Guam Coral Reef Resilience Strategy

June 2019

Overview

The **Guam Coral Reef Resilience Strategy (GRRS)** was developed collaboratively by the Guam Coral Reef Initiative, which includes partners from local and federal agencies, research institutions, non-profit organizations, and the private sector. **The goal of the GRRS is to enhance the resilience of Guam's coral reef ecosystems and human communities to the impacts of climate change by 2025.** The GRRS is a tool for adaptive, strategic management; an opportunity to engage and inform key stakeholders; a mechanism to increase effectiveness of coral reef management; and a guide for funding projects designed to reach a common goal. The GRRS is intended to be a living document and thus frequently updated.

The GRRS replaces the Guam Coral Reef Local Action Strategies (LAS) and Guam's Coral Reef Management Priorities for 2010-2015, the latter developed cooperatively by the Territory of Guam and the NOAA Coral Reef Conservation Program (CRCP). The Guam Reef Resilience Strategy will primarily be used by managers to guide coral reef management and conservation activities and provide justification for grant proposals and other funding requests. 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 seeking to address the impacts of both local stressors and global climate change on local reef systems.

The GRRS has four primary objectives:

1. Reframe Guam's coral reef management efforts and priorities in the context of coral reef resilience
2. Increase cooperation among local and federal agencies, decision makers, educational institutions, non-governmental organizations, resource users, communities, and business groups
3. Prioritize implementation of coral reef management interventions
4. Shift from reactive efforts to proactive, adaptive coral reef management

The target audience of the GRRS includes:

- All Government of Guam and federal agencies that work directly or indirectly in coral reef management and/or conduct activities that may impact Guam's coral reef ecosystems
- Elected and appointed officials and other key decision makers
- Non-governmental organizations and community groups
- Private entities and other stakeholder groups that conduct activities that impact and/or rely upon coral reef ecosystems, including the tourism industry and the fishing community
- Grant makers and foundations

GUAM CORAL REEF INITIATIVE

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- Guam Visitors Bureau

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Acronyms

ADT = Adaptation Design Tool under CCAP project
BMP = Best management practice
BSP = Guam Bureau of Statistics and Plans
CCAP = Corals & Climate Adaptation Planning project
C^{3}PR = Guam Council on Climate Change Preparedness and Resiliency
CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act of 1980
CIA = Central Intelligence Agency
CIS = Center for Island Sustainability at UOG
CITES = Convention on International Trade in Endangered Species of Wild Fauna and Flora
CNMI = Commonwealth of the Northern Mariana Islands
COTS = Crown of thorns sea star (*Acanthaster planci*)
CRCA = Coral Reef Conservation Act of 2000
CRCP = Coral Reef Conservation Program within NOAA
CRI = Guam Coral Reef Initiative
CRICC = Guam CRI Coordinating Committee
CRIPAC = Guam CRI Policy Advisory Committee
CRTF = US Coral Reef Task Force
CWA = Clean Water Act of 1972
DAWR = Guam Department of Wildlife Resources within DOAG
DLM = Guam Department of Land Management
DOAG = Guam Department of Agriculture
DOD = US Department of Defense
DPR = Guam Department of Parks and Recreation
DPW = Guam Department of Public Works
EFH = Essential fish habitat
EO = Executive order
EOR = Eyes of the Reef Marianas
EPA = US Environmental Protection Agency
ESA = Endangered Species Act of 1973
FOR Guam = Friends of Reefs Guam
FSRD = Forestry and Soil Resources Division within DOAG
FWCA = Fish and Wildlife Coordination Act of 1934
GAR = Guam Administrative Rules and Regulations
GCA = Guam Code Annotated
GCC = Guam Community College
GCMP = Guam Coastal Management Program within BSP
GCRI = Guam Coral Reef Initiative
GEDA = Guam Economic Development Authority
GEPA = Guam Environmental Protection Agency
GHRA = Guam Hotel and Restaurant Association
GRRS = Guam Coral Reef Resilience Strategy
GSWA = Guam Solid Waste Authority
GVB = Guam Visitors Bureau
GWA = Guam Waterworks Authority
LAC = Limits of Acceptable Change
LAS = Guam's coral reef Local Action Strategies
LBSP = Land-based sources of pollution
MDA = Micronesian Divers Association
MP = Marine preserve
MSA = Magnuson-Stevens Fishery Conservation and Management Act of 1976
NAVFAC = Naval Facilities Engineering Command
NEPA = National Environmental Policy Act of 1970
NMFS = National Marine Fisheries Service within NOAA
NOAA = National Oceanic and Atmospheric Administration
NPDES = National Pollutant Discharge Elimination System
NPS = National Park Service
NRCS = Natural Resources Conservation Service within the USDA
NRDA = Natural resource damage assessment
OPA = Oil Pollution Act of 1990
PL = Public law
POC = Guam Coral Reef Point of Contact
RCRA = Resource Conservation and Recovery Act of 1976
UOG = University of Guam
UOGML = University of Guam Marine Laboratory
USCG = U.S. Coast Guard
USDA = U.S. Department of Agriculture
USFWS = U.S. Fish and Wildlife Service
UWW = Underwater World
WERI = Water and Environmental Research Institute of the Western Pacific at UOG
WestPac = Western Pacific Regional Fishery Management Council
WTP = Willingness to pay

CHamoru words

FISHES		
English name	**CHamoru name**	**Scientific name**
Juvenile goatfish	Ti'åo	Mullidae
Juvenile jack (trevally)	I'i'	Carangidae
Juvenile rabbitfish (< 5 cm)	Mañåhak	Siganidae
Adult rabbitfish	Sesjun	Siganidae
Convict tang	Kichu	*Acanthurus triostegus*
Unicornfish	Tataga'	*Naso unicornis*
Naso tang	Hangon	*Naso literatus*
Humphead wrasse	Tangison	*Cheilinus undulatus*
Bumphead parrotfish	Atuhong	*Bolbometopon muricatum*

INVERTEBRATES		
English name	**CHamoru name**	**Scientific name**
Trochus snail	Aliling	*Trochus niloticus*
Giant clam	Hima	*Tridacna* spp.
Coconut crab	Ayuyu	*Birgus latro*
Sea cucumber	Balåte'	Holothuroidea
Christmas tree worm	Ulo'	*Spirobranchus* spp.
Blue sea star	Puti'on tasi	*Linckia laevigata*

FISHING METHODS AND GEAR	
English name	**CHamoru name**
Cast net	Talåya
Drag net/seine	Chenchulon ma hålla
Surround net	Chenchulon ma sugon
Trap net	Chenchulon ma mongle
Butterfly net	Chenchulon ababbang
Gill net	Tekken

These CHamoru words and spellings were garnered from local language experts, existing Guam statutes, and Kerr 2012.

Background

Despite the immense value of Guam's coral reefs and their associated ecosystem services, Guam's reefs are experiencing rapid decline due to combined local stressors and the impacts of global climate change. As a result, local coral reef managers and scientists are focused on implementing adaptive management interventions based on the best available science to reduce local pressures and increase coral reef resilience to climate change. Guam's five desired outcomes for coral reef management are: (F) effective fisheries management; (P) decreased land-based sources of pollution; (RR) increased reef response and restoration; (RU) sustainable recreational use and tourism; and (H) human community resilience and climate change adaptation.

Value of Guam's coral reefs

More than 5,100 species inhabit Guam's coastal waters, including nearly 400 species of stony corals and over 1,000 nearshore fishes (Paulay 2003, Porter et al. 2005). In addition to the value of their biodiversity, coral reefs provide and support numerous ecosystem services, including commercial and subsistence fisheries, tourism, coastal protection, research and education opportunities, and support for social and cultural activities (Laurans et al. 2013). In the past, nearshore fishing provided a large portion of the CHamoru diet on Guam (Amesbury and Hunter-Anderson 2003). Although locally-caught fish are no longer a significant source of food for most residents, Guam's coral reefs are still used for subsistence fishing, some commercial fishing, and recreation by both locals and tourists (Burdick et al. 2008).

Calculating the monetary value of an ecosystem is complex and, in many cases, controversial; however, these valuations provide important metrics for natural resource managers and decision makers. In 2007, the total economic value of Guam's coral reefs was estimated at $169 million per year (adjusted to 2018 dollars; van Beukering et al. 2007). This figure incorporates six key ecosystem services of coral reefs: tourism, recreation, commercial fisheries, coastal protection, research, and amenity. About 75% of this value ($127 million, in 2018 dollars) was attributed to tourism (van Beukering et al. 2007). The Atlas of Ocean Wealth, produced by The Nature Conservancy (TNC) in 2016, appraised Guam's coral reef resources at a higher rate, indicating that the annual value of Guam's reefs from reef-based tourism alone is $323 million USD per year (Spalding et al. 2016).

Today, tourism is the largest industry on Guam, providing over 18,000 jobs and 60% of the island's yearly business revenue (Guam Visitors Bureau (GVB) 2014). In 2016, over 1.5 million visitors came to Guam and spent over $1.5 billion on the island (GVB 2017). This represents an almost 25% increase in annual visitor arrivals since 2007 (GVB 2011). According to exit surveys, over 30% of Guam's visitors cite the marine environment as a top reason for visiting the island (GVB 2018). Given this increase in visitor arrivals and spending, and the importance of Guam's coral reef and associated activities for the tourism industry (snorkeling, diving, etc.), the economic value of Guam's reefs has presumably increased in the last decade, although there has not been a formal assessment since 2007. GVB hopes

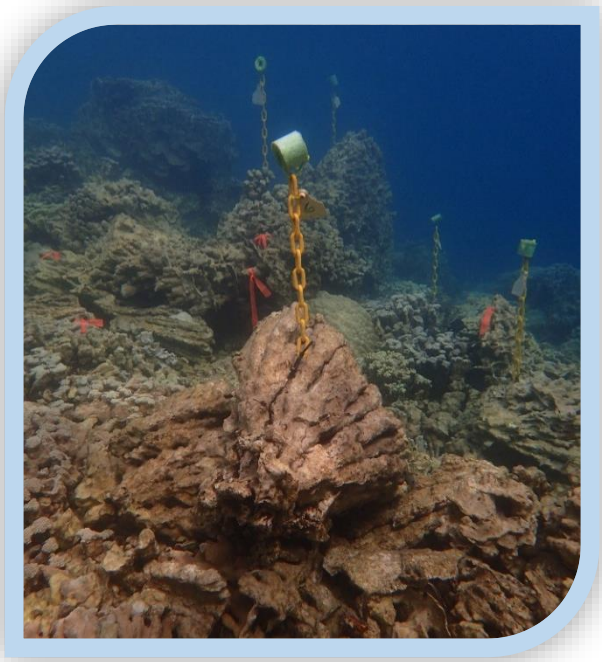
to attract two million annual visitors to Guam by 2020 (GVB 2014). Additionally, as coral cover has declined significantly in recent years due to impacts such as crown of thorns sea star (COTS) predation and warming-induced coral bleaching, each remaining square meter is increasingly valuable.

Reef quality is important to many tourists, especially divers. Environmentally conscious divers have greater willingness to pay (WTP) for higher reef quality; more abundant and diverse fish populations with larger individuals; the opportunity to see charismatic species; and diving in marine protected areas (Grafeld et al. 2016). Reef users are more willing to pay fees to visit healthy coral reefs; a fee for divers and/or snorkelers could be used on Guam to fund management and conservation through tourism (Grafeld et al. 2016). A survey of over 200 individuals (76% visitors, 24% residents) who participated in scuba diving on Guam's reefs in 2013 found that 46% of the divers had strong preferences for reefs with greater fish biomass and larger fish, especially sharks (Grafeld et al. 2016). The study found that divers' WTP increases for reefs with greater biomass, diversity, and abundance of charismatic megafauna such as sharks, turtles, and Napoleon wrasse (*Cheilinus undulatus*) (Grafeld et al. 2016). Based on the estimated ~300,000 dives occurring on Guam's reefs per year (from van Beukering et al. 2007), greater fish biomass could increase total WTP by $3.4-4.5 million, while decreased biomass in preserves could reduce diver WTP by $1 million (Grafeld et al. 2016).

Threats facing Guam's reefs

Although coral reefs have survived for 500 million years, their continued existence is at risk due to increasing human impacts. Around one fifth of all coral reefs have already been lost and over one quarter of surviving reefs are in danger of imminent decline (Wilkinson 2006; Riegl et al. 2009). Guam's coral reef ecosystems face an array of threats, encompassing both local stressors and the impacts of global climate change and ocean acidification.

The shallow nearshore waters surrounding Guam host approximately 108 km^2 of coral reef habitat, with an additional 110 km^2 of reef area located greater than 3 nautical miles offshore (Burdick et al. 2008). The health of these reefs has deteriorated in recent decades, indicated by overall downward trends in coral cover, coral recruitment rates, and fish biomass. Coral cover on Guam's seaward slopes has decreased by approximately 80% in the last half century, with mean coral cover declining from about 50% in the 1960s to 10% since 2009, based on local studies and data collected by NOAA (Randall 1971, Burdick et al. 2008, Burdick 2016). Two studies conducted on coral recruitment on Guam's reefs in 1979 and 1992, using similar methodologies, recorded the number of coral recruits that settled on PVC tiles; the mean number of recruits was 98% less in 1992 compared to 1979 (Birkeland et al. 1981, Birkeland 1997). Creel surveys conducted by the Division of Aquatic and Wildlife Resources (DAWR) within the Guam Department of Agriculture (DOAG) indicate that mean total annual catch declined by 63% between 1985 and 2012, while reconstructions of historical biomass of target fish species showed that fish biomass decreased by around 65% during this period (Weijerman et al. 2016).



The growing population has increased the strain on Guam's coral reef resources. The island, which has a total land area of 544 km^2 and 125.5 km of coastline, is home to over 167,000 people, with a density of about 300 people per km^2 (Central Intelligence Agency (CIA) 2017). This equates to over 1,500 people per km^2 of coral reef. Sandin et al. (2008) found that reefs surrounding densely populated islands had lower fish biomass, fewer top predators, less coral cover, and greater abundance of fleshy macroalgae. In addition to the stress on local reefs from Guam's inhabitants, the tourism industry is booming; over 1.5 million visitors came to the island in 2016 and two million annual visitors are expected by 2020 (GVB 2014, 2017). The increase in human inhabitants and visitors means Guam's reefs are subjected to greater impacts from pollution and runoff, coastal development, and recreational activities.

Guam's coral reefs have experienced severe degradation in the past; however, reefs were able to recover from acute impacts. In the early 1970s, a crown of thorns sea star (COTS) outbreak resulted in declines from 50-60% coral cover to less than 1% coral cover on some reefs; surveys conducted twelve years later found that coral cover had recovered to over 60% (Colgan 1987). Now, chronic local stressors such as poor water quality, sedimentation, and heavy fishing pressure threaten reef health and impede the ability of Guam's reefs to recover from events like COTS outbreaks, severe storms, and coral bleaching (Burdick et al. 2008). Other local stressors facing Guam's reefs include vessel groundings and associated oil and chemical spills; recreational use and misuse; marine debris; dredging; outbreaks of invasive and nuisance species; and coral diseases.

Fishing pressure and loss of herbivores

Globally, 83% of fished coral reefs have less than half of the expected fish biomass of unfished reefs, making fishing the leading cause of decreased reef function (MacNeil et al. 2015). The health of Guam's reefs has been severely impacted by fishing pressure. A meta-analysis of over 832 coral reefs in 64 localities found that only two localities had fish biomass low enough to indicate fisheries collapse: Papua New Guinea and Guam (MacNeil et al. 2015).

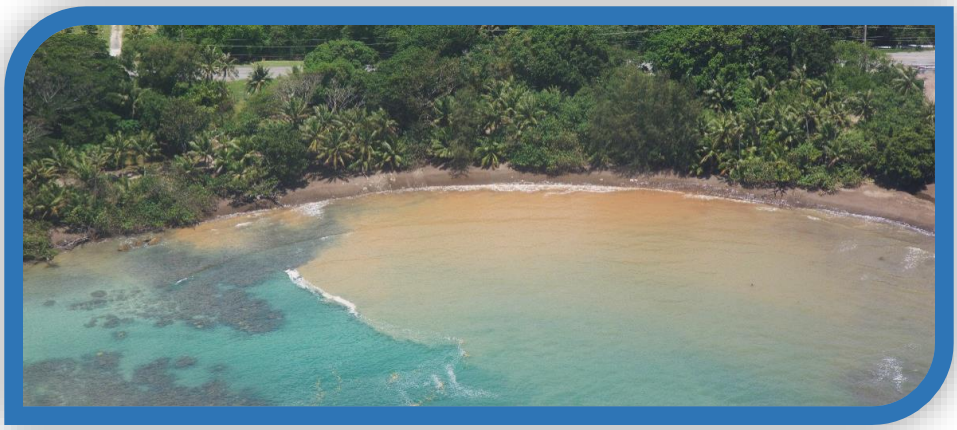
NOAA surveys conducted in 2011 recorded median reef fish biomass around Guam at 20.6 g/m^2 (Williams et al. 2012). Williams et al. (2015) indicated that coral reef fish biomass on Guam's reefs was 66% lower than the predicted biomass if there were no human impacts present. Without the impacts of fishing, the mean expected fish biomass on a coral reef is approximately 100 g/m^2 (MacNeil et al. 2015). It is important to note that the baseline fish biomass of a "pristine" reef system varies according to numerous biological and oceanographic factors; thus, comparing Guam's current fish stocks with a global expected average must be done cautiously.

