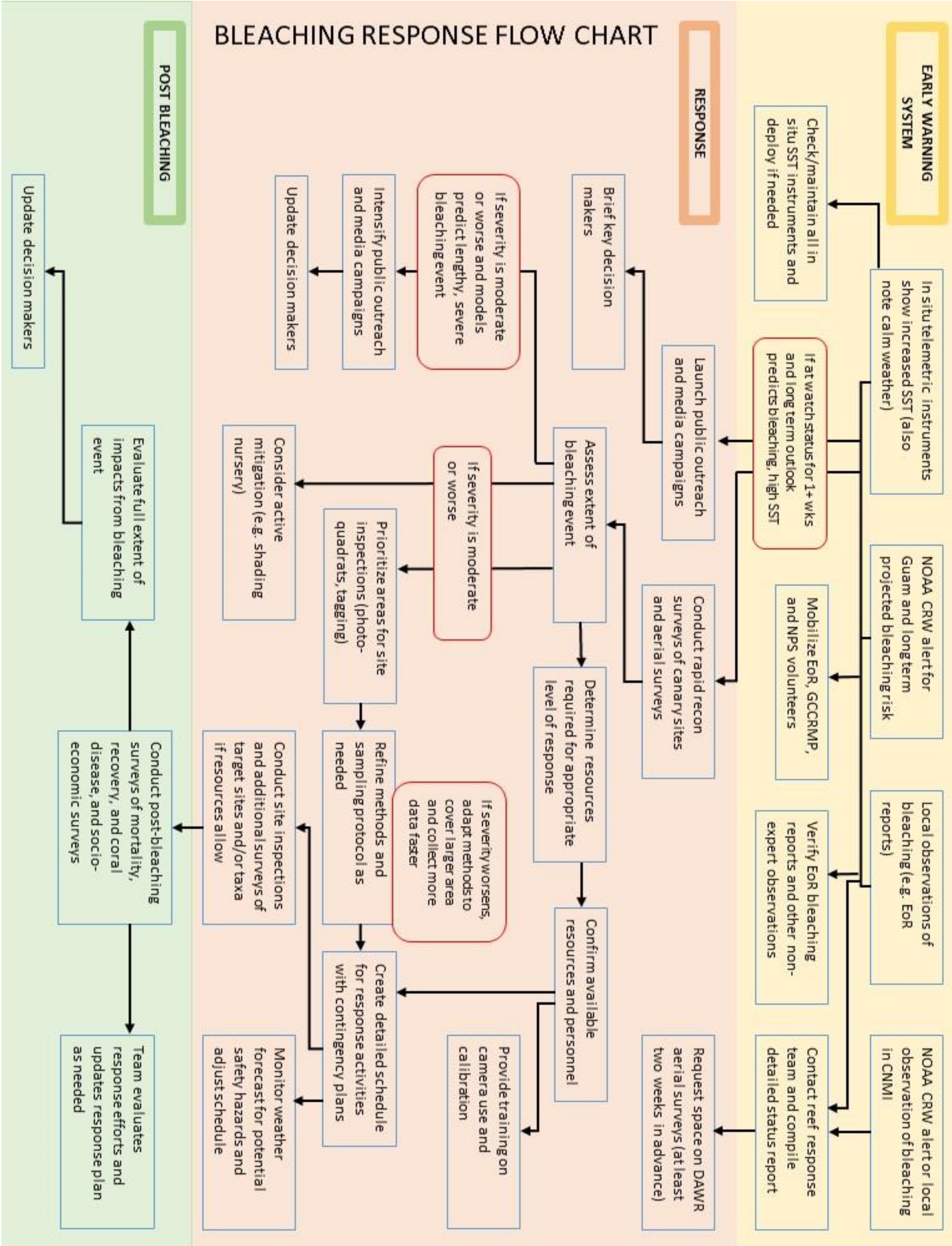
IF in situ telemetric instruments show rising SST and weather is calm **AND/OR** CRW issues an alert for Guam (Watch or higher) with long term bleaching outlook **AND/OR** there are local observations of coral bleaching (e.g. EoR reports):

- Team coordinator contacts the response team and disseminates a detailed status report
- Current EoR participants are contacted via email, made aware of the bleaching risk, and asked to look carefully for signs of coral bleaching; participants may also be sent a list of the canary sites (described in "Bleaching Assessments" section) so that they may be especially observant if visiting these sites
    - If needed, EoR staff may schedule additional EoR trainings or a bleaching-specific training for all citizen scientist groups (EoR participants, Guam Community Coral Reef Monitoring Program (GCCRMP) volunteers, and NPS Preservation Rangers)
    - If baseline data is needed, GCCRMP reef flat survey(s) may be organized
- Researchers and agencies with in situ instruments deployed on reefs should check functioning and additional instruments should be added if needed and available
- EoR reports and/or other non-expert observations of bleaching must be confirmed
- Response team requests space for additional passenger on DAWR aerial surveys if not already arranged (at least two weeks in advance of flight)

IF Guam has been at bleaching watch status for longer than one week **AND** the long term thermal stress outlook projects future bleaching and increasing SST:

- Launch a public outreach campaign, which may include television advertisements, radio interviews, a press releases or newspaper article, and posts on social media outlets
    - Raise awareness of potential bleaching without causing panic or creating a false alarm
- Brief key decision makers, such as agency heads, legislators, and the governor's office, on impacts of potential coral bleaching

Figure 6. Flow chart for coral bleaching response



IF bleaching alert status for Guam is elevated to Warning or above **AND/OR** there are verified reports of bleached *Acropora* spp. at two geographically disparate reef sites:

- Launch rapid reconnaissance surveys and conduct timed swims at all ten canary sites; record data on tagged colonies at these sites if possible
- Analyze rapid reconnaissance survey data to assess bleaching severity (at colony and site levels), spatial and depth extent, and taxa affected
- Determine resources required for appropriate response level, confirm available agency resources and personnel, and provide training on camera use and calibration if photo transect surveys will be conducted
- Consider active mitigation to protect coral nursery and employ if possible

IF overall bleaching severity is mild **AND** there is little evidence that event will be widespread:

- Continue monitoring components of early warning system and verifying EoR reports
- Conduct second round of rapid reconnaissance surveys after 2-4 weeks

IF bleaching severity is moderate or worse **AND** outlook projects a lengthy, severe bleaching event:

- Prioritize sites for site inspections (focusing on the 16 sites surveyed in 2015), refine sampling protocols as needed, and create schedule for response activities with contingency plans
    - Engage GCCRMP volunteers and/or Preservation Rangers for reef flat surveys if needed
    - Monitor weather and tidal forecasts and adjust survey schedule as needed
- Intensify public outreach and media campaign
    - Communicate importance of decreasing local stressors to increase resilience of Guam's reefs – provide tips to decrease impacts and instigate behavior change
    - Hold community meetings
    - Update decision makers on bleaching event with emphasis on the importance of decreasing local stressors
- Conduct site inspections and additional surveys of target sites and/or taxa if possible

Response management

Leadership

Coral bleaching response on Guam will be conducted according to the procedures within this document and input from a core team of local coral bleaching experts, including: Dr. Laurie Raymundo (UOGML), Dr. Peter Houk (UOGML), Dave Burdick (UOGML), and Val Brown (NOAA). These individuals, who serve as the Coral Bleaching Working Group, will meet regularly before and during coral bleaching events to maximize the effectiveness of Guam's response to bleaching and advise on scientific protocols. From January 2016 to December 2017, the Guam Coral Reef Response Team will be coordinated by Whitney Hoot, the NOAA Coral Fellow at the Guam Bureau of Statistics and Plans (BSP). The Coral Fellow will organize meetings of the response team and coordinate response activities.

Guam Coral Reef Response Team

The Guam Coral Reef Response Team will be responsible for conducting bleaching response activities on Guam. Local entities involved in the response team include BSP, GDOAG-DAWR, GEPA, and UOGML. Federal partners include NOAA, NPS, JRM, and USFWS. Broad roles of the local entities are outlined in the MOU signed in March 2016 (Appendix I). Specific tasks are outlined below (Table 7); assignments are expected to change and this table should be updated frequently.