Data collected during DAWR creel surveys reveal decreased herbivore catch rates in recent decades, signifying decreased biomass of these fishes (Weijerman et al. 2013). Herbivorous fishes (e.g. parrotfish, surgeonfish, rabbitfish, unicornfish) are vital to the health of coral reef ecosystems as they consume the algae that could overgrow reefs if left unchecked, and they create available substrate for coral growth and settlement (Mumby et al. 2013, Rasher et al. 2013, MacNeil et al. 2015). Greater herbivore biomass is correlated with lower macroalgae abundance, while reefs with lower herbivore biomass and higher macroalgae cover have fewer coral recruits (Williams and Polunin 2000, Hughes et al. 2007, Mumby et al. 2007b). Coral reef health may be especially susceptible to declines in parrotfish abundance and herbivores overall are very sensitive to fishing pressure (Mumby et al. 2007b, Mumby et al. 2013). Intact reef fish communities and herbivore abundance are important for preventing phase shifts from coral-dominated to algal-dominated systems and promoting reef recovery after disturbance (Hughes et al. 2007, Mumby et al. 2007a).

DAWR creel surveys indicate that Guam's coral reef fisheries have not yet recovered following a steep decline during the 1980s (Burdick et al. 2008). Catch data show that Guam's coral reefs have high fishing pressure, declining fish stocks, and decreased reef ecosystem function (Houk et al. 2012). Fishing methods commonly used on Guam's reefs include spear fishing (while free diving and scuba diving), hook and line, bottom fishing, jigging, spincasting, trolling, hook and gaff, and several types of nets: cast nets (*talaya*), gill nets (*tekken*), drag nets (*chenchulu*), and surround nets (Burdick et al. 2008). In addition to heavy fishing pressure, the use of particular fishing methods and gear (e.g. night-time scuba spearfishing with artificial light and monofilament gill nets) may be contributing to fishery declines and reef degradation; these methods are still legal on Guam, although they have been banned on many other Pacific Islands (Burdick et al. 2008). These fishing methods may have resulted in shifts in fish community composition on Guam's reefs from large, slow-growing fishes to small, fast growing species; unsustainable harvest of Napoleon wrasse (*Cheilinus undulatus*); and decreased stocks of other large wrasses, snappers, groupers, and parrotfishes (Houk et al. 2018). Additionally, derelict gill nets, which are regularly found by DAWR conservation officers, kill fish and damage corals (Flores 2006, Burdick et al. 2008). The decline of populations of large, slower-growing parrotfishes is of particular concern due to the vital role these species play in reducing macroalgae abundance and maintaining coral-dominated reef habitats.

Guam has five marine preserves covering 33.1 km^2 of nearshore marine waters, which were established in 1997 and enforced beginning in 2001 (Burdick et al. 2008). One of the marine preserves (Sasa Bay) is strictly no-take, while the others permit cultural fishing practices and/or hook-and-line fishing from shore (Burdick et al. 2008). Guam's marine preserves have greater fish biomass overall than reefs without fishing restrictions, particularly for parrotfishes and surgeonfishes, although there is no significant difference in the benthic community (coral cover,

algae cover, or topographic complexity) for marine preserves compared to unprotected reefs (Williams et al. 2012). Unfortunately, poaching is common in Guam's marine preserves as there are insufficient resources and manpower for consistent enforcement island-wide. In addition to lack of enforcement, one of the greatest challenges to effective fisheries management on Guam is the lack of reliable scientific data to inform management initiatives and guide policy efforts (Houk et al. 2012).



Land-based sources of pollution (LBSP)

LBSP include illegal dumping and runoff of storm water, waste water, fertilizers, and sediment from construction sites; erosion due to fires and recreational off-roading; and urban areas dominated by impervious surfaces. The main pollutants that impact Guam's nearshore waters and beaches are hydrocarbons, microbes, and sediment (Burdick et al. 2008). Sedimentation, caused by severe upland erosion, is one of the greatest threats to Guam's coral reef ecosystems (Gawel 1999, Burdick et al. 2008). Excessive sediment and eutrophication can reduce light availability for primary production by coral symbionts; smother corals and other benthic organisms; increase coral disease prevalence; inhibit coral reproduction; and impact the settlement, recruitment, and survival of coral larvae (Ward and Harrison 1997, Gilmour 1999, Wolanski et al. 2003, Haapkylä et al. 2011, Erftemeijer et al. 2012, Junjie et al. 2014, Jones et al. 2015).

In northern Guam, LBSP are discharged through freshwater seeps linked to drainage basins, storm water outfalls, and the Northern District Wastewater Treatment Plant outfall. These impacts have been documented in Agana Bay and Tumon Bay (Moran and Jenson 2004, Denton et al. 2005, Redding et al. 2013). Although the shoreline surrounding the Tumon Bay Marine Preserve is highly developed, there is no comprehensive storm water management plan for the area. Construction of new hotels and practices by existing hotels (e.g. heavy fertilizer use) are likely impacting water quality and coral reef health in Tumon Bay, the island's tourist center. In Apra Harbor, developments by the US Navy and Port Authority of Guam may be affecting water quality and reef communities (Burdick et al. 2008).

Sedimentation and decreased water quality from runoff and freshwater inputs are especially concerning for reefs along Guam's southwestern coast. Towed diver surveys conducted by NOAA in 2005 found that coral cover was over 50% higher on northeastern, northwestern, and southeastern reefs compared to reefs in the southwest (Pacific Islands Fisheries Science Center (PIFSC) 2006, Burdick et al. 2008). Guam's southwestern reefs have less coral cover and crustose coralline algae (CCA), greater abundance of non-calcifying algae, lower fish biomass, and higher turbidity compared to other parts of the island (Williams et al. 2012). The original drivers of this relatively low coral cover may be COTS outbreaks and a road construction project during the early 1990s that resulted in sedimentation

and widespread coral loss along the southwest coast (Turgeon et al. 2002, Burdick et al. 2008). Additionally, reefs in this area are subjected to chronic poor water quality due to riverine inputs (Burdick et al. 2008).

Numerous studies indicate that sedimentation is having detrimental effects on coral reef health in southwestern Guam (Minton 2005, Rongo 2005, Minton et al. 2007, Richmond et al. 2007). Although Guam's southern reefs may be accustomed to higher sediment loads than northern reefs because of their proximity to rivers, it is likely that the extremely poor health of reefs in this area is largely due to increased erosion and sedimentation driven by human activities, such as accidental fires and arson; poorly planned construction of roads and buildings; clearing of forested lands; grazing by wild pigs and deer; and recreational off-roading (Burdick et al. 2008).

High nutrient loads have been linked to increased abundance of nuisance species and prevalence of coral diseases. Although the exact drivers of COTS outbreaks are not fully understood, evidence indicates that high levels of nutrients resulting in elevated phytoplankton density (algal blooms) may increase the survival rates of COTS larvae and lead to outbreaks (Birkeland 1982, Brodie et al. 2005, Fabricius et al. 2010). This is another reason why sedimentation is a major cause for concern, as COTS outbreaks have been a major driver of coral cover loss on Guam's fore-reefs in recent years (Burdick 2016, Raymundo et al. 2018, *in review*). Marine bacteria and fungi are typically nitrogen-limited, thus nutrient enrichment may increase the abundance of these taxa, some of which are responsible for coral diseases (Bruno et al. 2003, Redding et al. 2013). Poor water quality and high nutrient concentrations can decrease coral fitness, leading to increased susceptibility to infections and bleaching (Bruno et al. 2003, Haapkylä et al. 2011, Vega Thurber et al. 2014). Other pollutants, such as plastic waste, have also been linked to increased coral disease prevalence (Lamb et al. 2018).

Recreational use and misuse

Coral reefs provide the sandy beaches and calm bays that attract tourists to Guam and also protect the coastal hotels, restaurants, and attractions they visit. However, the growing number of tourists increases the risk of impacts from recreational use and misuse on local reefs. In 2016, Guam welcomed over 1.5 million visitors with about 85% of arrivals coming from Japan (50.4%) and Korea (34.8%) (GVB 2017). In exit surveys, many Japanese and Korean visitors reported participation in reef-based activities while on Guam, such as snorkeling (19% and 27%, respectively) and scuba diving (9% and 7% respectively) (QMark Research 2016a, 2016b). This represents almost 300,000 snorkelers and over 100,000 scuba divers on Guam's reefs per year, not including local residents or visitors from outside of Japan and Korea. Many of these snorkelers and divers are inexperienced and unfamiliar with coral reef ecosystems, and thus more likely to cause abrasion or breakage by touching, kicking, or stepping on corals.

GVB aims to reach two million visitors per year by 2020 (GVB 2014). If their goal is met, this could mean almost 400,000 snorkelers and close to 150,000 divers on Guam's reefs per year from Japan and Korea alone, if the proportion of visitors from these nations and their activity preferences remain constant. In addition to snorkeling,

visitors also report engaging in various activities that both depend on and potentially impact coral reefs, including wind surfing, jet skiing, parasailing, visiting the beach, and participating in dolphin tours (QMark Research 2016a, 2016b). There are also several businesses on Guam that provide charter fishing trips and fish feeding excursions.

Although the impacts of recreational use and misuse on Guam's coral reef ecosystems are likely far less than those associated with LBSP and fishing pressure, particular high value reef areas have increased risk for damage associated with recreational use due to the number of visitors. Concerns about recreational use and misuse are greatest for the Tumon Bay Marine Preserve and the Piti Bomb Holes Marine Preserve, both of which are heavily used by both tourists and local residents. Studies on recreational use show that heavily used scuba diving and snorkeling sites may have higher rates of physical damage to corals, increased predation by the corallivorous snail *Drupella cornus*, greater prevalence of coral diseases, and decreased coral growth rates (Hawkins et al. 1999, Guzner et al. 2010, Lamb et al. 2014). A spatial analysis of human users in Tumon Bay found a strong positive correlation between human user density and the prevalence of coral damage (Hoot et al. 2017). Recreational users may also cause reef damage while operating motorized watercraft, such as jet skis, which are permitted in East Agana Bay, Apra Harbor, and Cocos Lagoon (Burdick et al. 2008). Raymundo et al. (2018) found that sites where corals suffered physical injuries due to vessel groundings had increased prevalence of coral disease.

A growing body of research identifies sunscreen as a source of chemical pollutants that damage coral reefs. Danovaro et al. (2008) found that the UV filters in sunscreen may catalyze viral infections that result in bleaching in several coral species. Oxybenzone, a UV filter found in sunscreen and other skincare products, has negative effects on coral larvae and other reef organisms, such as flatworms, diatoms, soft corals, and anemones (Downs et al. 2015, McCoshum et al. 2016). Although reef-safe sunscreens are promoted in many coastal tourist destinations, and some places, including the state of Hawaii, have outlawed sunscreens containing oxybenzone, reef-safe sunscreens are uncommon on Guam.

Impacts of climate change and ocean acidification

Anthropogenic emissions of greenhouse gases have severe implications for reef health, such as decreasing coral calcification rates caused by ocean acidification, promoting outbreaks and spread of coral diseases, and causing thermal stress that leads to coral bleaching and death (Riegl et al. 2009). Although ocean acidification poses a severe threat to coral reef ecosystems, which depend on the growth and survival of calcifying organisms, ocean warming is considered a more immediate threat to coral reefs globally, particularly in light of recent widespread coral bleaching and mortality between 2014 and 2017.

The concentration of carbon dioxide in the atmosphere is the highest it has been in 15 million years, which is warming our atmosphere and oceans (Bijma et al. 2013). From 1971 to 2010, more than 90% of the heat energy stored on this planet was absorbed by the oceans, with most warming occurring in shallow waters; in the past forty years, water temperature has increased by an average of 0.11^{o}C per decade in the shallowest 75 m of the oceans

(Intergovernmental Panel on Climate Change (IPCC) 2014). While ocean warming endangers many marine ecosystems, it is particularly threatening to coral reefs because reef-building stony corals are restricted to the relatively shallow waters where their algal symbionts (zooxanthellae) can receive sufficient light to photosynthesize and provide oxygen and glucose to their coral polyp hosts (Sebens 1994). Warming seas and more frequent temperature anomalies damage the photosynthetic organelles of zooxanthellae, making them toxic to their hosts. As a result, corals eject their symbionts and lose their vivid colors, thus appearing "bleached" (Lesser 2007; Baker et al. 2008). Corals are sensitive to slight temperature changes because most reefs exist where the water temperature is near the thermal tolerance threshold for corals. Coral bleaching can occur when sea surface temperature is only 1°C above the long-term summer season mean (Hoegh-Guldberg 2011). Bleached corals can recover if temperatures return to normal and the stressor is removed, but severe bleaching can cause widespread coral mortality, as the corals essentially starve to death without their symbiotic partners. The greatest threat to coral reefs from bleaching is the degradation of reef structure and habitat, which is associated with declines in reef-based ecosystem services and biodiversity loss for corals and other reef-associated organisms (Graham et al. 2007, Oxford Economics 2009).

Only one decade ago, coral bleaching events were considered uncommon for Guam (Porter et al. 2005). From 1998 to 2013, coral reef ecosystems around Guam were impacted by minimal to moderate seasonal bleaching with high rates of coral recovery (Raymundo 2016). However in the last five years, coral bleaching due to ocean warming has become the most severe and visible impact on Guam's reefs, with widespread bleaching occurring in 2013, 2014, 2016, and 2017. In 2013, extensive coral bleaching and mortality were recorded on Guam's shallow reef flats and at deeper sites around the island, with 85% of coral genera affected. Severe coral bleaching occurred on Guam's shallow and deeper reefs again in 2014. As a result of these back-to-back bleaching events and El Niño-associated extreme low tides in 2015, Guam lost approximately half of its staghorn corals (*Acropora* spp.), equating to about 17.5 hectares (Raymundo et al. 2017). In 2016, Guam's reef flats were severely impacted by coral bleaching, although deeper reefs were spared (Raymundo et al. 2018, *in review*). In 2017, widespread coral bleaching and mortality affected Guam, with moderate to severe bleaching island-wide impacting multiple coral genera to depths of 40 m (Raymundo et al. 2018, *in review*). *For further details on the impacts of coral bleaching on Guam's reefs, see the Guam Coral Bleaching Response Plan (Hoot and Burdick 2017).*

Coral bleaching events are expected to become more frequent and severe in the future. If greenhouse gas emissions continue at current rates, most coral reefs will be affected by severe, annual coral bleaching by the middle of this century and almost all reefs will experience severe yearly bleaching by 2100 (van Hooidonk et al. 2013, 2014, 2016). IPCC climate models indicate that by 2045, Guam's coral reefs may experience severe thermal stress and coral bleaching annually if global greenhouse gas emissions are not reduced (Heron et al. 2016, van Hooidonk et al. 2016, Maynard and Raymundo 2017).

What is coral reef resilience?

Coral reef resilience is the capacity of a coral reef ecosystem to absorb or resist the impacts of disturbances (such as severe storms, coral bleaching events, and COTS outbreaks) and subsequently recover to pre-disturbance condition (Hughes at al. 2007). A resilient reef may be characterized by high diversity and functional redundancy of reef taxa; high fish biomass and diversity among functional groups, especially herbivores; high density of juvenile corals and fishes and strong larval supply; high structural complexity; high coral cover versus algal cover; and/or good water quality (Nystrom 2006, Cote and Darling 2010, Graham et al. 2015, Heenan and Williams 2013, Maynard et al. 2015). When resilience decreases, a coral reef can undergo a phase shift from coral dominance to algal dominance (Hughes et al. 2007, Mumby et al. 2007b). Reefs that are unable to recover from a disturbance may also experience a shift in coral community from stress-susceptible corals (e.g. *Acropora, Montipora*) to stress-tolerant taxa (e.g. *Porites, Platygyra, Favia*) (Loya et al. 2001, Rachello-Dolmen and Cleary 2007, Cleary et al. 2008, Cote and Darling 2010). In the context of reef management, coral reef resilience is a general indicator of reef health and the ability of the ecosystem to stay healthy while facing the impacts of climate change.

There remain questions regarding the combined effects of local stressors, climate change, and acidification on coral reefs and the relative impacts of these threats (Anthony et al. 2011, 2015). Some research appears to contradict the theory that reduction of local stressors can improve reef resilience to climate change. Even more remote reefs that do not experience the degree of local threats facing reefs near densely populated areas have been severely impacted by coral bleaching, indicating that the intensity of local stressors is not the only factor influencing reef resilience (Cote and Darling 2010, Bruno and Valdivia 2016, Hughes et al. 2017). There is also conflicting evidence as to whether reefs that currently experience high stress conditions (e.g. temperature fluctuations, chronic sedimentation, decreased fish biomass) may be better adapted to survive future impacts of climate change (Cote and Darling 2010, Darling et al. 2010, Camp et al. 2016).

Despite this uncertainty, several empirical studies have shown that local pressures, including overfishing and degraded water quality, can increase coral bleaching susceptibility (Carilli et al. 2009, Vega Thurber et al. 2013, Zaneveld et al. 2016), while reefs subject to less local stress may be more likely to recovery from disturbance (Houk et al. 2014, Graham et al. 2015). Although local reef management efforts cannot prevent ocean warming or acidification, which are caused by the emission of greenhouse gasses, they may be able to improve the health of coral reef ecosystems and thus decrease coral reef vulnerability to these global threats (Shaver et al. 2018). Chronic stressors such as poor water quality due to pollution, overfishing, and ocean warming and acidification threaten the processes on coral reefs (e.g. herbivory, recruitment) that maintain the resilience needed for reefs to survive disturbances such as bleaching events, severe storms, and COTS outbreaks (Anthony et al. 2015). Local management efforts designed to increase coral reef resilience generally focus on reducing chronic local stressors (Hughes at al. 2005, Mumby and Steneck 2008, Cote and Darling 2010). Evaluating the impact of any local management initiative or stressor on reef resilience is challenging, but vital to improving our understanding of how we can conserve coral reefs in the Anthropocene (Cote and Darling 2010, Darling et al. 2010, McClanahan et al. 2012).

Overview of federal policies relevant to coral reef protection and management on Guam

Executive Order (EO) 13089 – Coral Reef Protection, 1998:

- EO 13089 was issued by President Clinton in 1998 to "preserve and protect the biodiversity, health, heritage, and social and economic value of US coral reef ecosystems and the marine environment." The EO states that any federal agency whose actions may affect coral reef ecosystems must identify these actions and ensure that they do not degrade these ecosystems.
- EO 13089 established the US Coral Reef Task Force (CRTF), an interagency entity co-chaired by the Secretary of the Interior and the Secretary of Commerce via the Administrator of NOAA, and requires the CRTF to oversee implementation of this EO. The CRTF is also responsible for coral reef mapping and monitoring; research; conservation, mitigation, and restoration; and promoting international cooperation to protect global coral reef resources.
- In 2000, the CRTF produced the National Action Plan to Conserve Coral Reefs as a roadmap for achieving the purpose of EO 13089. This was the first national plan in the US to address the degradation of coral reefs. The Action Plan outlines 13 conservation strategies to address threats facing coral reefs and eight core conservation principals to guide future efforts.
- For more information: https://www.boem.gov/Environmental-Stewardship/Environmental-Assessment/13089/index.aspx, https://www.coralreef.gov/about

Coral Reef Conservation Act (CRCA) of 2000:

- The CRCA was enacted to preserve, sustain, and restore coral reef ecosystems; promote effective management and sustainable use of coral reef resources; collect data on the health of coral reefs; support and fund conservation programs; and establish a mechanism to collect and distribute donations from the private sector for coral reef conservation. The CRCA includes definitions for the following terms: coral, coral reef, coral reef ecosystem, and coral products.
- Under the CRCA, the NOAA Administrator may provide grant funds to US jurisdictions that manage coral reefs to address the impacts of natural disasters or other unforeseen emergencies on coral reef ecosystem health.
- The CRCA established the NOAA Coral Reef Conservation Program (CRCP), which is focused on reducing the impacts of climate change, unsustainable fishing, and land-based sources of pollution on coral reefs. CRCP administers grants for coral reef conservation projects and programs.
- In 2002, NOAA produced the National Coral Reef Action Strategy to fulfil the mandate of the CRCA and evaluate implementation of the National Action Plan to Conserve Coral Reefs.
- For more information: https://coralreef.noaa.gov/about/welcome.html

Legislation requiring consultations and/or permitting

The following federal laws require consultation for projects that have a federal nexus (permit, funding, action, etc.). All of these laws have been used to prevent impacts to coral reefs.

Fish and Wildlife Coordination Act (FWCA), 1934:

- The FWCA gives the US Fish and Wildlife Service (USFWS) authority to evaluate potential impacts to fish and wildlife from planned water resources development projects that control or modify any stream or water body, and requires that these resources receive "equal consideration" as other features of the project. Under the FWCA, any federal agencies that license, permit, or construct water resources development must consult with USFWS, and the National Marine Fisheries Service (NMFS) within NOAA in some cases, in addition to state resource agencies, to describe the potential effects of the proposed project on fish and wildlife and plans to mitigate any negative impacts.
- Under the FWCA, NMFS evaluates the potential impacts of proposed projects on fish species and associated habitats that are outside the mandate of the Magnuson-Stevens Act and provides recommendations for decreasing impacts. Consultations under the FWCA are typically integrated into a consultation process with the Clean Water Act (Section 404), the National Environmental Policy Act, or other federal requirements.
- For more information: https://www.fws.gov/laws/lawsdigest/fwcoord.html, https://darrp.noaa.gov/fish-and-wildlife-coordination-act

National Environmental Policy Act (NEPA), 1970:

- NEPA requires that all federal agencies produce environmental assessments and environmental impact statements for proposed actions that may affect the environment. Before undertaking a major action, a federal agency must calculate potential environmental impacts, consider alternatives to the planned project, and make a decision based on the outcomes of the assessment. The agency must also provide the opportunity or public review of the proposed action. NEPA compliance is overseen by the Council on Environmental Quality within the Office of the President.
- For more information: https://www.epa.gov/nepa/what-national-environmental-policy-act

Clean Water Act (CWA), 1972:

- The CWA, administered and enforced by the US Environmental Protection Agency (EPA), is the principal federal law regulating water pollution. The CWA provides a framework for regulating the discharge of pollutants into US waters and determining water quality standards for all surface waters. Under the CWA, it is illegal to discharge any point source pollutant into navigable waters without a permit from the EPA's National Pollutant Discharge Elimination System (NPDES) program.
- Section 404 of the CWA regulates dredge and fill activities and lists coral reefs as "special aquatic sites" requiring additional protection and scrutiny. Permitting agencies must evaluate alternative actions and document avoidance

and impact minimization efforts. Unavoidable losses may require compensatory mitigation to replace lost ecosystem function.

- President Bush's US Ocean Action Plan (2004) directed the EPA to develop biological criteria ("biocriteria") and evaluation methods for US jurisdictions to assess coral reef health and water quality. In addition to chemical and physical water quality standards, US states and territories can set biocriteria to measure the condition of biological communities, such as coral reefs, and determine whether the body of water is meeting biological standards (Bradley et al. 2010).
- For more information: https://www.epa.gov/laws-regulations/summary-clean-water-act

Endangered Species Act (ESA) of 1973:

- The ESA was enacted to implement conditions of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and prevent extinctions. This act is administered by USFWS, who are charged with protecting terrestrial and freshwater species, and NMFS, who are responsible for marine organisms.
- Under the ESA, species at risk of extinction are listed as threatened or endangered. The ESA protects these listed species by prohibiting the take* of animals and the interstate and international trade of plants and animals without a permit. These permits are typically issued for scientific and conservation purposes. (*Take is defined as to "harass, kill, trap, capture, or collect or attempt to engage in any such conduct.")
- Currently, approximately 2,300 species are listed as threatened or endangered, including 675 species that are only found outside of the US and its waters. This list includes over 159 marine species, ~94 of which can be found in US waters. There are 25 coral species listed: 22 species designated as threatened and three as endangered. Three of these threatened coral species can be found on Guam's reefs: *Acropora globiceps, Acropora retusa* (unconfirmed), and *Seriatopora aculeata*. Listings for Guam also include the green sea turtle, *Chelonia mydas* (endangered); hawksbill sea turtle, *Eretmochelys imbricata* (endangered); oceanic whitetip shark, *Carcharhinus longimanus* (threatened); and scalloped hammerhead shark, *Sphyrna lewini* (threatened).
- For more information: http://www.nmfs.noaa.gov/pr/laws/esa, https://www.fws.gov/endangered/laws-policies, http://www.nmfs.noaa.gov/pr/species/esa/listed.htm#invertebrates, http://www.nmfs.noaa.gov/pr/conservation/states/guam.htm

Magnuson-Stevens Fishery Conservation and Management Act (MSA), 1976:

- The MSA, administered by NMFS, is the principal legislation regulating management of marine fisheries in federal waters within 200 nautical miles of the coast. The main goals of this law are to prevent overfishing; restore overfished populations; build the long-term social and economic benefits of fisheries; and ensure availability of safe, sustainable seafood. The MSA also established eight regional fishery management councils charged with creating fishery management plans. Guam is part of the Western Pacific Regional Fishery Management Council.
- Under the MSA, stock assessments are conducted to determine the status of a fish stock and whether it is overfished. According to these assessments, each fishery management council sets catch limits for target species. As a fishery nears or exceeds its catch limit, the council applies accountability measures such as size and trip limits, seasonal closures, and gear restrictions to prevent overfishing.
- In 1996, the MSA was amended to include a provision for identifying and describing "essential fish habitat" (EFH) in management plans produced by regional councils. EFH is defined as "waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity." Federal agencies must consult with NMFS on any actions or proposed actions "that may adversely affect EFH," which will be followed by recommendations from NMFS to prevent, reduce, or mitigate any damages to EFH areas. Guam's EFH areas can be viewed here: http://www.habitat.noaa.gov/protection/efh/efhmapper/index.html
- For more information: http://www.nmfs.noaa.gov/sfa/laws_policies/msa

Legislation designed to reduce and address impacts

Resource Conservation and Recovery Act (RCRA), 1976:

- RCRA, administered by the EPA, is the primary federal legislation the regulations the disposal and clean-up of solid and hazardous wastes. RCRA focuses on prevention, rather than clean-up. Under RCRA, the EPA has established regulations for the design and operation of landfills and a "cradle to grave" approach for controlling the handling of hazardous materials.
- RCRA is primarily implemented and enforced by state agencies, as most states have regulations as strict or stricter than those outlined in RCRA, but the EPA can enforce RCRA through several mechanisms, including administrative actions, civil judicial actions, and criminal actions.
- Facilities on Guam regulated by RCRA can be found here: https://cfpub.epa.gov/si/si_public_record_Report.cfm?dirEntryID=142598
- For more information: https://www.epa.gov/rcra/resource-conservation-and-recovery-act-rcra-overview, https://www.epa.gov/enforcement/rcra-corrective-action-enforcement-actions

Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), 1980:

- CERCLA established a federal "superfund" to restore abandoned hazardous waste sites and clean up releases of pollutants and toxins into the environment. CERCLA authorizes the EPA to hold responsible parties liable for their actions and associated clean up.
- There are two Superfund sites on Guam: Andersen Air Force Base (long-term clean-up of hazardous substances, including operational solvents, to protect the underlying aquifer) and the Ordot Landfill (clean-up of pollutants entering the Lonfit River).
- For more information: https://www.epa.gov/laws-regulations/summary-comprehensive-environmental-response-compensation-and-liability-act, https://www.epa.gov/superfund/search-superfund-sites-where-you-live

Oil Pollution Act (OPA) of 1990:

- OPA, administered by the EPA, was passed to prevent and address the impacts of oil spills. OPA created a framework for determining responsible parties and their financial liability, established a fund for the clean-up of spills if the responsible party is unwilling or unable to pay, and requires vessels and oil storage facilities to submit plans for possible spills. NOAA is required to develop regulations for natural resource damage assessments (NRDA) following oil spills.
- OPA requires the responsible party to pay for all damages, including damage to natural resources, if there is an oil spill or "substantial threat of discharge of oil." Damages resulting from salvage and clean-up efforts can also be charged to the responsible party. OPA is not activated if the ship remains floating after the grounding and there is no reasonable concern about a potential discharge.

- For more information: https://www.epa.gov/enforcement/oil-pollution-act-opa-and-federal-facilities, https://darrp.noaa.gov/oil-pollution-act-opa-1990

Overview of selected local policies and plans relevant to coral reef protection and management

Executive Order (EO) 89-31, 1989 – Adoption of the Recreational Water Use Management Plan (RWUMP) for the waters of Guam:

- In 1989, Governor Joseph Ada signed EO 89-31 to adopt the Guam RWUMP to regulate use of mechanized recreational watercraft in Guam's nearshore waters to reduce user conflicts, address safety concerns, and protect marine environments.
- The EO states that the RWUMP applies to all marine areas from the mean high water line to the outer reef edge. The use of mechanized watercraft and sports equipment are authorized only in areas specified in the RWUMP.

Guam's Coral Reef Local Action Strategies (LAS)

EO 97-10, 1997 – Adoption of the Guam Coral Reef Initiative (GCRI):

- In 1997, Governor Carl Gutierrez signed EO 97-10, which created the GCRI and established the GCRI Coordinating Committee (CRICC) and the GCRI Policy Advisory Committee (CRIPAC). The GCRI's vision is to develop a comprehensive program for the conservation and effective management of Guam's coral reef ecosystems through sustainable use and wise preservation. The vision relies on four strategies: building partnerships, coordinating activities, integrating all critical ecosystem components and linkages, and building local capacity through education, training, and infrastructure development.
- EO 97-10 is superseded by EO 12-05, which updated the membership and duties of the CRICC and CRIPAC.

EO 12-05, 2012 – Adoption of the GCRI to establish a policy development mechanism for the protection of Guam's coral reefs:

- In 2012, Governor Edward Calvo signed EO 12-05, superseding EO 97-10. The EO describes the continued reef decline that has occurred since 1997 and changes in coral reef conservation strategies.
- The EO updates CRICC membership to consist of: the Governor's Point of Contact to NOAA on coral reef issues; the Directors of DOAG, BSP, Department of Parks and Recreation (DPR), and the Guam Economic Development Authority (or designees) (GEDA); Administrator of GEPA (or designee); Presidents of the Department of Chamorro Affairs and the University of Guam (or designees); and the General Manager of GVB. The Governor's Point of Contact serves as the chairperson for the CRICC. The CRICC serves to: develop, update, and monitor Guam's LAS; utilize the LAS to develop prioritized lists of coral reef issues; determine funding priorities and coordinate applications for federal grant money for coral reef projects; incorporate input from the CRIPAC into the LAS; provide advice to the Governor and local agencies; and provide quarterly reports to the Governor on the status of coral reef issues, funding, and priorities.
- The EO updates CRIPAC membership to consist of: the Governor's Point of Contact; Governor-appointed representatives of academia, commercial fisheries, recreational fisheries, maritime industry, maritime recreation, a traditional/indigenous CHamoru organization with an emphasis on fishing, and an environmental NGO; and one community representative with coral reef interests. The Governor's Point of Contact serves as the chairperson for the CRIPAC. The CRIPAC serves to provide the CRICC with input and recommendations related to the LAS; concerns and recommendations relevant to coral reefs; reviews of current and potential future coral reef policies, regulations, etc.; and minute meetings and other reports.

Development of Guam's LAS:

- In August 2002, the CRICC began to identify the primary threats facing Guam's coral reefs with the goal of prioritizing funding and management efforts. In 2003, the CRICC assigned local navigators to lead the efforts and draft LAS for five priority areas: LBSP; overfishing; recreational misuse and overuse; lack of public awareness; and climate change and coral disease. Guam's LAS outline goals, objectives, and activities for each of the five priority areas. The LAS were developed based on the goals of the US National Action Plan to Conserve Coral Reefs (CRTF 2000).
- Guam's LAS working groups added project lists to the LAS documents in 2005; these lists were updated in 2013 (GCMP 2013). The five priority areas were updated to include: LBSP; fisheries management; recreational use and misuse; climate change and reef resilience; and impacts of Department of Defense (DOD) expansion.
- Guam's coral reef management priorities, goals, objectives, and associated actions, as created through the LAS process, were further refined in Guam's 2010 Coral Reef Management Priorities (Territory of Guam and NOAA CRCP 2010). This priority setting document was produced collaboratively by local government agencies, non-governmental partners, and CRCP, in alignment with the CRCP Goals and Objectives for 2010-2015 (CRCP 2009).

Laws passed by the Guam Legislature

Public law (PL) 12-108, 1974 – Guam Territorial Seashore Protection Act of 1974:

- PL 12-108 was passed by the 12th Guam Legislature in 1974 to establish the Guam Seashore Reserve and require development of a Seashore Reserve Plan to maintain, restore, and enhance Guam's nearshore environment. Seashore reserve is defined as all land and water extending seaward to the 60 ft depth contour (10 fathoms), including islands within the Government of Guam's jurisdiction, and land extending inward from the mean high water line on the horizontal plane for 10 m. The law establishes the Territorial Seashore Protection Commission to implement the policy.
- As of mid-2018, the Seashore Reserve Plan is still in draft form (see below).

PL 24-21, 1997 – Establishment of fishing regulations and marine preserves (MPs):

- PL 24-21 was passed to conserve nearshore fisheries and preserve traditional fishing practices. DOAG was given the authority to regulate Guam's fishery resources (both marine and freshwater), determine the need for MPs, and manage these preserves.
- This legislation contains definitions for many terms, including: aquatic animal, plant, and life, boundary marker, commercial export and harvesting, harvest/take, locally-caught, marine animal, marine mammal, marine preserve, pelagic fish, personal use, reef margin, shore, and waters of Guam. Fishing methods and gear are also defined, such as bottomfishing, cast net (*talaya*), fish aggregating device (FAD), gill net (*tekken*), hook and line, spear, spearfishing, and surround net.
- PL 24-21 prohibits the take of marine mammals and the relocation or transplant of any aquatic life or substrate from one area to another without a permit. The law also restricts certain fishing methods and gear.
- PL 24-21 establishes five MPs, their boundaries, and allowable fishing methods and gear within each MP: Tumon Bay MP, Piti Bomb Holes MP, Sasa Bay MP, Achang Reef Flat MP, and Pati Point MP. It defines the extent of MPs relative to high tide marks and depth, establishes a requirement for boundary markers and publicly-available maps, and defines types of fishing that are prohibited in all MPs.
- This law also establishes varying restrictions (including size limits) and license requirements for personal take and commercial harvest and export of marine invertebrates: *Trochus* snails (*Tectus niloticus*), giant clams (*Tridacna* spp.), bear claw clams (*Hippopus hippopus*), other gastropods and bivalves, crabs and lobsters, echinoderms (sea stars, sea cucumbers, and urchins), and other invertebrates.
- The regulations for PL 24-21 are listed in the Guam Code Annotated (GCA) (Title 5: Government operations, Division 6: Agriculture, Chapter 63: Fish, game, forestry, and conservation) and in the Guam Administrative Rules and Regulations (GAR) (Title 9: Animal regulations, Division 2: Conservation, hunting, and fishing regulations, Chapter 12: Fishing regulations). However, after compiler updates there are inaccuracies with the regulations listed in the GAR, including incorrect boundaries for the MPs.