Table 7. Key tasks and roles for reef assessments and bleaching response activities

ONGOING	
Task/Role	**Assigned Personnel/Agency**
Read new publications and reports on coral bleaching; keep response team members informed of relevant findings	Coral Fellow (BSP)

Monitor CRW alerts and weather patterns (with increasing frequency during ENSO cycles and summer months)	Coral Fellow (BSP)
Maintain and update lists of agency resources that may be needed in upcoming bleaching events	BSP, DAWR, GEPA, UOGML, NOAA, NPS, JRM, USFWS
Check EoR report responses	NOAA
Monitor for coral bleaching during regular aerial surveys	DAWR
PRE BLEACHING	
Task/Role	**Assigned Personnel/Agency**
Continue monitoring CRW alerts and increase monitoring of local data sources, such as telemetric instruments, tidal patterns, weather conditions, etc.	Coral Bleaching Working Group (UOGML, NOAA)
Plan additional trainings for EoR volunteers and contact current participants to encourage reporting	NOAA
Check EoR report responses; confirm EoR reports via site survey if report includes observation of coral bleaching	Coral Fellow (BSP) and Coral Bleaching Working Group (UOGML, NOAA)
Organize GCCRMP monitoring event(s) to survey reef flats	NOAA
Media outreach, including press releases, newspaper articles, posts on social media, etc.	NOAA, BSP, GEPA
Confirm available resources and personnel for response activities	BSP, DAWR, GEPA, UOGML, NOAA, NPS, JRM, USFWS
Brief key decision makers	BSP, DAWR, GEPA, UOGML, NOAA, NPS, JRM, USFWS
Contact DAWR to arrange for larger plane so coral biologist can participate in aerial survey (requires 2 weeks notice)	Coral Fellow (BSP) and Coral Bleaching Working Group (UOGML, NOAA)
Verify that currently deployed SST and water level instruments are functioning	UOGML, NPS
Deploy additional in situ instruments if needed to provide island-wide coverage	BSP, DAWR, GEPA, UOGML, NOAA, NPS
Conduct aerial monitoring of Guam's reefs and record any possible bleaching (Feb-Sept)	DAWR

Revise rapid reconnaissance datasheet if needed and share with all response team members	Coral Fellow (BSP)
DURING BLEACHING	
Task/Role	**Assigned Personnel/Agency**
Conduct rapid reconnaissance surveys at all ten canary sites	BSP, DAWR, GEPA, UOGML, NOAA, NPS
Assess available data in accordance with decision criteria and determine appropriate level of response based on bleaching severity and extent	Coral Bleaching Working Group (UOGML, NOAA)
Continue and intensify media outreach and public awareness raising	NOAA, BSP, GEPA
Host community meetings if necessary	BSP, DAWR, GEPA, UOGML, NOAA, NPS, JRM, USFWS
Continue aerial monitoring	DAWR
Update key decision makers on extent of bleaching, response activities to date, and plans for upcoming response activities	BSP, DAWR, GEPA, UOGML, NOAA, NPS, JRM, USFWS
Check EoR report responses; confirm EoR reports via site survey if report includes observation of coral bleaching	Coral Bleaching Working Group (UOGML, NOAA)
Organize GCCRMP monitoring event(s) to survey reef flats if needed	NOAA
Prioritize reef sites for site inspections	Coral Bleaching Working Group (UOGML, NOAA)
Conduct site inspections at 16 sites or more using photo transect method	BSP, DAWR, GEPA, UOGML, NOAA, NPS
POST BLEACHING	
Task	**Assigned Personnel/Agency**
Continue assessments of reef health, mortality, and recovery	BSP, DAWR, GEPA, UOGML, NOAA, NPS
Organize GCCRMP monitoring event(s) to survey reef flats to identify mortality and recovery	NOAA
"Lessons learned" meeting with members of the response team to evaluate process and results of response activities	BSP, DAWR, GEPA, UOGML, NOAA, NPS, JRM, USFWS
Update key decision makers on impact of coral bleaching event, outcomes of response activities, and next steps	BSP, DAWR, GEPA, UOGML, NOAA, NPS, JRM, USFWS

Evaluate extent of bleaching damage and implement feasible restoration projects if needed	Coral Bleaching Working Group (UOGML, NOAA)
Collect and compile temperature data and other data from non-telemetric in situ instruments	Coral Fellow (BSP), UOGML, NPS
Submit bleaching reports to NOAA CRW to validate CRW products	Coral Fellow (BSP)
Analyze data and determine which reefs were most resilient and least resilient to bleaching	Coral Bleaching Working Group (UOGML, NOAA)

Bleaching assessments

Guam's bleaching assessment methods involve surveys of varying scales and resource requirements, with the goal of measuring the extent and severity of bleaching events and evaluating the ecological impacts of coral bleaching on reef communities. The data collected during the assessments and in post-bleaching surveys will improve our understanding of the extent and severity of coral bleaching; the duration of bleaching events on Guam; the ecological effects of bleaching, such as impacts on species richness and relative abundance, coral cover, reef structure, and implications for non-coral species, such as reef fishes; the capacity of reefs to recover after bleaching; and the impact of local stressors on bleaching severity and subsequent recovery. Given that coral bleaching events are expected to occur with increasing frequency and severity, we hope that these assessments will provide insight into what Guam's future reefs may look like. We also aim to use this data to measure the relative resilience of Guam's reefs and produce data-driven management recommendations for conserving Guam's coral reef resources.

The bleaching assessments detailed in this plan include **citizen scientist observations, rapid reconnaissance surveys,** and **in-depth site inspections**. These three components are listed in order from least to most resource intensive. As detailed in this plan, specific decision criteria are required to trigger each level of bleaching assessment.

Citizen scientist observations

If telemetric instruments show rising SST and weather is calm and/or CRW issues a Watch alert for Guam with a long term outlook projecting bleaching and/or there have been local observations of bleaching, current EoR participants will be contacted and may be provided with a list of the prioritized canary sites that will be the focus on the rapid reconnaissance surveys. EoR staff may schedule EoR trainings and/or bleaching-specific trainings for EoR, GCCRMP, and NPS Preservation Ranger volunteers. If baseline data is needed for reef flats sites, GCCRMP and/or Preservation Ranger survey events may be scheduled.

The Guam Community Coral Reef Monitoring Program (GCCRMP), launched in July 2012, trains community members to conduct surveys of corals, algae, and benthic invertebrates. After completing a monitoring training session, members can begin participate in surveys of Guam's shallow reef flat areas. Participants are trained to utilize both quadrats and transect survey methods. As of May 2016, over 1000 participants have completed the GCCRMP monitoring training.

GCCRMP members can be recruited to participate in scheduled survey events to check shallow reef areas for beaching impacts before, during, and after bleaching events. These participants receive more extensive training compared to EoR participants. It is more likely that data collected through GCCRMP will be useful in assessing specific sites, while EoR reports are designed to provide the earliest notification of bleaching occurrence.

GCCRMP: https://guamreefmonitoring.wordpress.com
GCCRMP Facebook: https://www.facebook.com/GUreefmonitoring

NPS CoralWatch Preservation Rangers should also be mobilized. NPS has installed permanent transects at two sites near Asan Beach, at the Governor's complex (Adelup) and next to the War in the Pacific Park, where they conduct community monitoring with trained citizen scientists (Preservation Rangers) using the CoralWatch bleaching survey protocol, developed by the University of Queensland. NPS has trained 34 volunteers as of May 2016, who have completed both classroom and in-water training. The goal is to monitor these transects three times per year; volunteers record taxa morphologies, coral color (used as an indicator of coral health and possible bleaching), and algae cover. Data has been collected since 2015 and is available online. During a bleaching event, Preservation Rangers could be mobilized to conduct surveys at the two permanent transect sites at Asan Beach, and at a third site at Agat Cemetery, where transects will be installed in June 2016. Both the Adelup and Agat sites have been designated as canary sites for the rapid reconnaissance surveys.

NPS CoralWatch data: http://www.coralwatch.org/web/guest/reef
Data > Reefs > Country (Guam) > Reef Name (Asan Beach Gov Complex)
Coral Health Chart: http://www.coralwatch.org/web/guest/coral-health-chart

Rapid reconnaissance surveys

If the alert status for Guam is elevated to warning or above and/or there are verified reports of bleached *Acropora* at two separate reef sites, rapid reconnaissance surveys will be conducted at designated canary sites around the island. If overall bleaching is found to be mild, rapid reconnaissance surveys may be conducted again several weeks later.

Rapid reconnaissance surveys are long swims conducted at ten canary sites spread throughout Guam's four quadrants. Additional sites may be selected based on resource availability and reports of localized bleaching. The objective of these shallow snorkel-based surveys is to evaluate the overall spatial extent and severity of coral bleaching on reef flats, in addition to identifying affected taxa. These sites were selected because they are easily accessible by snorkelers from the shore and are known to have populations of bleaching-susceptible corals. Before a bleaching event, the canary sites will be assigned to response team members for surveying.

Canary sites (identified by the Coral Reef Response Team in May 2016):
- North (1): Ritidian Point (Guam National Wildlife Refuge)
- West (5): Gun Beach; Outrigger (Tumon Bay); Ypao (Tumon Bay); Asan Beach (Adelup); Agat Cemetery
- South (1): Merizo Pier
- East (3): Ipan Beach Resort; Jeff's (Togcha Bay); Pago Bay (UOGML)

In teams of two, snorkelers conduct ~20 minute swims over an area of approximately 20 m x 50 m, depending on the distribution of coral at the site. Data to be recorded includes max depth, bleaching occurrence (yes or no), bleaching severity, number of bleached colonies, estimated percent of total coral cover bleached, and genera/species affected. The shared datasheet is stored on Google Drive and can also be downloaded.

Close-up inspection of a coral colony is needed to determine whether a coral is bleached or recently dead, as newly dead corals are also white. If a colony appears to be very clean and free of sediment and tentacles are visible when viewing the coral in profile, the colony is bleached but still alive. Dead colonies no longer secrete the mucus that allows them to remove debris that has settled on their outer tissue layer, so any sediment built up or biofilm on a coral indicates mortality (Oliver et al. 2004).

If time allows, snorkelers should record colony level data for any tagged colonies and/or affected colonies. Data to be recorded includes tag number (if tagged), species (or genera if species is unknown), colony location (lat/long), colony depth (at base), colony diameter (longest axis), and bleaching description, location, and severity.