The GCA is available here: http://www.guamcourts.org/CompilerofLaws/gca.html
The GAR is available here: http://www.guamcourts.org/CompilerofLaws/gar.html

PL 27-87, 2004 – Creation of an eco-permitting system for marine preserves:

- PL 27-87 authorizes DOAG-DAWR to regulate non-fishing activities in MPs through permitting, reviewing criteria and standards for activities, and enforcement of these regulations by administering penalties for violations. The permitting system is designed to maximize public use and access to natural resources while assessing potential negative impacts on species or ecosystems.
- In 2011, public input was gathered using the Limits of Acceptable Change (LAC) Model to inform regulations needed to enforce PL 27-87. LAC management and implementation plans were produced with extensive stakeholder input for the Tumon Bay MP and the Piti Bomb Holes MP.
- As of mid-2018, there are no regulations for PL 27-87 and it has never been enforced.

PL 28-107, 2005 – Updates and additions to definitions related to MPs and fishery regulations listed in GCA Title 5, Division 6, Chapter 63:

- PL 28-107 amends or adds definitions for the following terms: altering, angling, aquatic life, coral, firearm, fish, fish weir (main and auxiliary), game, juvenile goatfish, juvenile jacks, juvenile rabbitfish, mangroves, marine preserve, resource, rock, sand, seagrass, snagging, take, traditional fishing methods (cast net, drag net/seine, surround net, trap net, butterfly net), vehicle, vessel, and waters of Guam.
- This law also adds new sections to Chapter 63 describing the purpose of the MPs, defining activities within MPs, and requiring that CHamoru words for terms defined in this law be used in all Guam statutes and regulations.

PL 28-30, 2005 – Creation of a Civilian Volunteer Conservation Officer Reserve program:

- PL 28-30 acknowledges the need for increased manpower for DOAG and establishes the Civilian Volunteer Conservation Officer Reserve program to address this capacity gap by providing back-up manpower and better protect Guam's natural resources.
- According to this law, DAWR is to recruit local volunteers for this program, provide basic training and supplies, provide a monthly allowance for volunteers, and establish a training program for recruits, in collaboration with the Civil Defense Office.
- As of mid-2018, the Civilian Volunteer Conservation Officer Reserve program has not been established.

PL 29-127, 2008 – Addition of a new section to Chapter 63 of Title 5 of the Guam Code Annotated relative to indigenous fishing rights:

- PL 29-127 asserts that since Spanish colonization, the CHamoru people have been denied the right to practice traditional fishing methods and that these traditional methods are still threatened by contemporary conservation policies and restrictions. This law states that to address this historical inequity, the CHamoru people should have special rights to fishing access and harvesting of marine life.
- The law created the Indigenous Native Resources Task Force to collaborate with the Department of Agriculture to develop rules and regulations for the law. The Task Force was unable to reach consensus and as of mid-2018, there are no regulations to implement PL 29-127.

PL 33-144, 2016 – Guam Ocean and Fisheries Conservation Act of 2015:

- This law establishes the Guam Ocean and Fisheries Management Council composed of nine voting members appointed by the Governor to coordinate and promote activities related to the conservation and development of Guam's ocean, fisheries, and marine resources, including implementation of PL 29-127, development of permit requirements for fishing, and advising the Governor and Legislature.
- The council is composed of four community at large members, three members of key fishing organizations, faculty member of UOG, and the director of DOAG.
- The law also establishes the Guam Ocean and Fisheries Conservation and Development Fund for boating access, research, pollution mitigation, cultural preservation, and other related activities.
- As of mid-2018, the Council members have not been appointed and the Council has not been convened.

PL 33-159, 2016 – Establishment of the Southern River Erosion Council and mandate for master plans to address erosion in southern Guam:

- PL 33-159 acknowledges that erosion threatens to diminish both public and private lands, impact jobs in the agricultural and tourism sectors, decrease water quality, deter navigation of rivers, and damage nearshore benthic ecosystems.
- This law establishes the Southern River Erosion Council to identify erosion issues and recommend mitigation strategies to address erosion along rivers in southern Guam. The Council includes representatives from DOAG,

UOG, BSP, Guam Waterworks Authority (GWA), GEPA, Department of Public Works (DPW), Department of Land Management (DLM), US Department of Agriculture (USDA), US Army Corps of Engineers, private landowners, and mayors of the seven southern villages (Agat, Umatac, Inarajan, Santa Rita, Talofofo, Merizo, and Yona).

- This law also mandates the development of a comprehensive master plan(s) for southern Guam to identify and mitigate erosion problems according to the recommendations of the Southern River Erosion Council.
- As of mid-2018, the Council has not been convened and the master plan(s) have not been developed.

PL 34-17, 2017 – Establishment of the Guam Council in Climate Change Preparedness and Resiliency:

- PL 34-17 supports the Guam Climate Change Task Force and Climate Change Advisory Committee (established by EO 15-08) by creating the Guam Council on Climate Change Preparedness and Resiliency (Guam C^3PR) to provide policy recommendations to the Legislature and address adverse impacts of climate change on Guam.
- The members of Guam C^3PR are the legislative chairperson with oversight over environment or his/her designee (who will serve as chairperson of the C^3PR); the President of UOG or his/her designee (who will serve as vice chairperson); the legislative chairperson with oversight over appropriations or his/her designee; one majority member of the Legislature appointed by the Speaker or his/her designee; one minority member of the Legislature appointed by the Speaker; the chairperson of the Guam Climate Change Task Force; one member of the Climate Chang Advisory Committee; the chairperson of the Consolidated Commission on Utilities or his/her designee; the director of the UOG Center for Island Sustainability or his/her designee; and all other members of the Legislature as ex-officio members.

PL 34-72, 2018 – Marine Conservation Act of 2018:

- PL 34-72 states that the issues facing Guam's coral reefs are too numerous and severe to be addressed by any one Government of Guam agency, and thus a participatory community-based fisheries management approach is necessary to properly manage and conserve these resources. The law defines community-based fisheries management as "a system in which fishermen and their communities exercise primary responsibility for stewardship and fisheries management, to include taking part in the decision-making on all aspects of fisheries management, such as harvesting, access, compliance, research, and marketing."
- This law grants authority to the Director of DOAG, village mayors, and Municipal Planning Councils to establish community-based fisheries managed areas and create fisheries management plans. The Directors of DOAG and BSP are enlisted to provide technical guidance to the mayor and the Municipal Planning Council of Humatak to establish Humatak Bay as a community-based fisheries management area and develop a community-based management plan. The law states that the management plan should be finalized by January 2019.
- This law does not alter any existing marine preserves on Guam.

Proposed legislation

Bill No. 397-30, 2009 – Prohibition of SCUBA spearfishing:

- A bill to ban SCUBA spearfishing was introduced to the 30th Legislature of Guam in 2009, but the bill did not leave committee and was not passed. The bill noted continued decline of Guam's fisheries, with particular emphasis on two large-bodied, slow-growing herbivores, the bumphead parrotfish (*Bolbometopon muricatum*) and humphead wrasse (*Cheilinus undulatus*).
- SCUBA spearfishing is banned in the Commonwealth of the Northern Mariana Islands (CNMI), Pohnpei, American Samoa, Independent Samoa, Fiji, Tonga, Solomon Islands, Maldives, Mauritius, Seychelles, and Kenya.

Bill No. 120-31, 2011 – Guam Coral Reef Protection Act:

- The Guam Coral Reef Protection Act was proposed to the Legislature of Guam in 2011, but was not passed. This bill included definitions for several terms, including aggravating circumstances, coral, coral reefs, damages, hazardous material, pollutant and unpermitted release of pollutants, spill, and responsible party.
- This bill was created to address the issue of vessel groundings and chemical spills or releases that impact, or have potential to impact, Guam's coral reefs. The bill was designed to identify the responsible party for an impact and create a mechanism to recover damages from that responsible party. The bill also described civil penalties for reef damage and included creation of a Coral Reef Restoration Fund.
- This language of this bill was based on the Florida Coral Reef Protection Act, enacted in 2009. A similar bill in CNMI has been passed by the Legislature as of mid-2018.

Local plans and strategies

Recreational Water Use Management Plan (RWUMP), 1989, updated in 1998:

- The RWUMP was developed to reduce conflict between mechanized recreational watercraft, specifically jet skis, and traditional fishers; address safety concerns; and reduce environmental impacts. The RWUMP was adopted by EO 89-31 in 1989 (see above) and rules and regulations were approved in 1991. The RWUMP was updated in 1998 to include regulation of dinner cruises in East Agana Bay. A 2010 update to the RWUMP was drafted but not formally adopted.
- The RWUMP applies from Oka Point in Tamuning to Tepungan Channel in Piti, encompassing the area between the high tide mark and the reef crest. The RWUMP designates certain areas within Agana Bay where mechanized recreational watercraft may be used inside the reef. Commercial operations within these areas require a permit from the Department of Parks and Recreation. Mechanized recreational watercraft are also used in Cocos Lagoon and Apra Harbor, but these areas are not included under the RWUMP.
- Executive orders and laws relevant to the RWUMP: EO 90-08, EO 89-10, EO 89-31 (see above), EO 90-08, PL 20-117, PL 23-78, PL 23-89, PL 24-74, PL 24-137, PL 24-218

Guam Seashore Reserve Plan, 2003, updated 2012 (draft):

- The Guam Seashore Reserve Plan, which is mandated by PL 12-108 (see above), was drafted in 2003 and updated in 2012; the document is still in draft form. The purpose of the plan is to preserve and protect the seashore reserve area designated in PL 12-108 and provide guidance and permitting for development in these coastal areas. The Guam Coastal Management Program is responsible for implementing the plan.
- The draft plan recommends amending the boundaries of the seashore reserve described in PL 12-108 to include all nearshore waters to the 300 ft depth contour (increased from 60 ft) and inland to 10 m on the horizontal plane from the mean high water line (decreased from 100 m) or to the inland edge of the nearest public right of way, whichever is closer.

- Areas of the seashore reserve are classified under two categories of protection, preservation (more restrictive) and conservation. Areas designated under preservation include all marine preserves, sea turtle habitat and nesting areas, mangrove forests, and unique coastal features and marine communities. All other areas within the seashore reserve are classified as conservation. In both preservation and conservation areas, casual recreational use is allowed without a permit.
- The plan also establishes the Seashore Reserve Fund, which is supported by fees and fines related to the plan and used to support implementation and administration of the plan.

The following master plans (Table 1) and management plans (Table 2) may provide useful information for coral reef managers on Guam.

Table 1. Master plans for the Territory of Guam

Title	Date published	Notes
Territory of Guam Master Plan	1966	Updated in 1972
Storm Water Drainage Master Plan for Tamuning-Dededo, Agana, Asan-Piti, Merizo, and Agat-Santa Rita	Aug. 1970	
Guam Comprehensive Development Plan	Sept. 1978	
Guam Territorial Seashore Park Plan	Jan. 1979	
Tumon Bay Master Plan	1984	Not implemented
Southern Guam Flood Control Master Plan	Dec. 1996	
Master Plan for Park and Conservation Land	April 1999	
Hagatna Master Plan	Sept. 2005	Updated in April 2013
Guam 2020 Highway Master Plan	Oct. 2005	
Water Resources Master Plan	Oct. 2006	Update in progress since 2016
North and Central Guam Land Use Plan	Sept. 2009	
Village Streets Master Plan	Nov. 2009	
Storm Water Drainage Master Plan	Dec. 2010	

Table 2. Management plans for the Territory of Guam

Title	Date published	Notes
Agana Marina Development Plan	1976	
Community Design Plans for Guam: 1977-2000	Oct. 1977	
Guam Fisheries Development and Management Plan	1980	
Overall Economic Development Plan for Guam, 1989-1993	1988	
Recreational Water Use Management Plan (RWUMP)	1989	Updated in 1998; update in 2010 not formalized
Clean Water Action Plan for Guam Unified Watershed Assessment	Sept. 1998	
Guam Integrated Solid Waste Management Plan	2006	
Guam Comprehensive Wildlife Conservation Strategy	Nov. 2006	
Natural Resources Strategy, 2012	Aug. 2008	

Conservation Action Plan for Piti Bomb Holes Marine Preserve and Adjacent Watershed	Aug. 2009	Draft, not finalized
Guam Seashore Reserve Plan	Aug. 2012	Draft, not finalized
Guam Waterworks Authority Comprehensive Management Plan	2013	
Guam Zero Waste Plan	June 2013	
Guam Energy Action Plan	July 2013	
Guam Tourism 2020 Plan	2014	
Guam Statewide Comprehensive Outdoor Recreation Plan	2014	
Guam Hazard Mitigation Plan	July 2014	
Guam Marine Biosecurity Action Plan	Sept. 2014	
Merizo Community-based Management Plan	2015	
Guam State Wildlife Action Plan	Sept. 2015	
Marine Conservation Plan	2017	
Guam Invasive Species Management Plan, 2013-2017	2017	Interim plan
Guam Coral Bleaching Response Plan	April 2017	
Manell-Geus Habitat Focus Area Implementation Plan	Aug. 2017	
Guam Crown of Thorns Sea Star Outbreak Response Plan	Dec. 2017	
Watershed Management Plan for Manell and Geus Watersheds	June 2018	

Micronesia Challenge

The Micronesia Challenge, which began in 2006, is an agreement between the Federated States of Micronesia, Republic of the Marshall Islands, Palau, Commonwealth of the Northern Mariana Islands, and Guam to protect the natural resources of Micronesia, and thus the Micronesian way of life, by effectively conserving at least 20% of forest and 30% of nearshore marine resources across the region by 2020 (Declaration of Commitment: The Micronesia Challenge 2006). The Micronesia Challenge encompasses 6.7 km^2, over 5% of the Pacific Ocean, and more than 2,000 islands inhabited by half a million people who speak 12 unique languages; this area is home to 85 bird species, 1,400 plants, 1,300 reef fishes, and almost 500 corals, representing greater than 60% of the world's known coral species (The Nature Conservancy (TNC) 2017).

Guam's existing marine preserves, coupled with federal properties (e.g. War in the Pacific National Historical Park, Guam National Wildlife Refuge, Haputo and Orote Ecological Reserve Areas), cover 15.5% of Guam's nearshore marine resources, just over half of the amount required to fulfill the Micronesia Challenge commitment (Micronesia Challenge Steering Committee 2011). However, increasing the area covered by marine preserves is not a priority for Guam or favored by local communities, so Guam plans to meet the Micronesia Challenge goal by reducing stress on coral reefs by increasing watershed management, improving coastal infrastructure, and more effectively managing and enforcing existing marine preserves (Micronesia Challenge Steering Committee 2011).

Development of the GRRS

Survey on Guam's coral reef management efforts and priorities (October 2017)

Local natural resource managers and other relevant stakeholders completed an online survey on Guam's coral reef management efforts and priorities in October 2017. The results of the survey informed development of the GRRS and contents of the Strategizing for Reef Resilience Workshop (Nov. 2017). A total of 29 respondents representing 15 entities completed the survey: three local agencies (BSP, GEPA, DAWR); four federal agencies (NOAA, USFWS, NPS, DOD-NAVFAC); four local educational institutions/programs (Guam Community College (GCC), UOGML, UOG-CIS, UOG-Sea Grant Program); two non-governmental organizations (TNC, Ayuda Foundation), one local business (Micronesian Divers Association (MDA)); and one intergovernmental program (Micronesia Challenge). Respondents have worked for an average of 15 years in coral reef management or research, or in a related field that depends on coral reef ecosystems. Respondents answered eight questions about the threats facing Guam's coral reef ecosystems; the most important coral reef management priorities for the next five years; the most and least successful aspects of reef management efforts on Guam; and the greatest knowledge and capacity gaps limiting Guam's ability to understand and manage its coral reef resources. Full results of the survey (including questions and data analysis methods) are described in Appendix I.

Key takeaways from the survey results:

- Twenty-seven out of 29 respondents (93%) identified ocean warming/coral bleaching as one of the three most important threats to Guam's coral reef ecosystems; twenty respondents identified this as the most important threat. Sedimentation and fishing pressure were also listed as one of the three most important threats by a majority of respondents.
- Nineteen out of 29 respondents (66%) identified "Reduce impacts of climate change by enhancing resilience" as the first or second most important priority for coral reef management; fourteen respondents identified this as the #1 most important priority. "Reduce impacts of LBSP" was also listed as the first or second most important priority for coral reef management by a majority of respondents.

Strategizing for Reef Resilience Workshop (November 2017)

The Strategizing for Reef Resilience Workshop was held on November 8, 2017 in the Hall of Governors at the Governor's Complex, Adelup. The workshop was guided by five objectives:

1. Gain a shared understanding of the state of Guam's coral reef ecosystems, reasons for decline, and threats facing local coral reefs.
2. Update coral reef management priorities, goals, objectives, and actions to focus on enhancing the resilience of Guam's coral reef ecosystems.
3. Gather input to shape the GRRS.
4. Identify challenges to implementing the GRRS and brainstorm approaches to overcome these challenges.
5. Assign tasks for GRRS finalization and implementation.