All bleached corals and tagged colonies should be photographed; GPS should be enabled on the camera when photos are taken. Photographs should be labeled according to the following convention and uploaded to the shared folder, accessible to all response team members. Tag number is only included if the photo shows a tagged colony.

Photo labeling convention: SITEID_MMDDYY_OBSERVERINITIALS_PHOTONUMBER_TAGNO
e.g. S02_052516_JS_001 or S10_052516_JS_001_S10A05

Required supplies:
- Meter stick or transect tape
- GPS-enabled camera

- Snorkel gear, dive slates, compass, GPS
- If surveying tagged colonies:
    - Abrasive brush or other tool to remove algae from tags
    - Underwater map for locating tagged colonies

<u>Reef flat bleaching surveys</u>

During the 2016 coral bleaching event, members of the response team began surveying coral bleaching along Guam's reef flats. These semi-quantitative snorkel-based surveys were launched following the observation of moderate to severe bleaching at many shallow reef sites along the island. These surveys were conducted at eight of the ten canary sites (excluding Outrigger and Pago Bay). The number of sites was restricted given the limited availability of resources and staff time, and the need to resurvey sites frequently to capture bleaching and mortality. Ideally, these surveys would be conducted at 2 week intervals throughout the bleaching event and for several months afterward.

These surveys can be conducted with two trained snorkelers or one trained snorkeler and a buddy, who can take rapid recon photos while the trained snorkeler completes the surveys. At each site, three parallel transects (non-permanent) are surveyed for 20 minutes. Transects are clockwise around the island, parallel to the reef margin. Each time a site is surveyed, the coordinates of the start and end points of each transect are recorded (written on datasheet and marked as GPS waypoints). Following any site resurveys, the starting points from the first survey are used as the starting points for all transects during subsequent surveys. The ending points will vary as the survey is limited by time rather than distance, but the GPS points are always recorded so that the transect length can be approximated. The heading is also recorded during the first survey and the same heading is repeated during all subsequent surveys.

Before entering the water, turn on the track function and take a photo of the time, date, and location on the GPS so that photos taken during the surveys can be associated with the GPS points. Starting at the established waypoint for each transect, swim for 20 minutes at the established heading and record all coral colonies within a 1 m band, using the one-meter stick as a guide. For each colony, record species (or ID to genera and take a photo of both the datasheet and the colony if unable to ID to species); bleaching status (unbleached; partial pale; partial bleached or fluorescent; whole pale; whole bleached or fluorescent; whole bleached, part dead; whole dead). Note bleaching mortality for all colonies; count only recent mortality that can be reasonably attributed to bleaching. Species are recorded on the left side of the datasheet and each colony is marked with a tally according to its bleaching status. If a colony exhibits another impact, it is marked with a letter instead of a tally in the lower portion of the cell (e.g. W = white syndrome, C = COTS, D = *Drupella*, P = Predation, T = *Terpios*, M = Mortality). After the surveys, it is recommended that snorkelers swim around the site and take photographs to further document the extent of bleaching and other impacts. All photos should be added to the shared response team folder on Google Drive.

Supplies needed:

- Datasheet, clipboard, pencil, rubberbands
- Underwater camera
- Float, GPS, and GPS drybag
- One-meter stick

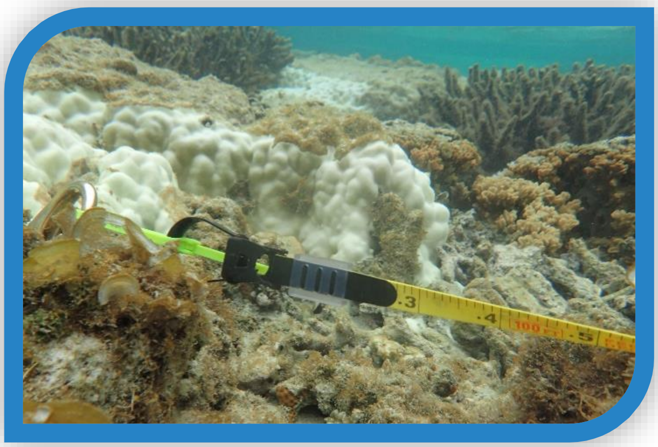
Several members of the response team completed training on these methods in August 2016. This training should be repeated during future bleaching years. Although this method is simple and semi-quantitative, it may answer some important questions, such as:

- Community composition at reef flat sites
- Relative percentage of corals bleached at reef flat sites
- Bleaching susceptibility of different taxa
- Density of coral colonies per area
- Correlation between bleaching prevalence/severity and other impacts

Site inspections

If results of the rapid reconnaissance surveys and/or reef flat surveys indicate that bleaching severity is moderate or worse and/or the thermal stress outlook predicts a lengthy, severe bleaching event, site inspections will be conducted. The 16 sites surveyed in both 2013 and 2015 will be prioritized, with additional sites selected based on resource availability and anticipated extent and severity of impacts.

The goal of the site inspections is to improve our understanding of the ecological impacts of coral bleaching events and collect robust data that can be compared to surveys from previous bleaching events. These detailed site assessments allow measurement of the average proportion of coral colonies or percent of coral cover affected by bleaching, and thus calculation of relative resistance of corals through creation of a hierarchy of susceptibility. Depending on the site, baseline data may exist to help evaluate long-term changes to reef community structure as a result of one or more coral bleaching events. Pre-bleaching event data may be available through the long-term coral reef monitoring program, GEPA's Environmental Monitoring and Assessment Program, GCCRMP, and research conducted by UOGML scientists.



If bleaching is widespread and has affected coral communities at permanent monitoring sites, photo transect surveys should be conducted at these sites at the peak of the bleaching event, with the objective of documenting spatial and taxonomic patterns of bleaching. If possible, surveys of associated biological communities (e.g., algae, sponges, macroinvertebrates, fishes) should be conducted if baseline data is not available. This data can be compared to post-bleaching data to evaluate community-level bleaching impacts.

Reef sites containing a high proportion of bleaching-susceptible taxa, such as *Acropora muricata*, *A. pulchra*, *A. digitifera*, *A. azurea*, *A. austera*, Montipora spp., and *Pocillopora* spp. should be visited regularly during peak bleaching on Guam. Based on previous observations, *A. pulchra* and other staghorn species appear to be especially sensitive to thermal stress.

Two sampling methods are outlined below. The first method (broad-scale bleaching assessments using photo transects) is most appropriate for a broad effort by multiple agencies and citizen scientists involved in community outreach programs. The latter method (target species tagging) is most likely to be utilized by UOGML researchers. For each protocol, the number of sites and sampling intervals should be determined based on event severity, resource availability, and prioritization of data to be collected. A list of resources accompanies each sampling method outlined below. This list includes only specialized supplies that may be needed for each particular method, and not general supplies required for all methods such as trained divers, dive gear, boats, safety equipment according to protocols, etc.

General resources needed for sampling include:

- Trained scientific divers and/or trained citizen scientist snorkelers
- Dive equipment, including tanks and air fills, and safety equipment to support scientific diving

- Vessel time, vessel operators, and fuel
- Dive slates and pencils
- Underwater torches/flashlights
- Meter sticks or transect tapes for measurements
- Underwater cameras w/training provided to all camera operators
- GPS and/or GPS-enabled cameras

Modifications to the 2013 bleaching survey methods:

- Utilize citizen scientists to survey reef flats, which were not surveyed in 2013
- Prioritize site inspections at 16 sites assessed during 2015 resurvey to minimize resource inputs and contribute to a long term dataset
- Set up permanent transects at these 16 sites to reduce noise in data from photo transect surveys
- Prioritize surveys of taxa that were especially degraded by previous bleaching events and evaluate the severity of the impacts from successive events

NOTE: As of April 2017, there is extremely limited water access on the east side of the island due to lack of a functioning boat launch. With a powerful 4WD truck, it is possible to launch a vessel < 20 feet long from Talofofo Bay. Slightly larger vessels can be launched from the Mannell Channel in Merizo.

Method 1: Broad-scale quantitative surveys

An island-wide assessment aimed at quantifying the extent and severity of the bleaching event should be initiated when there is confirmation of widespread bleaching affecting multiple taxa across Guam's reefs. In addition to documenting impacts to the coral community, these assessments also aim to document the current state of the broader benthic community, the fish community, and macroinvertebrate community. The resource- and time-intensive broad-scale quantitative assessment is best approached through collaboration between multiple partners, including UOGML, GEPA, BSP, DAWR, NPS, and NOAA, to achieve maximize coverage in a timely manner.