The workshop was attended by thirty-eight participants representing four Government of Guam agencies and programs (BSP, GCMP, DOAG, GVB); four federal government entities (NOAA, NPS, USFWS, DOD-NAVFAC); three programs from the University of Guam (UOGML, CIS, Sea Grant Program); two non-governmental organizations (Humatak Community Foundation and TNC); two businesses (Fish Eye Marine Park and UWW); and one private citizen. Names and affiliations of all workshops attendees are listed in Appendix II.

The workshop was led by Whitney Hoot, BSP. Hoot and Valerie Brown (NOAA) delivered presentations on the state of Guam's coral reefs; an introduction to coral reef resilience; an overview of the GRRS, adaptive management, and climate-smart design; a review of Guam's existing management priorities and goals; results from a survey on Guam's coral reef management efforts; and recommendations for revisions to existing priorities and goals. Participants worked in small groups to review and revise coral reef management priorities, goals, objectives and actions; brainstorm approaches to improve research and monitoring efforts; and identify anticipated challenges to implementing the GRRS and strategies to overcome these challenges (Table 3).

Table 3. A list of potential challenges to implementing the GRRS and suggested strategies for overcoming these challenges, developed during the Strategizing for Reef Resilience Workshop

Anticipated challenges to GRRS implementation	**Suggested strategies**
Community resistance and apathy	Increase presence at festivals and events Conduct more outreach and education with students Provide additional service learning opportunities Manage expectations of community involvement Incentivize community participation
Lack of support from executive and legislative branches	Identify a "policy champion" Create a mechanism to provide guidance to leaders
Lack of buy-in from tourism industry	Make coral reef management profitable Develop an "ocean pledge" like the Håfa Adai Pledge Give businesses ownership over programs (e.g. Adopt A Reef) Provide recognition for participating businesses
Lack of funding and inefficient use of funds	Improve grants administration Hold agencies accountable for fulfilling grant requirements Address issues with procurement
Unengaged and/or obstructionist stakeholders	Reach out to stakeholders – give presentations at their offices Change style and content of messaging if needed
Uncertainty surrounding climate change impacts	Down-scale climate models to provide projections at scales relevant to local management interventions Incorporate uncertainty into management planning
Insufficient enforcement of natural resource regulations	Support funding and implementation of the Civilian Volunteer Conservation Officer Reserve program

Climate-smart Design for Coral Reef Management Workshop (September 2018)

The Climate-smart Design for Coral Reef Management Workshop was held on September 24 & 25, 2018 at the Pacific Star Resort and Spa in Tumon. The intended outcomes of the workshop were:

- Increased understanding among local coral reef managers, scientists, and other stakeholders of:
    - Climate change adaptation and climate-smart design principles
    - Predicted future climate change impacts, vulnerabilities, and uncertainties
    - Predicted impacts of climate change on both local stressors and the effectiveness of management actions
- Refined climate-smart coral reef management outcomes, goals, objectives, and actions for Guam, to be included in the Guam Reef Resilience Strategy

The workshop was attended by twenty-six participants representing three Government of Guam agencies (BSP, GEPA, DOAG-DAWR); two federal government agencies (NOAA, NPS); the University of Guam Marine Laboratory; and Underwater World. Names and affiliations of all workshops attendees are listed in Appendix III. The workshop was coordinated by BSP and UOG and facilitated by Dr. Kitty Courtney from Tetra Tech, Inc. (Honolulu, HI).

This training workshop was based on the Adaptation Design Tool (ADT) developed under the Corals and Climate Adaptation Planning (CCAP) project (Parker et al. 2017). The ADT was created with funding from the US Environmental Protection Agency, NOAA Coral Reef Conservation Program, and Department of the Interior's Office of Insular Affairs. The ADT was produced to guide coral reef managers in integrating climate-smart design into plans, projects, and programs related to coral reef management.

The overarching goal of the workshop was to improve the effectiveness of coral reef management efforts on Guam and thus better protect coral reef resources. Attendees received training on use of the ADT and increased capacity to integrate climate-smart design into existing and future projects and programs related to coral reef management. During the workshop, participants learned about principles of climate-smart planning and discussed climate change impacts and vulnerabilities related to Guam's coral reef resources and human communities, based on a vulnerability assessment developed for the workshop. The vulnerability assessment (Appendix IV) describes how climate change indicators are predicted to impact environmental conditions and affect Guam's natural and social resources, based on both climate science and community knowledge. Participants applied their training and knowledge to develop and refine the coral reef management outcomes, goals, objectives, and actions within the GRRS. **The workshop focused on activities within Guam's three priority sites: Manell-Geus watershed (and Achang Reef Flat Marine Preserve); Piti-Asan watershed (and Piti Bomb Holes Marine Preserve); and Tumon Bay watershed/Yigo-Tumon sub-basin of the Northern Guam Lens Aquifer (and Tumon Bay Marine Preserve).**

Based on a post-workshop evaluation survey, 79% of participants stated that their knowledge of climate-smart design principles for coral reef management increased after completing the workshop and 86% of participants reported that they expect to use what they learned during the workshop in the future.

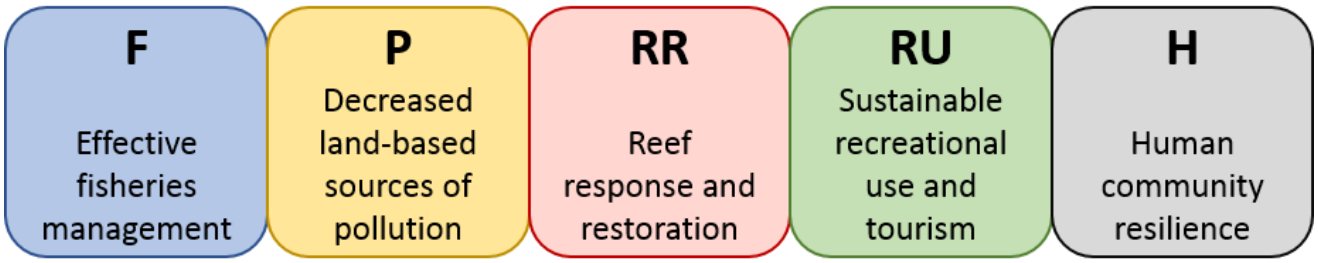
Coral reef management outcomes, goals, objectives, and actions

The **coral reef management outcomes, goals, objectives, and actions** described in this section were adapted from the Guam Local Action Strategies (LAS) and revised during the Strategizing for Reef Resilience Workshop in 2017, the Climate-smart Design for Coral Reef Management Workshop in 2018, and through further engagement with key stakeholders. These outcomes, goals, objectives, and actions reflect the priorities of coral reef management efforts on Guam from **2019 to 2025** and are aligned with the 2018 NOAA CRCP Strategic Plan. Guam's five desired outcomes for coral reef management (replacing "priorities" from the LAS) are: (F) Effective fisheries management; (P) Decreased land-based sources of pollution (LBSP); (RR) Increased reef response and restoration; (RU) Sustainable recreational use and tourism; and (H) Human community resilience and climate change adaptation.

Guam's coral reef managers have defined these terms as follows:

Outcome: A key focus area for coral reef management
Goal: The highest-level result that Guam aims to achieve by 2025
Objective: An environmental, social, or institutional target that Guam must achieve to reach a goal
Action: A specific project, technique, or procedure designed to realize an objective

To increase the efficacy of Guam's coral reef management efforts and maximize the utility of limited resources, many of the objectives and actions included in the GRRS are focused on prioritized key fisheries taxa and sites (target watersheds, priority marine preserves, and restoration areas), which are listed in Appendix V.



OUTCOME F: Effective fisheries management

Goal: *Enhance the resilience of Guam's coral reef ecosystems through effective fisheries management that improves the condition of reef fish communities and protects the sustainability of fisheries for current and future generations.*

Objectives and actions:

1. Improve community engagement in science-based fisheries management by 2022.
   1.1. Strategically engage fishers and the fishing community through monthly community meetings to exchange information, discuss fisheries management strategies, and produce stakeholder-driven solutions to fisheries challenges by 2019.
   1.2. Engage all sectors of the fishing community (e.g. residents, immigrants, military, tourists, commercial, recreational) in climate change impact monitoring through the Eyes of the Reef Marianas program by 2019.
   1.3. Evaluate the Guam fishing community to inform targeted engagement efforts, to include assessment of relevant methods, organizations, and languages, by 2020.

1.4. Establish a fishery policy advisory group (which includes representation from federal land holders) to provide input on fisheries regulations by 2020.
1.5. Develop guidance on sustainable seafood choices for Guam by 2020.
1.6. Implement targeted outreach on sustainable seafood choices to key reef fish consumers (e.g. hotels and restaurants) by 2021.
1.7. Create and implement an outreach program on sustainable seafood choices for the general public and an updated "size matters" guide for fishers by 2022.

2. Conduct management-driven monitoring and research to assess the status of reef fish communities, habitats, and target marine species; the impacts of climate change on fisheries; and the effectiveness of management. Prioritize species that make up the largest proportions of takes for research, monitoring, and stock assessments.
   2.1. By 2019, the Effective Fisheries Management Working Group will develop standardized definitions for key terms: target fish stocks, food fish, reef fish, pelagic fish, freshwater fish, marine invertebrates, etc.
   2.2. By 2020, synthesize existing fisheries data from research and monitoring efforts to establish a continuous data stream for Guam describing current fish community status, resilience information, and potential climate vulnerability for key reef fish species, which will be used to inform and improve management and enforcement by local agencies and federal partners.
   2.3. By 2020, assess commonly used fishing techniques to determine ecological impacts, number of users, and cultural importance of fishing methods and quantify and characterize recreational and commercial fishing efforts.
   2.4. Conduct research to better understand fish population connectivity around Guam to identify key source populations, with a special focus on Guam's marine preserves; methods may include fish tagging/tracking, ocean current characterization and modeling, etc.
   2.5. By 2021, synthesize existing data and collect new data as needed to identify vulnerable habitats for key reef fish taxa to prioritize fish habitat restoration efforts.

3. Improve enforcement of Guam's fishery management statutes, regulations, and marine preserves by 2021.
   3.1. Increase the operations budget for conservation officers within the Guam Department of Agriculture by the end of 2019.
   3.2. Provide support for the Conservation Officer Reserve Program, which requires sustainable funding for stipends and equipment, by the end of 2019.
   3.3. Establish a conservation enforcement hotline by 2019.
   3.4. Improve partnerships with federal agencies, such as the National Oceanic and Atmospheric Administration, National Park Service, US Fish and Wildlife Service, and Joint Region Marianas, to increase effectiveness of the management of marine resources in federally-controlled areas.
   3.5. By 2020, support decriminalization of Title 5 and implementation of the Citation Program for the Law Enforcement Section of the Guam Department of Agriculture.
   3.6. By 2020, provide legal assistance to implement the actions within objective F4 and, additionally, support implementation of a citation program with resulting fines funding enforcement.
   3.7. Create an outreach program to strengthen partnerships with businesses, community partners, and other stakeholders to improve reporting of violations by 2020.
   3.8. Re-delimit the mean high water line (mark) around Guam by the end of 2020.

4. Develop and implement new policies to sustainably manage Guam's nearshore fisheries by 2021.
   4.1. Review existing policies and regulations to identify implementation and policy gaps by 2019.

4.2. Identify vulnerable and/or ecologically important species that may need specific regulations to build resilience by 2020.
4.3. By 2020, engage stakeholder groups, e.g. WestPac and the Fishermen's Cooperative Association, to assess the impact of scuba spear fishing on reef fish communities and evaluate the need for regulation of scuba spear fishing on Guam's reefs.
4.4. By 2020, assess the potential effectiveness of and support for a fishing licensing and/or permitting system for recreational and/or commercial fishing activities on Guam's coral reefs, including socioeconomic evaluation of potential license structures.
4.5. Update policies and regulations related to the harvest of fish and marine invertebrates to ensure sustainable harvest of these taxa, including species-specific regulations and moratoria if needed, by 2021.

OUTCOME P: Decreased land-based sources of pollution (LBSP)

Goal: *Enhance the resilience of Guam's coral reef ecosystems by reducing the introduction of sediment, nutrients, and pollution from coastal development, fires, land-based recreational users, and agriculture in Guam's watersheds.*

Objectives and actions:

1. Develop programs to engage the public, businesses, and decision makers in reducing LBSP and remove barriers to sustainable practices.
   1.1. Encourage use of onsite best management practices, such as green infrastructure technology, at commercial and residential sites.
   1.2. Develop incentives for use of pre- and post-construction best management practices and regular maintenance of practices to reduce LBSP.
   1.3. Update Guam's Building Code to include green infrastructure criteria for residential and commercial buildings.
   1.4. Partner with architects, contractors, and developers to encourage use of modern green infrastructure concepts and technologies in new developments.
   1.5. Install sediment catchment systems in appropriate areas with consideration of future climate change impacts, including changing precipitation and storm patterns.

2. Implement scaled-up watershed restoration projects and application of best management practices with measurable outcomes, focusing on Guam's three target watersheds: Manell-Geus watershed; Piti-Asan watershed; and Tumon Bay watershed/Yigo-Tumon sub-basin of the Northern Guam Lens Aquifer.
   2.1. Continue funding the Coral Reef Watershed Coordinator position to coordinate and implement watershed management and restoration efforts on Guam.
   2.2. Build capacity and provide tools and funding to support existing and newly-established community-based organization focused on watershed restoration initiatives by 2022.
   2.3. Increase the number of acres of land effectively managed for conservation by the Government of Guam, federal agencies, and private landowners by 20% by 2024.
   2.4. Develop Fire Mitigation Plans that include converting fire-prone grassland areas (badlands) with trees and/or preferred vegetation (e.g. nitrogen fixing species and native species) and increase the number of acres managed for firebreaks.
   2.5. Develop Fire Mitigation Plans and fire break management for residential areas such as Cross Island, Nimitz Hill, etc.

2.6. Partner with Guam Waterworks Authority to increase the number of fire hydrants in fire prone areas.
2.7. Install and maintain firebreak areas at sites where watershed restoration projects are conducted.
2.8. Increase enforcement for arson and other illegal activities related to LBSP by 2022, including hiring additional conservation officers and foresters for Wildland Fire Investigations.

3. Conduct management-driven research and develop new tools for watershed restoration and best management practices for tropical coastal ecosystems.
   3.1. Improve techniques and evaluation methods to guide siting for low-tech community-based restoration projects to maximize return on investment.
   3.2. Monitor existing watershed restoration sites over longer periods of time and collect data on the impacts of watershed restoration efforts on coral reef ecosystem health.
   3.3. Collect and analyze data on water quality parameters (e.g. concentrations of dissolved and particulate nutrients, turbidity/suspended solids, and/or chlorophyll *a*) to assess the impacts of erosion, runoff, and sedimentation in nearshore marine waters around Guam by the end of 2020.

4. Improve regulations and strengthen implementation and enforcement of storm water regulations, permit requirements, and plans by 2025.
   4.1. Document and assess existing storm water management systems on Guam and develop recommendations for the addition of new or updated systems to improve water quality by 2020.
   4.2. Monitor and enforce required storm water management systems on Guam, while ensuring that systems are updated and maintained as needed to comply with regulations.
   4.3. Develop and implement a Storm Water Management Master Plan for Guam, including climate-smart design considerations, by 2024.
   4.4. Support implementation of permit requirements for Department of Public Works MS4 permits and the Guam Waterworks Authority's Illegal Connection/Illicit Discharge (IC/ID) program to better manage storm water that enters the marine environment.

5. Apply best management practices, such as those in Tread Lightly programs, and sediment control systems at existing popular off-roading sites by 2021 in collaboration with the off-roading community and local businesses.
   5.1. Conduct an outreach and education campaign related to raising awareness of impacts of off-roading on Guam's terrestrial and marine resources by 2019.
   5.2. By the end of 2019, hold meetings with key stakeholders (e.g. land owners, natural resource management agencies, and the off-roading community) to discuss potential off-roading sites (including issues of access) to be targeted for best management practices and sediment control systems.
   5.3. By mid-2020, collaborate with stakeholders to design eco-friendly off-roading areas at two sites on Guam.
   5.4. By the end of 2021, establish eco-friendly trails at two sites using erosion and sediment control best management practices and implement a long-term maintenance and enforcement plan with consideration of climate-smart design principles.

6. By 2025, improve storm water management in Tumon Bay, a priority site, and in other commercial areas by upgrading existing infrastructure that contributes to flooding.
   6.1. Map impervious surfaces in Tumon Bay and in other commercial areas and assess their potential contributions to runoff and impacts on coral reef health by 2020.
   6.2. Conduct outreach and education efforts related to storm water impacts and management at at least two schools, two hotels, and two shopping centers in the Tumon Bay area by the end of 2020.

6.3. Upgrade and improve maintenance of existing storm water management systems in Tumon Bay and implement a consistent schedule for maintenance by the end of 2021.
6.4. Identify all illegal connections to storm water and enforce regulations.
6.5. With community participation, install green infrastructure – e.g. rain gardens and green roofs – at at least one school, one hotel, and one shopping center in the Tumon area by the end of 2022.
6.6. By 2025, increase the amount of permeable surface area in Tumon and other commercial areas by at least 10%.

7. Assess and reduce the impacts of improper agricultural practices and on Guam's coral reefs.
   7.1. Encourage and promote organic farming as an alternative farming method on Guam.
   7.2. Determine appropriate methods for farming on steep hillsides.
   7.3. Develop outreach materials that promote agricultural practices that minimize impacts to coral reefs.
   7.4. Pass legislation to ban the use of fire to clear agricultural property.
   7.5. Pass legislation to regulate the types of fertilizers that can be used on coastal properties.