During the 2013 bleaching event, divers surveyed the NOAA Coral Reef Ecosystem Program (CREP) sites from the 2011 Rapid Ecological Assessment (REA) fish surveys (Williams et al 2012) (Figure 7) with the addition of seven sites in the northeast quadrant, where no CREP surveys were conducted (Figure 8). A total of forty-eight (48) sites at 4-6 m depth were randomly selected for quantitative assessment (16 sites per island quadrant). **It is recommended that the same set of 48 sites surveyed in 2013 be re-visited during future bleaching events, with the 16 surveyed in 2015 (Figure 9) as the priority in the event that only a subset can be surveyed. If fewer than 48, but more than 16 sites, can be surveyed, it is recommended that the selection of additional sites be carried out randomly or systematically to prevent bias, and that the sites be allocated evenly across the island quadrants.**

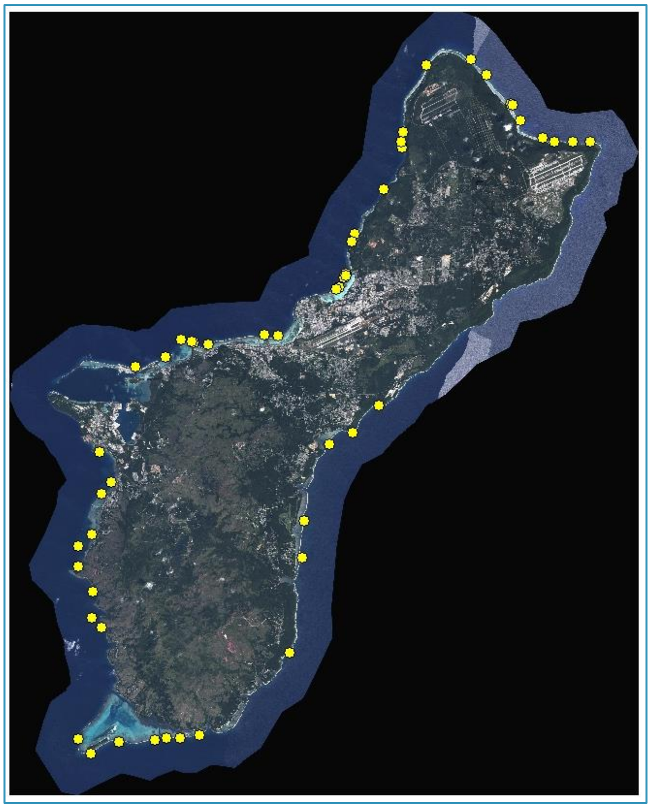


Figure 7. Sites surveyed during 2011 CREP fish REA surveys

If more than 48 sites can be surveyed, or if a new set of sites is desired, it may become necessary to generate additional survey site locations or generate a new set of random survey site locations using GIS software. When generating new survey site locations at shallow depths (< 10 m), it is recommended that a single depth contour be used to constrain the random point generation procedure, rather than using a polygon representing a depth range. If a depth range polygon is used, the disparity in the amount of shallow reef area at different locations around the island would result in disproportionate allocation of survey sites at locations with more reef area and fewer (or no) sites where shallow reef area is limited, resulting in an uneven distribution of sites island-wide. For example, reefs in the northeast coast of Guam, and along the southern coast of Orote Peninsula, which are generally narrow with steep slopes and limited shallow reef area, would likely be under-represented using the depth range polygon approach to random point generation. If the time and staff resources are not available to create a smooth, continuous contour feature at the desired depth, an available contour feature for another, perhaps more commonly

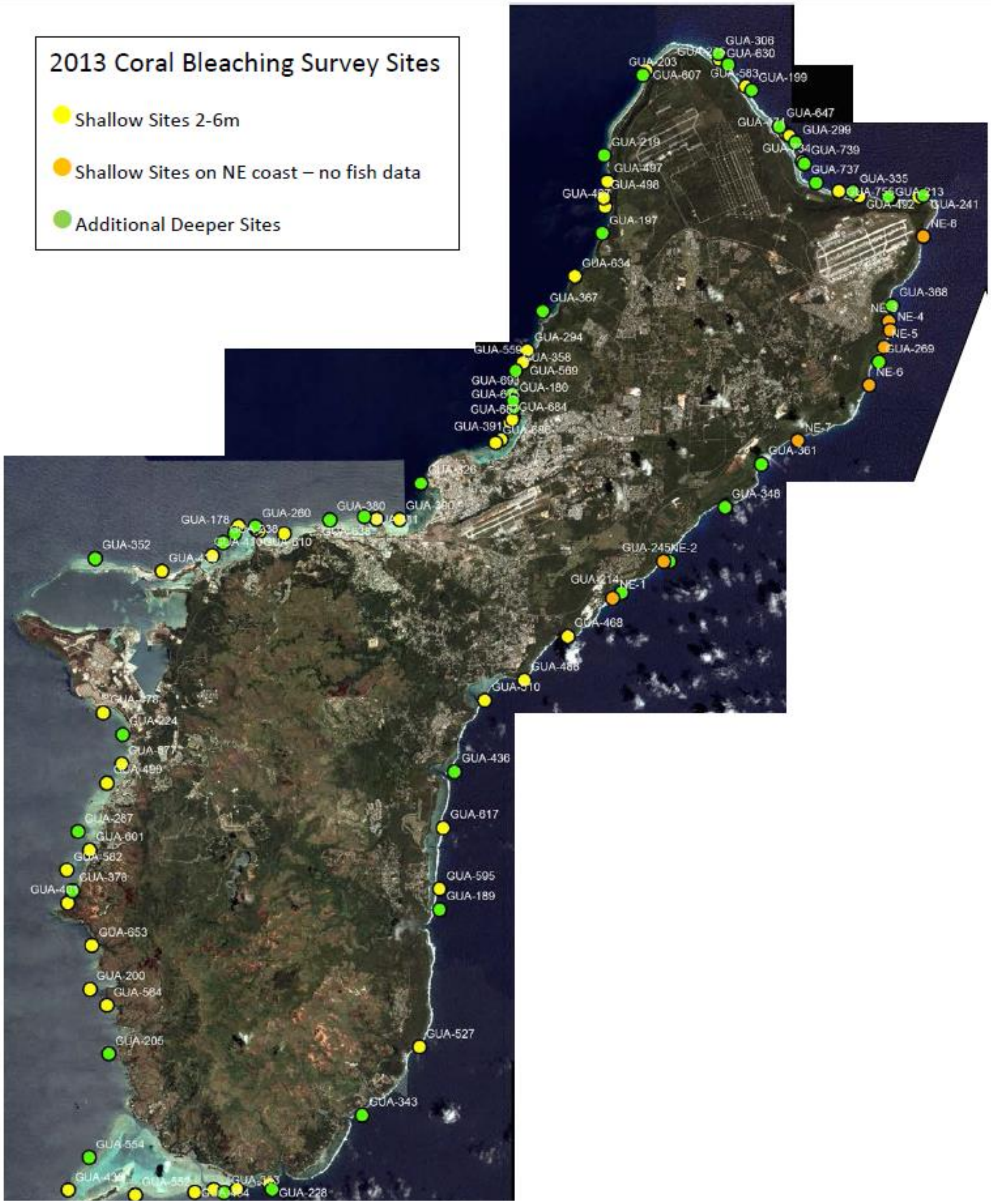


Figure 8. Sites surveyed during 2013 bleaching event

used, depth can be used to generate the new survey site locations. If this approach is used, divers would enter the water at the location of the site generated by the GIS analysis, swim in a direction perpendicular to the reef margin until the target depth is reached, and mark the actual site location using a GPS before beginning the surveys.