OUTCOME RR: Increased reef response and restoration

Goal: *Enhance the resilience of Guam's coral reef ecosystems by responding rapidly and effectively to acute impacts and restoring coral reef habitats to preserve the viability of coral communities.*

Objectives and actions:

1. Adopt legislation to hold responsible parties accountable for physical damage (e.g. vessel groundings) and spills that impact coral reef health by 2021.
   1.1. Provide expert technical guidance for policy development and identify links between stakeholder groups and members of the legislature, and the judicial branch by 2019.
   1.2. Engage with decision makers to revisit the Coral Reef Protection Act and its feasibility for reintroduction by the end of 2019.
   1.3. By 2020, conduct a study to reassess the value of Guam's coral reefs, which was last conducted in 2007.
   1.4. Develop a sustainable financing mechanism to fund emergency reef restoration after vessel groundings, impacts from severe weather events, and other sources of acute physical damage to reefs by 2021.
   1.5. Develop a Coral Reef Vessel Grounding Response Plan with appropriate emergency management and incident command structure once legislation is passed.

2. Increase the capacity of the Guam Coral Reef Response Team to rapidly respond to acute impacts affecting Guam's coral reefs (e.g. coral bleaching events; vessel groundings and spills; and outbreaks of disease, COTS, and nuisance and invasive species).
   2.1. Continue funding the Coral Reef Resilience Coordinator position within an appropriate Government of Guam agency to coordinate the Response Team, conduct response activities, and support restoration efforts.
   2.2. Improve the efficiency of resource mobilization during and following acute impacts.
   2.3. Support annual training activities for members of the Response Team.
   2.4. Develop and test approaches for mitigation, rehabilitation, and restoration after acute impacts such as bleaching events, vessel groundings, and severe storms.
   2.5. Increase participation of relevant natural resources agencies in response activities.

2.6. Develop response plans to address vessel groundings, oil and chemical spills, coral disease outbreaks, and outbreaks of nuisance and invasive species as needed.
2.7. Produce a report on the history of acute impacts on Guam's reefs to create a timeline of events, build institutional knowledge, learn from past response activities, and determine existing knowledge gaps.
2.8. Conduct research on the drivers of coral bleaching and disease-related coral mortality to better understand the relative resilience of Guam's coral species and reef sites.
2.9. Quantify the extent of nuisance and invasive species impacting Guam's reefs and investigate and test management approaches to address these impacts.

3. Develop and implement a science-based, community-driven Coral Reef Restoration Plan to restore viable coral communities on Guam's reefs by 2020.
   3.1. Establish the Guam Reef Restoration and Intervention Partnership (GRRIP), which should be convened regularly and include participation from all relevant stakeholders.
   3.2. By mid-2019, determine the necessary steps for development of a Reef Restoration Plan, including identification of key stakeholders; assessment of any legislation needed for implementation; review of techniques and methods that could be used on Guam; potential funding sources; evaluation of capacity gaps; and identification of links between economic sustainability and reef health.
   3.3. Formalize relationships between appropriate local government agencies and non-governmental entities (via MOUs, MOAs, etc.) to expand and strengthen the Reef Response and Restoration Working Group and the Guam Reef Restoration and Intervention Partnership by 2020.
   3.4. By the end of 2020, conduct a public outreach and education campaign to generate interest in coral reef restoration and increase community participation in restoration efforts.
   3.5. By the end of 2020, create a map of all known locations of all ESA-listed coral species around Guam and include these populations and species in the Restoration Plan.
   3.6. Finalize the Coral Reef Restoration Plan by May 2020 and commence implementation by the end of 2020.
   3.7. Hire a full time Coral Reef Restoration Coordinator at a Government of Guam Agency by 2020.
   3.8. Up-scale current reef restoration efforts via sexual and asexual propagation while incorporating novel technologies (e.g. stress-hardening of corals; manipulation of symbiotic partnerships; assisted migration and gene flow; larval propagation techniques) to maximize efficiency and ensure that restored coral populations are resilient to impacts such as coral bleaching, disease, ocean acidification, and predation by COTS and other nuisance species, e.g. *Drupella cornus*.
   3.9. Incorporate alternative approaches to restoring the viability of coral communities (e.g. through seagrass and mangrove restoration; herbivore propagation and replenishment; and removal of invasive and/or nuisance species, such as *Chaetomorpha* spp., COTS, *Drupella cornus*, and *Coralliophila* spp.) into Guam's reef restoration activities.
   3.10. By 2021, assess genotypes of coral colonies within Guam's in situ coral nurseries and study population genetics of donor sites to better understand coral resilience to stressors and increase success of restoration activities.
   3.11. Conduct studies to improve understanding of taxonomy of Guam's corals and identify endemic species and/or sub-populations, then assess relative risk of extirpation/extinction of local coral species due to climate change to support management and/or restoration efforts designed to reduce biodiversity loss.

4. Enhance the mid-water ocean-based coral nursery in the Piti Bomb Holes Marine Preserve by expanding structural capacity to grow fragments and sexual recruits, increasing the number of species propagated, and improving coral survivorship by 2025.

4.1. Double the capacity of the ocean-based Piti coral nursery by 2022.
4.2. Develop protocols to increase genetic diversity in restoration activities by 2022.
4.3. Conduct research on spawning times of at least three target coral species by 2022.
4.4. Improve survival of fragments and sexual recruits housed in the nursery through more frequent maintenance and improved propagation methods by 2025.

5. Establish a total of two community-based coral outplanting sites within Guam's three priority sites (Piti Bomb Holes Marine Preserve; Tumon Bay Marine Preserve; Achang Reef Flat Marine Preserve/Cocos Lagoon) by 2021.
   5.1. Host stakeholder meetings to garner community feedback on site selection for outplant sites by mid-2020.
   5.2. Develop protocols and training programs for community outplanting methods, site maintenance, and outplant monitoring by the end of 2020.
   5.3. Outplant coral fragments and/or sexual recruits with community participation at at least two sites within Guam's priority areas by the end of 2021 and implement regular monitoring and maintenance of outplant plots by community members.

6. Plan and implement coral outplanting in the Tumon Bay Marine Preserve by 2021.
   6.1. Assess the health and extent of remaining staghorn patches in the Tumon Bay Marine Preserve by 2020.
   6.2. By 2020, identify potential outplant sites in the Tumon Bay Marine Preserve that will be resilient to climate impacts and local stressors by assessing depth, water flow, substrate, and level of human use.
   6.3. Outplant coral fragments and/or sexual recruits with community participation at at least one site in the Tumon Bay Marine Preserve by 2021 and implement regular monitoring and maintenance of outplant plots by community members.

7. Continue to support Guam's Long-term Coral Reef Monitoring Program and conduct research that quantifies change in Guam's reef communities to inform response and restoration efforts.
   7.1. Hire staff or fund a UOG graduate student to analyze existing datasets and answer management-driven research questions by 2019.
   7.2. Build capacity within local resource agencies and partners to better understand fish and coral taxonomy and identification by 2020. Utilize experts within local agencies to hold regular workshops for various personnel to build this capacity.
   7.3. Synthesize existing data and collect new data as needed to quantify the extent of *Acropora* spp., *Montipora* spp., and other key taxa around Guam and map sites with the greatest proportions of these genera, which are vulnerable to both COTS and bleaching.
   7.4. Use data analyzed under RR7.3 to create a spatial model of these corals on Guam's reefs, which will contribute to the management of *Acropora globiceps*, a listed species under the Endangered Species Act.
   7.5. Sustain existing community engagement programs focused on reef monitoring and impact reporting, such as the community-based coral reef monitoring program under Friends of Reefs Guam and the Eyes of the Reef Marianas program.
   7.6. Conduct fine-scale current modeling of Guam's nearshore waters to better understand local connectivity of reef taxa, including between preserves and unprotected areas and among Guam's marine preserves, by the end of 2020.

OUTCOME RU: Sustainable recreational use and tourism

Goal: *Enhance the resilience of Guam's coral reef ecosystems and improve marine experiences for local residents and tourists by reducing impacts of recreational use and misuse and promoting sustainable recreational use of coral reef resources.*

Objectives and actions:

1. Implement and enforce existing statutes and plans related to sustainable recreational use and tourism, including the Guam Territorial Seashore Protection Act of 1974 (PL 12-108), the Recreational Water Use Management Plan, and the Marine Preserve Eco-permit law (PL 27-87).
   1.1. Prepare a report outlining the Guam Territorial Seashore Protection Act of 1974 (PL 12-108) and the draft Guam Seashore Reserve Plan, the Recreational Water Use Management Plan, the Marine Preserve Eco-permit law (PL 27-87), and other plans and statutes relevant to sustainable recreational use and tourism, including updates on their status, by the end of 2019.
   1.2. Complete a needs assessment on how to improve and effectively implement plans documented by RU1.1, including a feasibility study of sustainable financing options, then update these plans as needed, by the end of 2020.
   1.3. Conduct inreach with Government of Guam agencies and the Legislature and outreach with local businesses and stakeholders to increase awareness of the importance of these statutes and plans by 2020.
   1.4. Support training opportunities for relevant Government of Guam staff that will build capacity to successfully complete objective RU1.
   1.5. Seek funding for technical legal assistance to prepare and finalize regulations for PL 27-87 by 2020.
   1.6. Identify a sustainable source of funding, such as a green fee for visitors, for data collection and monitoring, permitting, and enforcement of plans and statutes outlined by RU1.1 and increase success of enforcement efforts by 2023.
   1.7. Implement and enforce updated plans and statutes by 2025 once barriers identified by RU1.1 have been addressed.

2. Develop and implement programs to engage stakeholders and the public in sustainable recreational use.
   2.1. Collaborate with Naval Facilities Engineering Command, US Air Force, and US Army (e.g. Start Right Program) to improve the marine outreach portion of the incoming education program for active duty and temporary duty personnel.
   2.2. Conduct a broad outreach campaign using effective design and marketing practices to educate the public on sustainable recreational use and other relevant topics (e.g. marine debris issues), to include development of products such as radio and television advertisements, mascot development, social media messaging, art/sculpture exhibits, etc. Ensure that outreach and education efforts targeted at public schools are aligned with core curriculum standards for science.
   2.3. Improve and increase signage near reef areas by 2020. Signage should be presented in multiple languages and include information designed to prevent coral damage, illegal fishing and gleaning, marine life harassment, littering, etc.
   2.4. Partner with local organizations (e.g. Guam Swimming Federation, Manukai Athletic Club, Manhoben Swim Club, paddling groups) to create and/or enhance programs that provide opportunities for youth to experience Guam's coral reef environments first-hand.

2.5. Develop a culturally-relevant outreach and education campaign related to sustainable recreational use of reefs and beach areas targeted to migrants from the Federated States of Micronesia and translated into relevant languages.
2.6. Develop a list of alternative activities and/or sites for use by marine tour operators during coral bleaching events, extreme low tide events, and other periods of high stress for coral reefs and also during coral and fish spawning seasons and fish runs to relieve pressure and reduce impacts at heavily-used reef sites.

3. Develop and implement outreach and education programs for visitors in cooperation with the tourism industry to reduce impacts of recreational use on Guam's coral reefs.
   3.1. Strengthen relationships with tour operators through collaboration with the Guam Visitors Bureau and the Guam Hotel and Restaurant Association.
   3.2. Cooperate with the Guam Visitors Bureau and Guam Community College to incorporate marine education (including information on legal and appropriate interactions with marine mammals, regulations on shark, and impacts of fish feeding) into the Tour Guide Certification Training course.
   3.3. Amend existing legislation (PL 23-136) to classify marine tour operators (e.g. dive operators and instructors, dive guides, and boat captains) as tour guides in order to mandate participation by these individuals in the Tour Guide Certification Training course.
   3.4. Work with the Guam Visitors Bureau and the Guam Hotel and Restaurant Association to develop culturally-relevant outreach materials translated into multiple languages, potentially including an ocean pledge, visitors passport, videos to be played on airplanes, social media messaging, and/or brochures for hotels.
   3.5. Develop and implement a framework for a sustainable financing mechanism through tourism by 2020 to support coral reef management, conservation, and restoration efforts.

OUTCOME H: Human community resilience and climate change adaptation

Goal: *In recognition of humans as part of local ecosystems, enhance the resilience of Guam's human communities by increasing the capacity of local communities to adapt to climate change while facilitating sustainable economic development and preserving culture, traditions, and ways of life.*

Objectives and actions:

1. Incorporate socioeconomic considerations into coral reef management, planning, and activities.
   1.1. Assess the feasibility and benefits of public-private partnerships for coral reef management and restoration efforts.
   1.2. Increase Guam's participation in regional initiatives, such as the Micronesia Challenge, that aim to safeguard human wellbeing and protect natural resources.
   1.3. By the end of 2020, develop interagency guidelines to improve capacity to engage in community-focused natural resources management and enhance community engagement across Government of Guam activities and programs.
   1.4. By the end of 2020, compile existing socioeconomic data and survey results, then conduct further studies as needed to measure public awareness of climate change issues and how climate change impacts are being experienced and perceived by the people of Guam.
   1.5. By 2023, complete an island-wide vulnerability assessment to support resilience-based management and better understand the anticipated impacts of climate change on human communities and coral reefs, incorporating both community knowledge and climate science.

1.6. Ensure that decision makers, community leaders, and groups are effectively and consistently engaged in discussions about climate change and coral reef resilience.

2. Evaluate, develop, and promote alternative livelihood programs to reduce local impacts on coral reefs from unsustainable practices and protect livelihoods that may be threatened by climate change.
   2.1. Assess feasibility of the economic potential of various alternative livelihood options, such as aquaculture, cultural tourism, etc.
   2.2. Identify leaders within disenfranchised communities, such as immigrant communities, to improve engagement on issues such as alternative livelihoods and fisheries.
   2.3. Support community-based non-governmental organizations that are focused on developing alternative livelihood programs and reducing unsustainable practices.
   2.4. Support the creation of jobs related to coral reef and watershed restoration, management, and industry.

3. Develop and support programs to increase awareness of climate change and marine conservation, while engaging the public in climate change adaptation, conservation, and citizen science.
   3.1. Secure funding to hire a Coral Reef Outreach and Education Coordinator to coordinate and implement coral reef outreach and education activities by 2021.
   3.2. Secure funding to support educators, community leaders, and advocates to provide education to the public on coral reef issues.
   3.3. Continue to support community-focused programs (e.g. Friends of Reefs Guam, Eyes of the Reef Marianas, Guardians of the Reef, Guam Nature Alliance projects, Humatak Community Foundation, Micronesia Challenge, UOG Sea Grant projects) and other outreach initiatives that increase community engagement in conservation, monitoring, citizen science, and climate change adaptation.
   3.4. Incorporate relevant climate change adaptation strategies developed by other islands and jurisdictions into outreach and education programs on Guam.
   3.5. Support scholarship and internship programs for students interested in marine biology, environmental science, and conservation.

4. By 2021, collaborate with the tourism sector to plan for climate change adaptation in Tumon by developing a Conservation Action Plan to collectively address issues of flooding and sea level rise.
   4.1. Identify key stakeholders in the tourism sector, including the Guam Visitors Bureau and the Guam Hotel and Restaurant Association, and engage them in the Conservation Action Plan development process by the end of 2019.
   4.2. Develop a list of best management practices for inclusion in the Conservation Action Plan for Tumon, including increased use of green infrastructure by the end of 2019.
   4.3. Inventory and re-evaluate grey structures (e.g. sea walls, surf breaks) and assess the need for additional ponding basin systems in Tumon by 2020.
   4.4. Review and assess maintenance plans for private and public properties in Tumon to determine how they address issues with storm water and flooding by the end of 2020.
   4.5. Finalize the Tumon Conservation Action Plan with input from the tourism sector and community members by the end of 2021.
   4.6. Develop and/or amend regulations and laws as needed to address unsustainable practices occurring in Tumon Bay (e.g. vehicles driving on the beach).

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Appendices

APPENDIX I: Coral reef management survey results

Survey overview

The survey on Guam's coral reef management efforts and priorities, which was administered online in October 2017, received a total of 29 responses from representatives of 15 entities:

- Three local agencies (BSP, GEPA, DAWR)
- Four federal agencies (NOAA, USFWS, NPS, DOD-NAVFAC)
- Four local educational institutions/programs (GCC, UOGML, UOG-CIS, UOG-Sea Grant)
- Two nonprofit organizations (TNC, Ayuda Foundation)
- One local business (MDA)
- One intergovernmental program (Micronesia Challenge)

Survey takers were asked basic demographic information: name; email address; job/position title; agency or organization; how their work relates to coral reefs; and their level of experience (number of years) in coral reef management and/or research (questions 1-6). Respondents answered eight additional questions about the threats facing Guam's coral reef ecosystems; the most important coral reef management priorities for the next five years; the most and least successful aspects of reef management efforts on Guam; and the greatest knowledge and capacity gaps limiting Guam's ability to understand and manage its coral reef resources (questions 7-14). Respondents also had the opportunity to provide their suggestions for potential training activities, programs, and/or workshops to address existing knowledge and capacity gaps (question 15).

Survey questions and summary responses

Q6. How many years have you worked in coral reef management or research, or in a related field that depends on coral reef ecosystems?

- Respondents reported a total of 430.5 years of experience in coral reef management or research, or in a related field that depends on coral reef ecosystems
- Average of ~15 years per person (14.84), range: 1 year to 48 years

Q7. What are the top three threats to Guam's coral reef ecosystems? Rank the following threats 1-3 with #1 being the most important today and for the next five years. You may add additional threats as "Other".

List of threats provided: Sedimentation, nutrient pollution, toxin/metal/chemical pollution, marine debris, fishing pressure, ocean warming/coral bleaching, ocean acidification, sea level rise, coral disease, crown of thorns sea stars (COTS), other nuisance or invasive species not including COTS, vessel groundings, recreational use and misuse

- 27 out of 29 respondents (93%) identified ocean warming/coral bleaching as one of the three most important threats to Guam's coral reef ecosystems; 20 respondents identified this as the #1 most important threat
- 21 out of 29 respondents (72%) identified sedimentation as one of the three most important threats to Guam's coral reef ecosystems; 4 respondents identified this as the #1 most important threat

- 17 out of 29 respondents (59%) identified fishing pressure as one of the three most important threats to Guam's coral reef ecosystems; 4 respondents identified this as the #1 most important threat

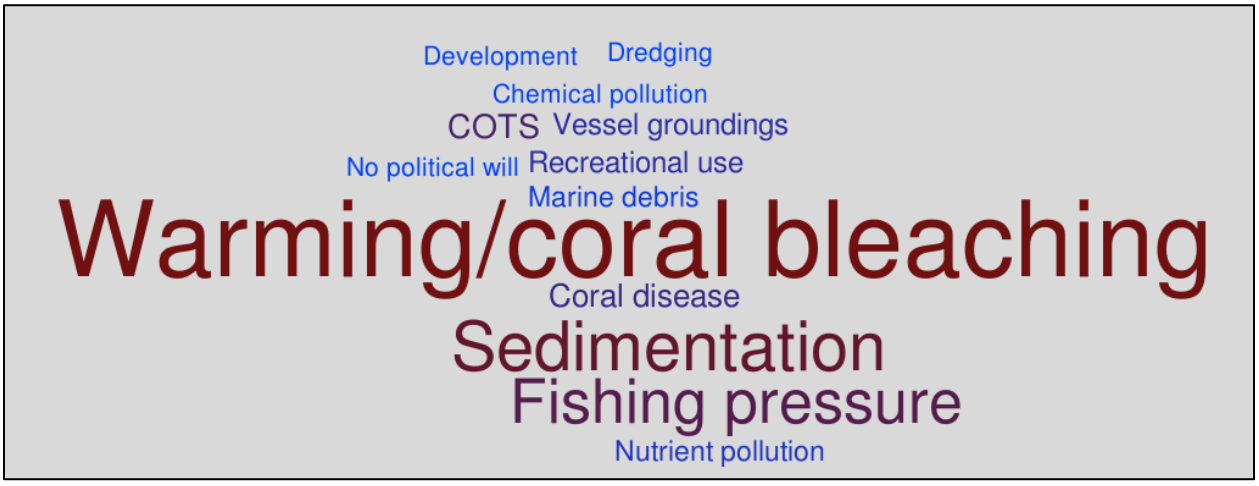
How this question was analyzed: Each threat was assigned three points each time it was identified as the most important threat, two points each time it was identified as the second most important threat, and one point each time it was identified as the third most important threat. This method was used to develop a score for each threat.

Threats that weren't listed, but were identified as important threats by respondents:

- Storm water/runoff (Identified by one respondent as #3)
- Dredging/military activities in Apra Harbor (Identified by one respondent as #3)
- Lack of political will (Identified by one respondent as #3)
- Development (Identified by one respondent as #3)

Scores:

Ocean warming/coral bleaching (71)	Vessel groundings (4)	Lack of political will (1)
Sedimentation (39)	Nutrient pollution (3)	Development (1)
Fishing pressure (32)	Marine debris (2)	Ocean acidification (0)
COTS (7)	Toxin/metal/chemical pollution (1)	Sea level rise (0)
Coral disease (6)	Storm water runoff (1)	Other nuisance or invasive species (0)
Recreational use and misuse (4)	Dredging/military activities in Apra Harbor (1)	



Q8. Explain why you selected those top three threats.

These answers have been summarized, revised for clarity, and categorized according to thematic areas.

General:

- Severity, frequency, and spatial extent of threat's impact
- Most likely to have increasing impacts in coming years
- Findings of monitoring efforts, coral reef research, and personal observations

- Some chose the most important threats based on what we can address through management efforts; others chose most important threats based on what is most out of our control

Related to ocean warming and coral bleaching:
- Coral bleaching has recently caused extensive coral mortality around Guam
- Guam's coral reefs are currently being affected by severe bleaching
- Bleaching events are expected to become annual by mid-century

Related to sedimentation:
- Sedimentation is a serious issue in southern Guam, where there is very low coral cover
- Storm water runoff and sedimentation increase coral vulnerability to bleaching
- Off-roading and burning continue to exacerbate sedimentation and erosion
- Sedimentation affects both adult corals and coral recruitment
- Erosion and sedimentation introduces nutrients and pathogens to coral reefs

Related to fishing pressure:
- Guam's fisheries are extremely depleted (near collapse if not already collapsed) due to lack of fishing regulations and enforcement (e.g. no regulations for scuba spearfishing)
- Fishing pressure has resulted in fish population declines around the island
- Fishing pressure has not been addressed because it is a sensitive topic
- Compromised fish populations reduce ecosystem resilience
- Healthy herbivore biomass is needed to prevent phase shifts to algal dominated systems and support ecosystem recovery after impacts

Related to COTS:
- COTS have resulted in major coral decline around Guam
- Decrease in abundance of preferred COTS prey (*Acropora, Montipora*) may have lessened the likelihood of severe, widespread COTS outbreaks around Guam

Related to coral disease:
- Coral diseases are currently poorly understood
- Guam's coral reefs have been affected – and are being affected by – several diseases
- Bleached corals may be more susceptible to disease and diseased corals may be more susceptible to bleaching
- Climate change is likely to increase disease occurrence

Related to recreational use and misuse:
- Growing number of tourists on Guam has increased – and will continue to increase – human use impacts on local coral reefs
- Human users, both tourists and locals, aren't aware that they're causing damage

Related to other threats:
- Increased population growth and development is leading to erosion, runoff, and degraded water quality
- Dredging is contributing to reef stress and degradation in Apra Harbor

Q9. Listed below are the top five coral reef management priorities identified for Guam for 2010-2015. Please rank these priorities 1-5, with #1 being the most important priority for coral reef management today and for the next five years. You may add additional priorities as "Other".

List of priorities provided: Reduce impacts of land-based sources of pollution (LBSP); protect fisheries and reduce impacts of fishing; reduce impacts of military build-up; reduce impacts of recreational use and misuse; reduce impacts of climate change by enhancing resilience

- 19 out of 29 (66%) respondents identified "Reduce impacts of climate change by enhancing resilience" as the first or second most important priority for coral reef management; 14 respondents identified this as the #1 most important priority
- 16 out of 29 (55%) respondents identified "Reduce impacts of LBSP" as the first or second most important priority; 5 respondents identified this as the #1 most important priority
- 13 out of 29 (45%) respondents identified "Protect fisheries and reduce impacts of fishing" as the first or second most important priority; 6 respondents identified this as the #1 most important priority

How this question was analyzed: Each priority was assigned 5 points each time it was identified as the most important priority, 4 points each time it was identified as the second most important priority, 3 points each time is was identified as the third most important priority, 2 points each time it was identified as the fourth most important priority, and 1 point each time it was identified as the fifth most important priority. This method was used to develop a score for each priority.

Priorities that weren't listed, but were identified as priority areas by respondents:

- Identify and map the most resilient and least resilient reefs around Guam (Identified by one respondent as #1)
- Increase political will to protect coral reefs (Identified by one respondent as #1)
- Produce scientific data to guide reef restoration (Identified by one respondent as #2)
- Invest in alternative livelihoods (Identified by one respondent as #5)
- Increase public awareness (Identified by one respondent as #5)
- Increase resilience of human communities to climate change (Identified by one respondent as #5)

Scores:

Reduce impacts of climate change by enhancing resilience (107)	Increase political will (5)
Reduce impacts of LBSP (101)	Produce data to guide reef restoration (4)
Protect fisheries and reduce impacts of fishing (83)	Invest in alternative livelihoods (1)
Reduce impacts of military build-up (58)	Increase public awareness (1)
Reduce impacts of recreational use and misuse (54)	Increase resilience of human communities (1)
Identify and map reef resilience (5)	

Q10. What were your key considerations for selecting your top five priorities?

These answers have been summarized, revised for clarity, and categorized according to thematic areas.

General:

- Severity, frequency, and spatial extent of the threat to be addressed by a priority
- Based on experiences in coral reef management, results of research and monitoring efforts, reviews of local plans, discussions with experts, and personal observations
- One respondent selected priorities based on corresponding management activities that could have greatest immediate impacts
- One respondent identified priorities based on what they think Guam can achieve based on current capacity in coral reef management
- One respondent prioritized island-wide problems (climate change and fisheries management) over localized problems (LBSP and military build-up)

Related to reducing climate change impacts by enhancing resilience:

- Projects that address this priority would also fall under the other priorities
- Important to identify local solutions to address global threat of climate change
- Need to understand how we can mitigate warming, acidification, and sea level rise and effectively restore coral reefs to increase resilience
- Importance of improving coral propagation and reef restoration techniques will become more valuable as coral reefs face increasing impacts of climate change

Related to protecting fisheries and reducing fishing impacts:

- Fisheries management is possible; there are specific management efforts to address this, while we can't decrease rate of climate change

Related to reducing impacts of military build-up:

- The impacts of the military build-up are likely to be quite localized

Related to reducing impacts of recreational use and misuse:

- Impacts of recreational use aren't as widespread as some of the other threats, but they occur on valuable reefs and within marine preserves

Related to other priorities:

- Increasing political will to protect coral reefs will trickle down and increase the effectiveness of all coral reef management efforts

Q11. What aspects of coral reef management on Guam have been most successful?

These answers have been summarized, revised for clarity, and categorized according to thematic areas.

Outreach and education:

- Coral reef awareness and education campaigns with students
- Giving people firsthand experiences with coral reefs through guided tours
- Tasi Beach Guides project
- Guardians of the Reef program
- Community engagement in coral reef management
    - Eyes of the Reef Marianas program
    - Guam Community Coral Reef Monitoring Program
- Guam Nature Alliance and the Environmental Education Committee
- Kika Camp

Policies:

- Ban on shark finning
- Establishment of marine preserves
- Local and federal regulations to reduce point and non-point source pollution
- Protection of corals under the Endangered Species Act has impeded large-scale in water construction and dredging activities

Research and monitoring:

- Long-term coral reef monitoring program
- Guam's in situ coral nursery
- Coral bleaching surveys

Other:

- Collaboration among local and federal agencies, NGOs, businesses, and academic institutions (e.g. Guam Coral Reef Response Team, Natural Resources Subcommittee on military build-up led by GCMP and BSP)
- Involvement of scientists in coral reef management activities
- Watershed restoration projects
- Non-governmental activism aimed at development projects with high potential to impact nearshore coral reefs

Q12. What aspects of coral reef management on Guam have been least successful?

These answers have been summarized, revised for clarity, and categorized according to thematic areas.

Outreach and education:

- Insufficient/unclear/missing signage at beaches and marine preserves to prevent recreational use impacts
- Lack of sustained effort to reduce fires in southern Guam

Policies:

- Lack of regulations to implement and enforce laws (e.g. Eco-Permit law, Conservation Officer Reserve program)
- Lack of fisheries regulations and insufficient enforcement of existing regulations
- Illegal fishing occurring in marine preserves
- No statute to address vessel groundings or hold responsible parties accountable

Research and monitoring:

- Studies conducted by visiting scientists who lack knowledge of long-term trends and Guam's coral reef ecology

Other:

- Lack of political will/support
- Conflicts with fishing community; lack of trust between agencies and fishers
- Insufficient resources to manage reefs effectively
- Not enough work with on-the-ground staff in the tourism industry
- Installation of mooring buoys (project was funded, but most buoys were not installed)
- Watershed restoration only implemented at small scale
- Lack of storm water management
- Ineffective efforts to reduce erosion and pollution and improve water quality

Q13. What are the biggest knowledge gaps that limit Guam's ability to understand and manage its coral reef ecosystems?

These answers have been summarized, revised for clarity, and categorized according to thematic areas.

Related to climate change:

- Lack of understanding of which corals and coral populations are most resilient (and least resilient) and why
- Data to support efforts to mitigate warming (e.g. reef fountains, cooling systems)
- Research to support selection of appropriate outplanting sites to improve success of reef restoration efforts and scale-up restoration activities
- Research on impacts of ocean acidification on Guam's corals
- Analysis of coral bleaching data collected since 2013
- How climate change may impact spread and abundance of coral diseases and nuisance and invasive species
- Research to increase understanding of the impacts of climate change on human communities and how communities can best adapt to these changes

Related to LBSP:

- Quantification of impacts of storm water runoff, nutrient loads and inputs, and sedimentation on coral reefs
- How to effectively mitigate sedimentation from erosion of southern grasslands

- Lack of knowledge or application of best management practices in construction and development projects
- Need pilot projects demonstrating effectiveness of watershed restoration approaches

Related to fish and fisheries:
- Effects of commercial fishing on Guam's fish communities
- Need more fisheries dependent data
- Data on status of Guam's reef fish communities, relative abundance of functional groups, and impacts of fishing on these assemblages
- Identification of overfishing thresholds and tipping points
- Data on life histories that can be applied to create species-specific regulations
- Data on effectiveness of marine preserves
- Need better understanding of demand and market for reef fish on Guam
- Impacts of overharvesting of sea cucumbers (balate') on Guam's reef communities
- Likely effects of climate change on fishery productivity

Other:
- Need to better understand the individual and interactive effects of local stressors and climate change on Guam's coral reefs
- Need more applied research that is relevant to management instead of basic science
- Past, current, and likely future changes in coral reef community composition and overall reef health and impacts on ecosystem functioning
- Population genetics and connectivity of Guam's corals
- Updated assessment on the economic value of Guam's reefs
- Lack of public awareness and understanding of coral reef ecosystems
- Lack of awareness of traditional knowledge and practices among reef managers
- Insufficient communication of scientific findings to inform management
- Need for assessment of effectiveness of local natural resources management agencies and their projects and programs

Q14. What are the biggest <u>capacity gaps</u> that limit Guam's ability to effectively manage its coral reef ecosystems?

These answers have been summarized, revised for clarity, and categorized according to thematic areas.

Related to outreach and education:
- Need more resources (staff and funding) to make outreach more effective
- Lack of agency presence and engagement in communities
- Need to improve levels of communication and trust between agencies and citizens
- Increase outreach in schools (primary, secondary, and post-secondary)

Related to policies and regulations:
- Insufficient legislation to protect coral reef resources and fisheries (e.g. need to ban scuba spearfishing and/or gill nets, ban or strictly regulate balate' harvesting, create licensing or permit system for fishing and recreational use)
- Lack of regulations to enforce fisheries legislation (Eco-permitting, Conservation Officer Reserve program)

- Need Coral Reef Protection Act to protect reefs from vessel groundings
- Need legal experts who can draft new legislation and regulations
- Insufficient prosecution of cases related to natural resource violations
- Lack of political will and environmental stewardship among elected officials

Related to enforcement of existing regulations:
- Lack of enforcement of fisheries regulations and marine preserves due to insufficient manpower and staff
- Lack of enforcement of storm water and runoff issues in Tumon Bay
- Need more Conservation Officers and funding for vehicles, equipment, etc.
- Need to increase budgets for DAWR and GEPA

Related to technical capacity:
- Not enough local staff trained in coral biology and identification
- Federal government should hire personnel or contractors to sit within local agencies and build capacity
- Technical staff need to be supported by mid- and upper-managers who can bring issues to legislature and governor's office
- Need equipment, supplies, and expertise for reef restoration
- Difficult to find qualified staff with technical expertise who are willing to accept low salaries offered by local agencies

Related to partnerships:
- Insufficient inreach among local agencies
- Need to develop better relationships with business leaders and policy makers
- Need a shared vision for coral reef management
- More focused working groups that meet regularly

Other:
- High staff turnover within local agencies
- Insufficient resources and staff to reduce sedimentation on a large scale
- No local non-profit organizations specifically focused on coral reef conservation
- Need for a local non-profit group specializing in coral reef restoration
- Need to shift from reactive to proactive coral reef management
- Lack of infrastructure to manage storm water inputs
- Ineffective or inappropriate prioritization of management actions

Q15. Do you have any suggestions for training activities, courses, or workshops that could address capacity gaps in Guam's coral reef management?

These answers have been summarized, revised for clarity, and categorized according to thematic areas.