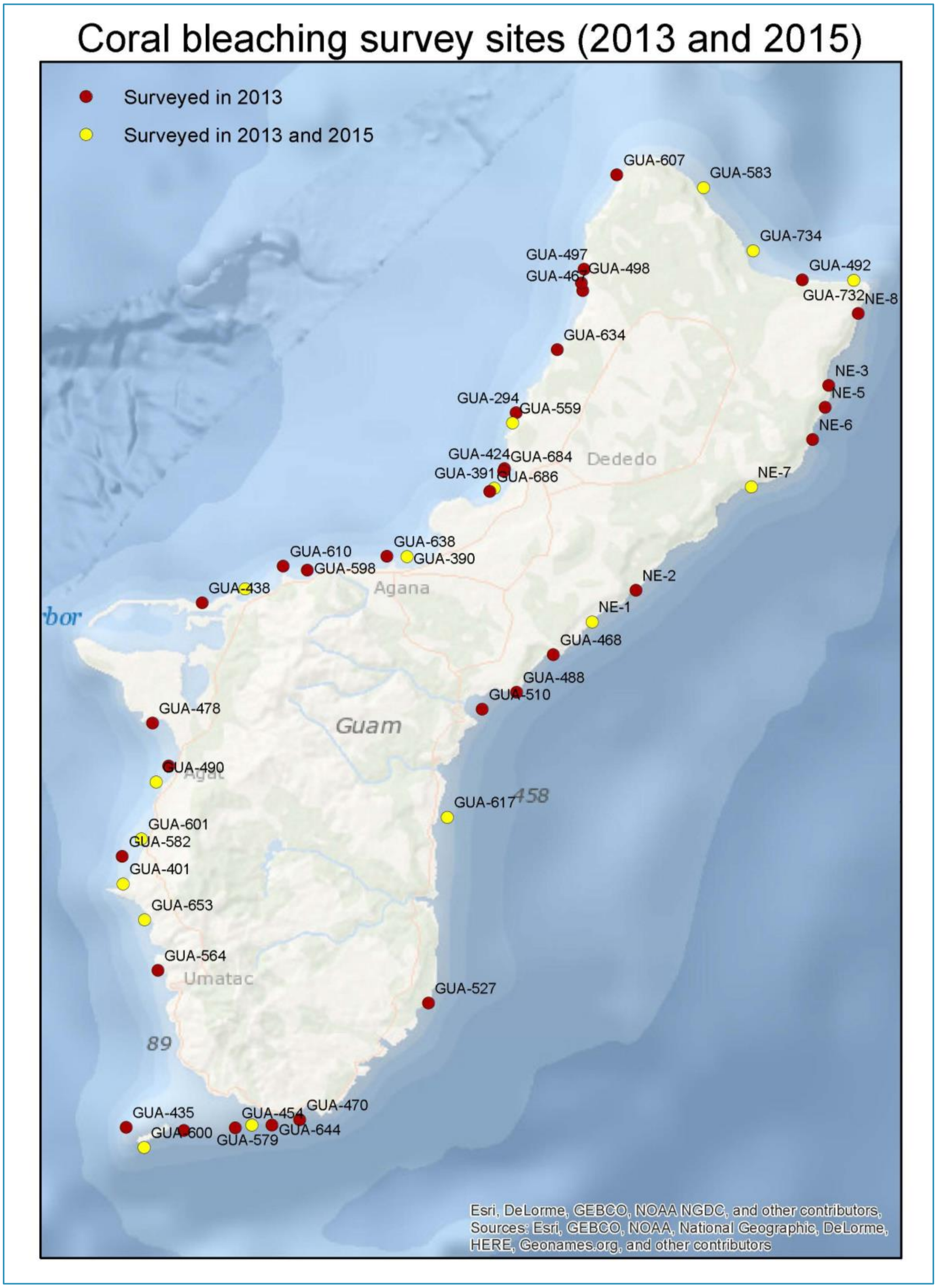


Figure 9. Sites surveyed in 2013 (48 total, 16 per quadrant) and sites surveyed in 2013 and 2015 (16 total, 4 per quadrant)

In previous bleaching events, photographic sampling along 30 m transects was executed. This method requires significant time and resources, but allows flexibility in diver selection, as divers do not have to be experts in coral identification. One disadvantage however is the significant amount of post-processing required to extract the data from the photos. During these surveys, divers photographed both corals and benthic macroinvertebrates; in future bleaching surveys, macroinvertebrate surveys may be excluded if time and resources are limited. This photo transect methodology was adapted from van Woesik et al. 2012.

To the extent possible, the same camera model should be used for all surveys. If two or more models must be used, an attempt should be made to maintain consistency in the field of view across camera models by adjusting the length of the monopod. The date and time and other settings should be calibrated among cameras prior to the survey effort. The white balance should be manually adjusted at depth when appropriate. Cameras with higher image resolution should be used when available, as the higher image resolution allows a greater degree of taxa discrimination. Divers who will be operating a camera should be trained to properly use the cameras and monopod to ensure that clear, high quality images are captured at a consistent height above the substrate.

At each site, record:

- Depth of transects
- General description of reef structure, including rugosity
- Water temperature
    - Given that dive computer temperature readings are unreliable, a probe with digital read-out should be deployed from the boat and temperature recorded at multiple depths (bottom; mid-depth; surface)

Transect deployment:

- At each site: Deploy three 30 m transects laid end to end (~2 m between), parallel to the reef margin along one depth contour
    - When laying transects, cross small cracks or depth changes less than 1.5 m
    - If site has high rugosity (e.g. spur and groove reef):
        - If groove is < 5 m, take photos across groove (place monopod on benthos beneath transect)
        - If groove is > 5 m, shift the transect or abort the site
- Survey heading: Clockwise direction (around the island, as viewed from above), parallel to reef margin

Coral community composition and bleaching severity surveys:

- Record all coral genera or species (when possible) within the vicinity of the photo transects
- For each taxa, categorize the degree of bleaching exhibited by the majority of colonies of that taxa (no bleaching, low (0-25% of colony), affected and not affected by bleaching, including bleaching severity, bleaching description, and bleaching location for each colony (if possible)
- Record depth extent of observed bleaching

Photographs to be taken:

- General site
    - Dive slate with site ID, transect number, and date
    - 360º views at beginning of each transect
    - Limited number of general site photos along each transect
- Benthos
    - Take one photo every meter using monopod centered on transect; an inverted "L" design, where the camera is placed at the end of a short portion of PVC piping extending perpendicularly from the primary. A vertical PVC post minimizes the monopod footprint in photo, while using a relatively tall monopod maximizes field of view (~100 cm wide x 70 cm long when using 1.3 m monopod, depending on lens

length). It is recommended that the length of the image not exceed 75 cm so that the overlapping of subsequent images is avoided in highly rugose areas.

When possible, divers should survey commercially important macroinvertebrates in a 4 m wide belt along up to three 25 m transects at each site. Record and photograph trochus (*Tectis* spp.), *Tridacna*, *Lambis* spp., COTS, holothurians, urchins (except *Echinostrephus*), and *Drupella*.

Diver roles:

- Diver 1 or 2: Lay transects; record date, depth, and description of rugosity
- Diver 1: Take 360^{o} photos and one photo per meter along transect
- Diver 2: Coral community composition and bleaching severity surveys
- Diver 3 (if available): Survey macroinvertebrates

During these surveys, it may also be appropriate for divers to descend to greater depths after surveying transects to evaluate depth extent of bleaching. These divers may also be able to conduct broad, semi-quantitative surveys of taxa groups found at the site, roughly classifying bleaching as mild, moderate, or severe per taxon.

Specialized resources needed for Method 1:

- Monopods (1.3 m max height to ensure stability)
    - Constructed with PVC, screws, and washers

<u>Method 2: Target species tagging</u>

Tag species known to be susceptible to bleaching (minimum 10 colonies of each targeted species at each site) and continue to survey throughout bleaching event. Surveys should be conducted as frequently as possible during event and for several months following the event to measure mortality and recovery.

Prioritized target species and sites for target species tagging are:

- *Porites rus* (Tumon Bay)
- *Acropora* spp. at established long-term monitoring sites
- Targeted species along fore reef sites around island:
    - *Acropora azurea*
    - *Acropora monticulosa*
    - *Pocillopora verrucosa,*
    - *Pocillopora meandrina*
    - *Pocillopora setchelli*
- Other taxa to be prioritized if resources allow:
    - *Acropora abratonoides*
    - *Acropora globiceps*
    - Favids
    - *Montipora* located near other tagged colonies

Using this method, the following data should be collected on each bleached colony:

- Site and depth
- Colony species and size
    - Diameter: hemisphere diameter on longest axis (half circumference) or longest axis (cm)
- Location of bleaching on colony (Upper surfaces, tips only, or entire colony)
- Bleaching description and severity (percent of colony affected) (Table 6)
- Photos: Above and/or oblique view, side view, and 360^{o} of surrounding location (with GPS-enabled)

- Record GPS coordinates or map tagged colonies

Specialized resources needed for Method 2:

- Tags (cattle tags and/or aluminum)
- Abrasive brush or other tool to remove algae from tags
- Dive camera
- GPS (or GPS-enabled camera)
- Underwater map of site and tagged colonies

Post-bleaching and recovery surveys

Coral bleaching does not always result in mortality; many corals can recover from bleaching events if anomalous temperatures soon return to within normal range and there is limited stress from other threats such as land-based sources of pollution. When mortality does occur, the impacts on coral reef ecosystems are much more severe, as the structural complexity of the habitat is degraded. Dead corals are quickly colonized by algae, making them difficult to differentiate from corals that died from other causes, such as COTS (Oliver et al. 2004). Branching corals such as *Acropora* spp. do not maintain their structure for long after the colony is dead and are soon reduced to loose rubble. During a lengthy bleaching event, mortality should be measured regularly in order to capture all death due to bleaching. Ideally, corals will be surveyed every 2-3 weeks to capture mortality and reliably attribute it to bleaching. The optimal sampling interval to monitor reef health following a bleaching event is after 2 months, 6 months, 12 months, and 24 months (Oliver et al. 2004). Post-bleaching surveys should begin once all corals have either recovered or died and no bleached corals are visible. Tagging individual colonies and surveying them before, during, and after bleaching events is a highly effective way to measure mortality and recovery. This also allows genetic analysis of samples from individuals that have proved highly resilient (or highly vulnerable) to bleaching.

In 2015, 16 of the 48 sites surveyed during the 2013 bleaching event were selected for resurvey (4 randomly selected sites per quadrant). During resurveys of sites impacted by bleaching, dead colonies should be identified to genus. Divers should look for recruitment, resheeting, and any evidence of coral disease or outbreaks of coral predators, such as COTS or *Drupella cornus*. Future surveys during and after bleaching events should be conducted at these 16 sites (and additional sites when possible) to continue building a record of the long term impacts of repeated bleaching of Guam's coral reefs. Methodologies should be kept consistent for subsequent surveys, underlining the importance of maintaining detailed records of protocols and alterations to sampling methods that may occur in the field. Establishment of permanent transects at the canary sites and 16 2-6 m sites surveyed in 2013 and 2015 would decrease statistical noise and increase robustness.

Data management and sharing

When compiling and inputting data from the field, observers should utilize the shared datasheets available on Google Drive. If a spreadsheet is downloaded for entry, it should be re-uploaded after all data is inputted or emailed to the designated data manager.

UOGML may be able to fund a student to create and manage a database that would include data collected during coral bleaching assessments. Otherwise, the response team should examine similar databases of coral reef impact data and find an easily adaptable model. In the future, the team should aim to have all data accessible online to registered users.

The use of citizen scientist-collected data is becoming more commonly accepted and integrated into ecological studies. The value of this data should not be underestimated, given the sheer amount of data that volunteers can collect. With proper training, citizen scientists can collect accurate, reliable data. Survey methods used by citizen scientists should be designed to approach those methods used by experts, allowing usage of citizen science data in academic studies. Given the variety of volunteer programs currently collecting data on Guam's reefs, such as the GCCRMP, EoR, and the NPS Preservation Rangers, this is an important opportunity to both increase the amount of available data during a bleaching event and enhance community engagement in science and conservation.

Integration with long-term monitoring

The Guam Long-term Coral Reef Monitoring Program (GLTCRMP) involves ongoing data collection on numerous coral reef health variables at several permanent sites along Guam's reefs. The GLTCRMP collects data on water quality, benthic habitats, and biological communities at prioritized coral reef areas around the island. This longitudinal data is vital for determining baseline conditions at a site-level before an impact, such as coral bleaching occurs, or to measure change after a management action, such as establishment of a marine protected area (MPA) or the implementation of watershed improvement projects. The data collected through this program is some of the most statistically rigorous data available on Guam's coral reef ecosystems. Assessments conducted during coral bleaching response should be designed to augment GLTCRMP surveys to avoid overlap and increase data coverage.

Data collection under the GLTCRMP began in June 2009 at seven sampling stations (2 permanent; 5 non-permanent) in the Tumon Bay MPA, using video transect surveys, coral quadrat surveys, and fish surveys with belt transects and stationary point counts. In 2010, surveys of coral size and condition; benthic cover; and fish and macroinvertebrate communities were conducted at a total of 20 sampling stations (10 permanent; 10 non-permanent) along the outer reef slopes of Tumon Bay and East Agana Bay. The following year, the same surveys were conducted at 23 sampling stations (11 permanent; 12 non-permanent) at Western Shoals in Apra Harbor. In 2012, field biologists with the GLTCRMP surveyed coral size and condition, benthic cover, and fish and macroinvertebrate communities at 20 sampling stations in Piti Bay. The same surveys, with the exception of fish, were also conducted at Tumon Bay (21 sampling stations) and East Agana Bay (10 sampling stations). Reef fish surveys were carried out at 5 of the stations in Tumon Bay. No GLTCRMP data was collected in 2013.

In 2014, coral size and condition, benthic cover, and macroinvertebrate surveys were conducted at all ten permanent sampling stations in East Agana Bay, all ten permanent stations within Tumon Bay, and at all ten permanent and two non-permanent stations in Piti Bay. All surveys (except coral quadrat surveys at three permanent sampling stations) were also conducted at 11 newly-established permanent and two non-permanent sampling stations in Achang Bay. Surveys of benthic and fish and macroinvertebrate communities were conducted at three newly-established sampling stations at Cocos-East. Between October 1, 2015 and March 31, 2016, staff with the GLTCRMP surveyed 35 long-term monitoring sampling stations (photoquadrats, coral and macroinvertebrate surveys, and rugosity assessments). Analysis of the 2013 bleaching data is ongoing.

Additionally, Dr. Laurie Raymundo at the UOGML is conducting a reef flat monitoring project, which includes data on benthic composition; coral populations, size, structure, and community composition; coral health impacts (such as predation, bleaching, and disease), and water quality, including temperature and nutrients. Dr. Raymundo is also leading a study of bleaching-related mortality of Guam's staghorn corals.

Data from GLTCRMP macroinvertebrate belt transect surveys since 2010: https://data.noaa.gov/dataset/guam-long-term-coral-reef-monitoring-program-macroinvertebrate-belt-transects-since-2010

Data from GLTCRMP coral colony size and condition surveys since 2010: https://catalog.data.gov/dataset/guam-long-term-coral-reef-monitoring-program-coral-colony-size-and-condition-surveys-since-2010

Report (2012): 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:
http://www.coris.noaa.gov/geoportal/catalog/search/resource/details.page?uuid=%7B17DC39FF-C795-4998-A85F-5F2D96DECA8E%7D

Report (2012): Comprehensive Long-term Monitoring at Permanent Sites on Guam: 2012 Status Report:
http://data.nodc.noaa.gov/coris/library/NOAA/CRCP/other/grants/MonitoringGrants_FY10_Products/NA10NOS4260046_Guam_Monitoring.pdf

Report (2014): Comprehensive Long-term Monitoring at Permanent Sites on Guam: 2014 Status Report:
http://data.nodc.noaa.gov/coris/library/NOAA/CRCP/other/grants/NA11NOS4820007/Guam_Reef_Monitoring_FinalRept.pdf

Socioeconomic assessments

Socioeconomic surveys after coral bleaching events allow natural resource managers to measure the social and economic effects of widespread bleaching; incorporate local knowledge with results from collection of ecological data and expertise of scientists; assess the costs and benefits of bleaching management techniques; and facilitate community engagement in the process of measuring the impacts of coral bleaching events (Marshall and Schuttenberg 2006). These surveys should aim to answer questions such as (TNC 2013):

- Which communities and user groups are most affected by a moderate bleaching event, a severe bleaching event, or a very severe bleaching event with extensive mortality?
- What are the socioeconomic impacts resulting from a moderate bleaching event, a severe bleaching event, or a very severe event with extensive mortality?
- How do the culture, traditions, and history of Guam shape the socioeconomic impacts caused by coral bleaching?
- What behaviors are people willing to change to reduce the impacts of coral bleaching?
- What is the perceived value of Guam's coral reefs among communities and user groups?
- What are the persisting attitudes towards climate change, coral bleaching, and coral reef ecosystems among communities and user groups?

Human use surveys

GCCRMP is currently collecting human use data (tourist use only) for Tumon Bay and Piti Bomb Holes Marine Preserves. This study aims to determine how many individuals are using these marine protected areas, which will allow calculation of the economic impact of lost revenue that could result from bleaching or the potential cost of prohibiting tourists from entering MPAs as a conservation measure. Data on both local use and tourist use of Tumon Bay and Piti Marine Preserve were collected in the Limits of Acceptable Change studies conducted in 2006.

Data on the relationship between human use, coral damage, and coral disease was collected in Tumon Bay during summer 2016 (Sturm et al., unpublished data). This data is still being processed, but preliminary results show a strong correlation between human use and coral damage.

Creel surveys

Creel surveys (sampling surveys of recreational fishing activities) on Guam have been conducted continuously since the early 1980s. The data, collected by DAWR, identifies the level of participation in various fishing methods utilized on Guam and measures the catch rate and counts and size for fish and invertebrate takes for each fishing method. Participation in the creel surveys is voluntary. Both boat-based and shore-based data is collected.

Boat-based creel survey data:
http://www.ngdc.noaa.gov/docucomp/page?xml=NOAA/NMFS/PIFSC/iso/xml/5620.xml&view=getDataView&header=none

Shore-based creel survey data: https://data.noaa.gov/dataset/guam-shore-based-creel-survey

Communication and outreach strategy

The communication and outreach strategy is designed to increase awareness of the impacts of coral bleaching on Guam's reefs among policy makers, community members, and other stakeholders. An effective communication strategy that incorporates social marketing will alter attitudes and perceptions of the target audiences, ultimately resulting in behavior changes, such as joining the EoR program or reducing personal impacts by avoiding recreation in marine reserves during bleaching. The interagency MOU signed in March 2016 states that BSP, GDOAG, GEPA, and UOG will assist with public outreach efforts related to bleaching. Specific activities associated with this strategy include:

- Developing media messaging before bleaching and disseminating statements before, during, and after bleaching
- Hosting community meetings and presenting briefings to agency administrators, legislators, the Governor's office, and other decision makers
- Instigating behavior change to reduce local stressors on coral reefs during periods of high thermal stress in order to increase resilience to coral bleaching

Press releases and media statements

The provision of concise, informative, and straightforward statements to the media is a key component of bleaching-related outreach. **The public outreach and media campaign will be triggered if Guam has been at watch status for over one week and the CRW outlooks predicts increasing temperatures and future bleaching. Messaging should be revised and refined by May of each year in preparation for potential summertime bleaching.**

Effective press releases must: be no longer than one page; concisely lay out the information intended for dissemination; include suggested actions for decision makers or specific stakeholder groups; and provide a contact person for further information. A sample press release can be found in Appendix III. The contact person listed in the release should be prepared to participate in interviews for local television, radio, and print media outlets. Outside of bleaching season, a designated response team member should be selected to translate published studies and UOG student research relevant to bleaching of Guam's reefs into executive summaries for decision makers and/or press releases for the public. Another venue for communicating information about coral bleaching and response is the quarterly GCMP newsletter, *Man, Land, & Sea.*

If funding became available, a movie theatre advertisement could be an effective venue for raising awareness of coral bleaching and the impacts of local threats on stressed coral reefs. An ideal ad will focus on actions that individuals can take to reduce their own impacts (e.g. swap sunblock for a rash guard; do not take herbivores) and increase the resilience of Guam's reefs to bleaching.