- Workshop on building rain gardens and/or community gardens
- Training on increasing effectiveness of communication (including communication of climate change impacts) and outreach efforts
- Workshop with natural resource managers and fishing community using effective mediation techniques
- Training program and/or educational videos in multiple languages to reduce recreational use impacts

- Workshop or training on identifying coral species and coral diseases
- Training on COTS removal methods
- Training in reef restoration methods and development of a scientifically-sound strategy for reef restoration
- Training in climate change adaptation approaches
- Workshop on evaluating effectiveness of management efforts
- Natural Resource Damage Assessment and Restoration training
- Workshop on strategic planning and project design including commitments from participants to complete tasks after the training

APPENDIX II: List of attendees from the Strategizing for Reef Resilience Workshop

Strategizing for Reef Resilience Workshop
November 8, 2017 – Hall of Governors, Governor's Complex, Adelup
Workshop Participants

LOCAL GOVERNMENT

Bureau of Statistics and Plans:
- Carl Dominguez
- Lola Leon Guerrero
- Millie Erguiza
- Tina Mafnas
- Whitney Hoot
- Patrick Keeler

Guam Coastal Management Program:
- Gil Suguitan
- Francis Damian

Guam Department of Agriculture:
- Nathan Rios
- Nathaniel Martin
- Richard Ragadio

Guam Visitors Bureau:
- Meriza Peredo

FEDERAL GOVERNMENT

National Oceanic and Atmospheric Administration:
- Val Brown
- Adrienne Loerzel
- Marybelle Quinata

National Park Service:
- Allison Miller
- Ashton Williams

US Fish and Wildlife Service:
- Jeried Calaor

Department of Defense-Naval Facilities Engineering Command:
- Hilary Goodwin
- Tammy Summers

UNIVERSITY OF GUAM

University of Guam Marine Laboratory:
- Laurie Raymundo, PhD
- Tom Schils, PhD
- Dave Burdick
- David Combosch, PhD
- Andrea Hershberger
- Nicole Burns

University of Guam Center for Island Sustainability:
- Phil Cruz
- Matthew Putnam
- Michael Rucinski

University of Guam Sea Grant Program:
- Marie Auyong
- Naomi Borg

NON-GOVERNMENTAL ORGANIZATIONS

Humatak Community Foundation:

- Joe Quinata
- Fred Gofigan

The Nature Conservancy:

- Farron Taijeron

LOCAL BUSINESSES

Fish Eye Marine Park:

- Akihiro Tani
- Renny Loren

Underwater World:

- Mike McCue

COMMUNITY

Private citizens:

- Luis Cabral

APPENDIX III: List of attendees from the Climate-smart Design for Coral Reef Management Workshop

Climate-smart Design for Coral Reef Management Workshop
September 24-25, 2018 – Latte Room, Pacific Star Resort & Spa, Tumon
Workshop Participants

LOCAL GOVERNMENT

Bureau of Statistics and Plans:

- Carl Dominguez
- Mallory Morgan
- Whitney Hoot
- Patrick Keeler

Guam Department of Agriculture:

- Celestino Aguon
- Nathaniel Martin

Guam Environmental Protection Agency:

- Margaret Aguilar
- Taryn Mesa

FEDERAL GOVERNMENT

National Oceanic and Atmospheric Administration:

- Val Brown
- Adrienne Loerzel
- Marybelle Quinata

National Park Service:

- Mike Gawel
- Ashton Williams

UNIVERSITY OF GUAM

University of Guam Marine Laboratory:

- Jason Biggs, PhD
- David Combosch, PhD
- Frank Camacho
- Andrew McInnis
- Dave Burdick
- Abram Townsend
- Mariel Cruz
- Constance Sartor
- Andrea Hershberger
- Julia Berg
- Lourdes Mafnas

NON-GOVERNMENTAL ORGANIZATIONS

The Nature Conservancy:

- Farron Taijeron

LOCAL BUSINESSES

Underwater World:

- Sara Hamilton

APPENDIX IV: Guam Vulnerability Assessment for CCAP Workshop

COMMUNITY NAME: *Guam, Mariana Islands*			
INDICATORS OF A CHANGING CLIMATE			
Climate Threat			**Impacts**
Indicator	**Magnitude and direction of change over time based on community knowledge and latest climate science**	**Changes in environmental conditions (Climate Stressors)**	**Potential impacts to natural and social resources**
Air/land temperature	**Air temperature has increased and is projected to continue increasing in Guam. Land is expected to continue warming, especially at higher elevations**. Historical: Average air temperature on Guam is 26°C (79°F) and air temperatures are relatively uniform throughout the year. Globally, mean land temperature increased by 0.74°C (1.3°F) during the 20th century and 0.13°C (0.21°F) per decade in the past 50 years, almost twice the rate of warming that occurred during the first half of the century (0.07°C or 0.13°F). Projected: By the end of the 21st century (2080-2099), surface air temperature over Guam is expected to increase by 1.5-2.0°C under RCP4.5 (medium emissions scenario) and by 3.0-3.5°C under RCP8.5 (high emissions scenario).	Warmer temperatures; higher rates of evapo-transpiration; shifts in rainfall patterns with potential increased drought conditions and possible changes in ocean salinity	Shifts in composition and distribution of native and non-native species; biodiversity loss; loss of soil-stabilizing vegetation and increased erosion; increased fire risk, causing erosion and danger to people and property; threats to human health (e.g. heat stroke); increased power consumption for aircon; decreased tourism
Sea-surface temperature	**Water temperature has increased and is projected to continue to increase in Guam with moderate inter-annual and inter-decadal variability**. Historical: Pacific Ocean sea temperatures exhibit strong inter-annual and decadal fluctuations. Climatic variability has increased, and is projected to continue increasing, in the North Pacific region. Since the 1950s, these waters have shown a warming trend from 0 to 200 m (0 to 656 ft) depth by as much as 2°C (3.6°F). Mean sea temperature increased by an average of 0.35°C (0.63°F) per decade for Guam between 1985 and 2012. Guam's coral reefs experienced thermal stress that likely resulted in mild to moderate coral bleaching (4 degree heating weeks, DHW) 19 times and warming that may have caused severe bleaching (8 DHW) eight times during that same period. Approximately half of Guam's reefs experienced moderate thermal stress 5+ times during that period. Between 2002 and 2012, Guam's reefs experienced moderate to severe stress nine times, three times more frequently than in the preceding ten year period. Projected: All of Guam's coral reefs are expected to experience severe thermal stress annually by 2045	Warming seas; increased ocean stratification and deoxygenation of deep waters	Coral bleaching and loss of reef habitat and associated fish; shifts in marine species distribution and pelagic migration patterns; shifts in fish behavior; impacts to fisheries and cultural fishing practices; decreased coastal protection due to loss of reef structure; shifts in prevalence and distribution of coral diseases; decreased tourism

COMMUNITY NAME: *Guam, Mariana Islands*			
INDICATORS OF A CHANGING CLIMATE			
Climate Threat			Impacts
Indicator	**Magnitude and direction of change over time based on community knowledge and latest climate science**	**Changes in environmental conditions (Climate Stressors)**	**Potential impacts to natural and social resources**
	under emissions scenario RCP8.5, which assumes that climate policies will be ineffective. Under RCP4.5, which assumes greater reduction of emissions than what is currently committed under existing climate policies, indicates that Guam's reefs will experience annual severe thermal stress by 2050, only five years later. Due to decreased ventilation and lower solubility of O2 in warmer, more stratified water, oxygen minimum zones are expanding in the tropical Pacific Ocean. Compared to 1870-1899 temperatures, global SST under RCP8.5 is expected to increase by 1.5°C (2.7°F) by 2050 and 3.2°C (5.8°F) by 2100. Increased thermal stress may be experienced during ENSO years.		
Sea level	**Sea level has risen and is projected to continue to rise in Guam with high inter-annual and inter-decadal variability.** Historical: Global average sea level has risen by about 20.32 cm (8 in) since 1900. Since the early 1990s, the rate of global mean SLR is estimated to be 0.34 ± 0.04 cm/year (0.134 ± 0.016 in/year) according to satellite altimeter measurements. This is two times the estimated rate for the entire 20th century based on tide gauge reconstructions. Regional SLR trends may significantly differ from the mean global rate over multi-year to multi-decadal time scales due to shifting wind patterns and ocean circulation fluctuations. Since 1993, SLR rate for the western Pacific region is as much as three times the global average. Projections: On Guam, sea level is expected to increase by 0.8 m (2.62 ft) during the 21st century. Climate models predict mean global SLR of 15 to 61 cm (6 to 24 in) by the end of this century. Including potential contributions from changes in ice-sheet discharge dynamics results in an additional 10 to 20 cm (4 to 8 in) of SLR. During the 21st century, the rate sea level rise in the Pacific region is expected to match the global average. "Semi-empirical models" estimate higher global SLR, ranging from approximately 0.91 to 1.52 m (3 to 5 ft) by 2100.	Increased storm surges and king tides; more frequent coastal inundation and larger areas of inundation; increased erosion; increased episodic flooding	Damage to infrastructure, homes, and cultural sites; loss of public and private property leading to potential conflict; decreased coastal water quality; coastal flooding and drainage issues; increased immigration from low-lying islands to Guam, leading to potential conflicts and increased pressure on resources; decreased tourism; increased demand for sea walls
Rainfall	**Rainfall has increased slightly and is expected to moderately increase in Guam, although the change may not be significant.**	Potentially more droughts and extreme events (e.g.	Damage to property and danger to people; impacts to

COMMUNITY NAME: *Guam, Mariana Islands*			
INDICATORS OF A CHANGING CLIMATE			
	Climate Threat		**Impacts**
Indicator	**Magnitude and direction of change over time based on community knowledge and latest climate science**	**Changes in environmental conditions (Climate Stressors)**	**Potential impacts to natural and social resources**
	Historical: Average annual rainfall for Guam is ~260 cm (102 in), with the wet season stretching from July to November (70% of annual rainfall occurs during this period). A small increase in mean annual rainfall has been detected for Guam and CNMI, with high ENSO-related variability. Rainfall is the source of all freshwater on Guam. Projections: Under both moderate (RCP 4.5) and high (RCP8.5) emissions scenarios, Guam is not expected to experience statistically significant change in rainfall patterns by the end of this century. More rainfall may occur, but with high inter-annual and inter-decadal variability.	floods, fires, landslides); increased runoff of sediments and pollutants; changes in ocean salinity	agriculture and livestock; issues with freshwater availability; degraded water quality along coast and increased sedimentation; increased algae abundance; decreased coral settlement; decreased tourism; increased mosquitos and mosquito-borne diseases
Extremes: Drought & Heavy Rain	**Guam expects to experience fewer but more intense tropical cyclones with high inter-decadal variability and shifting location of extra-tropical storm tracks. Episodic droughts are expected to continue.** Historical: Droughts are common on Guam and may be severe. Projected: More intense (although less frequent) typhoons may result in more intense rainfall events. ENSO may increase frequency of droughts. By the end of the 21st century, the frequency of weak tropical cyclones around Guam (within 500 km) is predicted to decrease, while the frequency of strong tropical cyclones is projected to increase.	Potentially more droughts and extreme events (e.g. floods, fires, landslides); increased runoff of sediments and pollutants; changes in ocean salinity	Damage to property and danger to people; impacts to agriculture and livestock; issues with freshwater availability; degraded water quality along coast and increased sedimentation; increased algae abundance; decreased coral settlement; decreased tourism; increased mosquitos and mosquito-borne diseases
Ocean pH	**Ocean acidity has increased (decreased pH) and is projected to continue to increase in Guam.** Historical: Ocean acidity has increased by ~26% since the preindustrial era. Historical and current observations of aragonite saturation state (Ωar) show a decrease from about 3.8 to 3.6 in the past two decades. Aragonite is very important for reef-building corals; an aragonite saturation state of > 4.0 is optimal	Less available calcium carbonate to form skeletons and shells, impacting corals and other calcifying organisms	Decreased growth and survival of corals and other calcifying organisms; biodiversity loss; loss of reef fish habitat and altered fish behavior; weaker shells/skeletons of

COMMUNITY NAME: *Guam, Mariana Islands*			
INDICATORS OF A CHANGING CLIMATE			
Climate Threat			Impacts
Indicator	**Magnitude and direction of change over time based on community knowledge and latest climate science**	**Changes in environmental conditions (Climate Stressors)**	**Potential impacts to natural and social resources**
	for the formation of coral skeletons; a state of 3.5-4.0 is adequate; 3.0-3.5 is marginal; and < 3.0 is extremely marginal. Projections: For Guam, Ωar is expected to change by -0.6 from 2006-2050, potentially causing a 9% decline in calcification rates. Ocean water has a natural pH of ~8.2; at 560 ppm CO_2, pH is expected to decline to 7.92. Major ecological shifts are expected at pH of 7.8. In the Pacific, Ωar is expected to have decreased enough to decrease coral survival and growth rates by 2035 to 2060.		marine plankton and shellfish; decreased coastal protection due to lost reef structure; impacts to fisheries and cultural fishing practices; decreased tourism
Ocean circulation	No consensus on how ocean circulation will change, but ENSO will continue to be a source of consistent climate variability. Guam is situated within an ENSO core region and the island experiences inter-annual variations of rainfall and drought-like conditions following El Niño cycles. During El Niño events, max annual temperatures for Guam are generally cooler than average.	Potential changes in circulation, sea level, rain patterns, drought, extreme rain events, king tides	Changes in freshwater availability; shifts in connectivity and larval distribution for corals, fishes, etc.
Typhoons/ Severe storms	**Guam expects to experience fewer but more intense tropical cyclones with high inter-decadal variability and shifting location of tropical storm tracks.** Historical: Guam is situated in a very active region for tropical storms. Since 1994, the island has been hit by four typhoons with sustained wind speeds > 240 km per hour (150 mph). Tropical storms develop quickly and generally occur in the more humid summer months and are more likely in ENSO years. Projections: While there is still little consensus as to how storms in the Pacific may be affected by climate change, most agree that increases in atmospheric and ocean temperatures will alter storm frequency, tracks, and intensity. These changes will modify the timing, magnitude, and patterns of large storm waves in the basin. Overall, Guam is expected to have fewer but more intense storms. By the end of the 21st century, the frequency of weak tropical cyclones around Guam (within 500 km) is predicted to decrease, while the frequency of strong tropical cyclones is projected to increase. ENSO may increase cyclonic activity.	Potentially more intense; possible change in tracks	Danger to people and property; increased power outages; impacts to fragile branching species (e.g. staghorn Acropora) and associated loss of fish habitat; decreased tourism

TARGET RESOURCE: *Coral reefs of Guam, Mariana Islands* **CONDITION AND TRENDS:** Guam's *coral reefs are in fair condition overall. Condition is declining due to coral bleaching, overfishing (including unsustainable take of herbivores), LBSP, COTS outbreaks, and invasive species.*					**Condition and Trend Rating** ***FAIR*** ↓
CLIMATE THREATS	**EXPOSURE**	**SENSITIVITY**	**POTENTIAL IMPACT (Exposure + Sensitivity)**	**ADAPTIVE CAPACITY**	**VULNERABILITY (Potential Impact + Adaptive Capacity)**
Warming SST resulting in increased frequency and severity of coral bleaching events Ocean acidification resulting in declining coral calcification rates Slightly higher annual rainfall and more severe (although less frequent) storm events may increase LBSP impacts on coral reefs	Very little protection from high exposure to these climate change-related impacts	Coral reefs have high sensitivity to increased SST Guam's coral reefs experienced severe bleaching 4/5 years from 2013 to 2017	High potential impact: Coral reefs are highly exposed and highly sensitive to climate impacts	Medium adaptive capacity: Some coral reefs exposed to previous bleaching events have recovered Improved watershed management is needed to reduce LBSP	Coral reef vulnerability to climate change is rated as high
	Exposure Rating	**Sensitivity Rating**	**Potential Impact Rating**	**Adaptive Capacity Rating**	**Vulnerability Rating**
	HIGH	**HIGH**	**HIGH**	**MEDIUM**	**HIGH**
	VULNERABILITY STATEMENT: • **Condition and Trends:** Guam's coral reefs are in fair condition but are continuing to decline due to bleaching, overfishing, LBSP, COTS outbreaks, and invasive species. • **Vulnerability:** Coral reefs are vulnerable to increased SST, ocean acidification, and increased LBSP. • **Resource Dependency:** Guam's coral reefs provide food to some community members and support a growing tourism industry that hosts 1/3 of all jobs on the island.				

APPENDIX V: Guam's priority sites and fisheries taxa for coral reef management

Target watersheds

1. Manell-Geus watershed
2. Piti-Asan watershed
3. Tumon Bay watershed (Yigo-Tumon sub-basin of the Northern Guam Lens Aquifer)

Priority marine preserves

1. Achang Reef Flat Marine Preserve
2. Piti Bomb Holes Marine Preserve
3. Tumon Bay Marine Preserve

Restoration areas

1. Manell-Geus Habitat Focus Area
2. Piti Bomb Holes Marine Preserve
3. Tumon Bay Marine Preserve

Key fisheries taxa (29 species in nine families)

1. Acanthuridae (surgeonfishes)
    a. *Acanthurus lineatus*
    b. *Acanthurus xanthopterus*
    c. *Naso literatus*
    d. *Naso unicornis*
2. Lutjanidae (snappers, fusiliers)
    a. *Aprion virescens*
3. Scaridae (parrotfishes)
    a. *Bolbometopon muricatum*
    b. *Chlorurus microrhinos*
    c. *Chlorurus spilurus*
    d. *Hipposcarus longiceps*
    e. *Scarus altipinnis*
    f. *Scarus forsteni*
    g. *Scarus psittacus*
    h. *Scarus rubroviolaceus*
    i. *Scarus schlegeli*
4. Carangidae (jacks, pompanos, mackerels, runners, scads)
    a. *Caranx melampygus*
5. Serranidae (groupers, rockcods)
    a. *Cephalopholis sonnerati*
    b. *Epinephelus fasciatus*
    c. *Plectropomus laevis*
    d. *Plectropomus leopardus*
    e. *Variola louti*
6. Labridae (wrasses)
    a. *Cheilinus trilobatus*
    b. *Cheilinus undulatus*
7. Lethrinidae (emperors, breams)
    a. *Lethrinus harak*
    b. *Lethrinus obsoletus*
    c. *Lethrinus rubrioperculatus*
8. Mullidae (goatfishes)
    a. *Mulloidichthys flavolineatus*
9. Siganidae (rabbitfishes)
    a. *Siganus argenteus*
    b. *Siganus punctatus*
    c. *Siganus spinus*