Communities and decision makers

Community meetings may be required if a severe mass bleaching event occurs. These meetings are triggered by overall severity of bleaching on Guam that is moderate or worse and projections of a long, severe event. Otherwise, the scheduling of community meetings is generally appropriate when: 1) bleaching has affected the majority of shallow scleractinian corals around the island and potential for widespread mortality is high; or 2) coral bleaching may not be observed island-wide, but the majority of scleractinian corals at high profile, high value reef sites (e.g., Ypao Beach, Piti Marine Preserve, Western Shoals) exhibit bleaching with high potential for mortality. Community meetings should be held in the village closest to a high profile reef site that has bleached and hosted at community or recreation centers as arranged through the village's Mayor's Office. The meetings should be scheduled for the early evening, to accommodate working residents, and last approximately 1-2 hours, although timing may vary depending on attendance and engagement. A brief presentation, provided by a member of the response team, should include: 1) an introduction to bleaching and climate change; 2) a summary of the current bleaching event; 3) a description of how this event may affect the community; and 4) actions that can minimize the impacts of bleaching on both coral reef ecosystems and human communities. The end of the meeting should consist of a question and answer session.

Briefings to senior management and policy makers should be provided during a severe mass coral bleaching event. Key decision makers should be briefed if Guam has been at watch status for over one week and the CRW outlooks predicts increasing temperatures and future bleaching. If the severity of the event is rated as moderate or worse and CRW projects lengthy, severe bleaching, a wider group of decision makers should be briefed, with a topical focus on the importance of decreasing local stressors to bolster reef resilience. Decision makers should also be fully briefed following bleaching events, when the extent of the impacts is evident. These post-event briefings should include concrete recommendations for management and policy changes.

These briefings are tailored to the interests and knowledge level of managers and policy makers. Unlike community meetings, they should be held during business hours and kept to a maximum length of one hour. Briefings should also be provided annually on the current state of coral bleaching and climate change science; the expected impacts to Guam's coral reef resources and its citizens; management actions currently underway to minimize the impacts of coral bleaching; and recommended management and policy actions for future implementation.

Additional outreach activities may include:

- Distribution of posters, factsheets, and other printed materials at community events
- Announcements about bleaching risk published in the *Guam Daily Post* and *Pacific Daily News*
- Distribution of printed materials, videos, and other bleaching-related media to the military's morale, welfare, and recreation programs
- Dissemination of materials that encourage voluntary participation in temporary no-take zones, encourage reduced recreational use of stressed reefs, and request limits to off-roading near reefs that are exposed to thermal stress

Communication strategy evaluation

Social surveys may be useful to measure the effects of bleaching-related communication and outreach activities, such as EoR or community meetings. Outreach efforts should use social marketing to instigate behavior changes. This includes increasing awareness of local impacts on coral reefs with the aim of eliminating behaviors that contribute to coral reef stress during bleaching events (e.g. offroading, which contributes to erosion and sedimentation, and thus increases coral stress). The impacts of such campaigns could be quantified through assessments of attitudes, knowledge, and behaviors. Surveys of community members following a bleaching event could also be conducted to measure the reach and impact of media outreach and communications related to bleaching response; these surveys could be integrated into post-bleaching socioeconomic assessments.

Recommendations

There are currently no viable management actions at the disposal of local resource managers for direct mitigation of the impacts of mass coral bleaching events. However, perhaps the most important management actions related to climate change and coral bleaching are those that deal instead with local impacts by ensuring that coral reef ecosystems are as healthy as possible, which will speed recovery following the coral mass mortality associated with bleaching. Coral reef managers can also implement temporary measures to minimize certain anthropogenic impacts during periods of known thermal stress, such as restricting entry to areas known to host susceptible coral communities.

The challenge of reducing GHG emissions is a global-scale problem that needs to be addressed through international coordination among all levels of government. Even if GHG emissions ceased immediately, SST is still expected to rise as a result of the lag between the change in atmospheric GHG concentrations and consequent changes in atmospheric and oceanic temperatures. Global average SST is expected to increase by 0.4-1.1^{o} C by 2025 (IPCC 2014). Within 40 years, 95% of all coral reefs are expected to experience severe bleaching on a near annual frequency (Burke et al. 2011), which may lead to the loss of a significant portion of the world's coral reef resources.

Recommendations to improve the effectiveness of Guam's coral bleaching response activities and natural resource management to increase resilience of Guam's coral reef ecosystems include:

Survey methods and data sharing

- Maintain detailed, descriptive records of all response activities and data collected on coral bleaching events. Make these records easily accessible to members of the Coral Reef Response Team and other stakeholders.
- Establish a permanent monitoring program of staghorn colonies around the island, as these species have demonstrated high susceptibility to thermal stress and coral bleaching.
- Develop a system for coordinated reef surveys, with maximum coverage of reef sites, types, and taxa groups, to be conducted by citizen scientists in GCCRMP, EoR, and NPS CoralWatch.
- Compile data collected in situ and provide to NOAA CRW (e.g. through ReefBase) to validate CRW products. Interpret local data according to projections to assess accuracy of bleaching outlooks and improve Guam's early warning system for future events.
- Share data and resources with researchers and reef managers in CNMI.
- Consider the cost-benefit of investing in novel surveying technologies, such as unmanned aerial vehicles (drones).

Areas for future research

- Identify and classify Guam's reefs according to resilience levels. Evaluate the thermal stress thresholds of specific reefs and taxa. Determine which reefs, and which taxa, are most and least resilient to coral bleaching. Prioritize reefs to be protected. Conservation of reefs that have high tolerance to thermal stress may create a refugia network capable of providing coral larvae to degraded reefs that are less resilient to warming (Marshall and Schuttenberg 2006).
- Conduct research that increases understanding of the susceptibility of Guam's corals to synchronous occurrence of coral bleaching and disease outbreaks. Evaluate which corals may be more likely to succumb to disease if bleached, and those that may be more likely to bleach if impacted by disease.

- Study the relationship between coral bleaching and outbreaks of the corallivorous gastropod *Drupella cornus*, which may receive chemical cues from stressed corals. Consider utilizing participants in Guam's community-based outreach programs to physically remove *Drupella* from reefs if an outbreak occurs following a bleaching event.

Natural resource management

- Implement interagency projects that reduce local stressors to Guam's reefs, such as land-based sources of pollution (LBSP) and heavy fishing pressure, which will improve the health of local coral reef ecosystems and increase their resilience to coral bleaching and other impacts of global climate change. These initiatives should be tied to Guam's Local Action Strategies (LAS) and their associated working groups. Impacts from coral bleaching could be reduced if local anthropogenic impacts lessened during bleaching events. Restricting access by recreational users within the preserves during bleaching events may also reduce stress and increase resilience to bleaching.
- Conduct "lessons learned" meetings with all personnel involved in response activities following each response. Continuously update the beaching response plan to reflect new scientific findings and improve the efficiency of the early monitoring system, SOPs, and data collection protocols. The bleaching plan should be updated, and agreed upon by all members of the Guam Coral Reef Response Team, every two years.
- Investigate the feasibility of novel, active responses to mitigate coral bleaching, such as shading; using sprinklers to increase capillary waves to decrease light; and heterotrophic feeding of corals to compensate for decreased nutrition due to zooxanthellae loss. These experimental approaches may be piloted in small areas, such as Guam's coral nursery or on a reef with an abundance of threatened and/or resilient coral taxa.
- Establish an interagency GovGuam scientific diver program and dive board to ensure dive reciprocity among agencies and increase efficiency of response activities.

Reef recovery and restoration

- Continue development of Guam's coral nursery. Transplant fragments and/or breed coral colonies that have survived bleaching and thus may be more resilient to future bleaching events. Protect the nursery during bleaching events with shading and/or water movement.
- Develop methods and capacity to scale up restoration work on Guam. This may include adding additional nursery sites and developing techniques to increase production of corals for outplanting such as sexual propagation, tile development and installation methods, and micro-fragmenting.
- Train community members in restoration techniques.

Funding for response activities

In the past, funding of bleaching response activities on Guam has been largely opportunistic, as most grant-makers are unlikely to fund activities that are contingent upon the uncertain occurrence of a large-scale climatic event. Planning for bleaching response in advance is challenging, given that the frequency and severity of bleaching events is still largely unpredictable. Furthermore, agency resources, personnel, and leadership are often in flux.

The largest expenditure for coral bleaching response on Guam is vessel time. Personnel availability is also a limiting resource. It may be possible to include funding for bleaching response in grant proposals if the activities are framed as training or capacity building. The funds will be used to support response activities if a bleaching event occurs during a given grant cycle, but if bleaching does not occur, the money will be spent on training for the Coral Bleaching Response Team and other stakeholders in order to prepare for expected future events.

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Appendices

APPENDIX I: Interagency MOU for the Guam Coral Reef Response Team (2016)

GUAM CORAL REEF RESPONSE TEAM

MEMORANDUM OF UNDERSTANDING
AMONG THE BUREAU OF STATISTICS AND PLANS, THE DEPARTMENT OF AGRICULTURE, THE GUAM ENVIRONMENTAL PROTECTION AGENCY, AND THE UNIVERSITY OF GUAM

FOR ACTIVITIES OF THE GUAM CORAL REEF RESPONSE TEAM WITHIN THE CORAL REEF INITIATIVE

The Bureau of Statistics and Plans (BSP), the Department of Agriculture (DOAG), the Guam Environmental Protection Agency (GEPA), and the University of Guam (UOG) enter into this Memorandum of Understanding (MOU) for the purpose of formalizing the activities to be carried out by the Guam Coral Reef Response Team. This MOU is based on the following statements of purpose and delineation of responsibilities. The term of this MOU will become effective once signed and remain in effect indefinitely from the date of signature.

The Coral Reef Response Team will be responsible for responding to acute coral reef impacts such as bleaching events, coral disease outbreaks, invasive species, vessel groundings, oil spills, and outbreaks of nuisance species such as *Acanthaster planci*, the crown of thorns starfish, on Guam, as part of the Guam Coral Reef Initiative (CRI). Members of the Coral Reef Response Team will include representatives from BSP, DOAG, GEPA, and UOG. When needed, the Coral Reef Response Team will consult and cooperate with US federal partner agencies, such as the National Oceanic and Atmospheric Administration (NOAA), Department of Defense (DoD), US Coast Guard, US Fish & Wildlife Service (USFWS), and the National Park Service (NPS).

RESPONSIBILITIES

The Bureau of Statistics and Plans (BSP) agrees to:

1. Coordinate the meetings and activities of the Coral Reef Response Team from 2016 to 2017.
2. Host at least one training, workshop, or exercise per year in 2016 and 2017 for members of the Coral Reef Response Team.
3. Provide Standard Operating Procedures to guide the activities of the Coral Reef Response Team.
4. Finalize the Guam Reef Resilience Strategy, which will include the reef impact Standard Operating Procedures and management recommendations.
5. Provide at least one representative to the Coral Reef Response Team from the Guam Coastal Management Program (GCMP). The representative will attend all meetings, provide guidance and technical assistance, and serve in a leadership capacity if needed.
6. Assist with public outreach, collection of data on coral reef ecosystem health, and documentation of response activities.

The Department of Agriculture (DOAG) agrees to:

1. Provide at least one representative to the Coral Reef Response Team. The representative will participate in response activities; attend all meetings, trainings, and workshops; provide guidance and technical assistance; and serve in a leadership capacity if needed.
2. Contribute input on Standard Operating Procedures (SOPs) for responding to acute impacts.
3. Contribute feedback on draft Guam Reef Resilience Strategy during 2016 to 2017.
4. Assist with public outreach, collection of data on coral reef ecosystem health, and documentation of response activities, including, when possible, provision of access to collect data before and after bleaching events during aerial surveys conducted by DOAG Division of Aquatic and Wildlife Resources (DAWR).

The Guam Environmental Protection Agency (EPA) agrees to:

1. Provide at least one representative to the Coral Reef Response Team. The representative will participate in response activities; attend all meetings, trainings, and workshops; provide guidance and technical assistance; and serve in a leadership capacity if needed.
2. Contribute input on Standard Operating Procedures (SOPs) for responding to acute impacts.
3. Contribute feedback on draft Guam Reef Resilience Strategy during 2016 to 2017.
4. Assist with public outreach, collection of data on coral reef ecosystem health, and documentation of response activities.

The University of Guam (UOG) agrees to:

1. Provide at least one representative to the Coral Reef Response Team from the UOG Marine Laboratory. The representative will participate in response activities; attend all meetings, trainings, and workshops; provide guidance and technical assistance; and serve in a leadership capacity if needed.
2. Contribute input on Standard Operating Procedures (SOPs) for responding to acute impacts.
3. Contribute feedback on draft Guam Reef Resilience Strategy during 2016 to 2017.
4. Assist with public outreach, collection of data on coral reef ecosystem health, and documentation of response activities.

ALTERATION OF TERMS OR ENTIRE AGREEMENT

The body of this MOU expresses the understanding of the signatories concerning all matters covered and shall constitute a total agreement. No alteration of this MOU, whether by written or verbal understanding of the signatories or the members of the Coral Reef Response Team, shall be valid unless made in the form of a written amendment to this MOU, which is formally approved and executed by the participating agencies.

AMENDMENTS

In the event that one or more participating agencies wish to amend the terms of this MOU, all participating agencies will comply with the terms of this MOU until such time as the amendment is agreed upon and approved in writing by all signatories.

CONCURRED:

William M. Castro, Director, Bureau of Statistics and Plans	MAR 03 2016 Date
Mathew L.G. Sablan, Director, Department of Agriculture	3/4/16 Date
Eric Palacios, Administrator, Guam Environmental Protection Agency	03/04/16 Date
For Dr. Terry J. Donaldson, Director, UOG Marine Laboratory	3/4/2016 Date
Dr. Robert A. Underwood, President, University of Guam	3/8/2016 Date

APPENDIX II: NOAA CREP data sharing recommendations

Data Sharing Recommendations

Thank you for your interest in NOAA Coral Reef Ecosystem Program (CREP) data. We welcome the opportunity to collaborate with you and your organization on research issues contributing to the scientific basis for better management of our marine ecosystems. As you may know, CREP has a very diverse set of field activities that generates large volumes of data using an array of data collection protocols. The following recommendations are for your consideration as you use this data:

1. Data analyses should take all field exigencies into account. The most effective way to do this would be active collaboration with CREP principal investigators.
2. In all presentations, product releases, or publications using data generated by CREP, proper acknowledgement of both CREP and the individuals responsible for data collection is expected. Citing the DOI (if available) is preferred, a non-DOI example citation is listed below.
3. If you collect or generate data for the same study areas, CREP requests that you share relevant information on complimentary data collections.
4. Those receiving data are strongly urged to inform the CREP Data Management team of any errors and discrepancies that are discovered during the course of using these data. They are further urged to bring to the attention of the team all problems and difficulties encountered in using these data. This information is necessary in order to improve the data collections and to facilitate more efficient and economical data processing and retrieval. The users are asked to supply copies of any missing data that may be located, and to provide information as to significant subsets and special aggregations of data that are developed in using the material provided.

Thank you again for your interest in CREP and your assistance in our efforts to better manage our living marine resources.

Example citation:

"This publication makes use of data products provided by the Coral Reef Ecosystem Program (CREP), Pacific Islands Fisheries Science Center (PIFSC), National Marine Fisheries Service (NMFS), National Oceanic and Atmospheric Administration (NOAA), with funding support from the NOAA Coral Reef Conservation Program (CRCP). The analysis and interpretations presented here are solely that of the current authors"

APPENDIX III: Sample press release for local media

Guam's coral reefs expected to reach coral bleaching alert level 1 next week
Press release – 29 July 2016

Reports from the Great Barrier Reef and across the Pacific Islands have drawn public attention to the devastating impacts of coral bleaching. When coral reefs are subjected to increased water temperature, extreme low tides, and calm, clear weather, coral polyps (the individual coral animals that contribute their skeletons to building reef habitats) eject the algae that live inside them. Normally, these algae – called zooxanthellae – provide the corals with the majority of the energy they need to grow and reproduce. However, when temperatures rise and light intensifies, the zooxanthellae become toxic to the corals. The corals then appear "bleached" because it is the zooxanthellae that lend them their bright colors. Bleached corals that have ejected their algae can survive and recover if conditions improve, but they are weak and vulnerable without their zooxanthellae. If temperatures remain elevated, many corals will die. Coral reefs are built very slowly by individual coral polyps, thus the increased frequency of coral bleaching events due to global climate change is a major threat to these valuable ecosystems.

Guam's reefs are currently facing a coral bleaching warning and we are expected to reach bleaching alert level 1 by next week, according to the latest outlook released by the National Oceanic and Atmospheric Administration (NOAA) Coral Reef Watch (CRW) program. Within the next five to eight weeks, the bleaching outlook is predicted to reach alert level 2. At alert level 1, coral bleaching is likely to occur, and at alert level 2 – the highest level – coral death is likely. Guam's coral reefs were affected by mass coral bleaching in both 2013 and 2014. Approximately 85% of Guam's coral types bleached in 2013. By 2014, about half of Guam's branching staghorn corals were lost due to combined effects of these bleaching events. Further details on Guam's bleaching alert status can be found on the NOAA CRW website: http://coralreefwatch.noaa.gov/satellite/index.php.

Currently, members of Guam's Coral Reef Response Team – which includes the Bureau of Statistics and Plans (BSP) and the Guam Coastal Management Program (GCMP), Guam Environmental Protection Agency (GEPA), Guam Department of Agriculture Division of Aquatic and Wildlife Resources (DAWR), the University of Guam Marine Laboratory (UOGML), US National Parks Service (NPS), NOAA, Joint Region Marianas (JRM), and the U.S. Fish & Wildlife Service (USFWS) – are surveying Guam's reefs to understand the potential severity of this projected bleaching event. Mild to moderate coral bleaching has already been detected in Pago Bay, Piti, Agat, and Tumon Bay. Over the coming weeks, the response team will continue to survey Guam's reefs to measure the extent of the coral bleaching and determine which of our coral species and reef sites are most vulnerable – and which are most likely to survive and recover.

In order to increase Guam's ability to respond to bleaching, over 60 private citizens have participated in Eyes of the Reef (EOR) training sessions, where attendees learn to identify reef impacts, such as coral bleaching, and report these impacts online at EORMarianas.org. There are many upcoming training dates scheduled for August and September. If you are interested in attending a training session or learning more about what you can do to protect Guam's reefs during coral bleaching, visit the EOR website, email eormarianas@gmail.com, or call 646-1905.