Global Climate Change and Reef Resilience
Local Action Strategy for Guam

Proposed by:
Dr. Laurie J. Raymundo, Navigator
University of Guam Marine Laboratory

Working Group members:
David Burdick, *Guam Coastal Management Program*
Val Brown, *NOAA Fisheries Division*
Romina King, *Bureau of Statistics and Plans, Guam Coastal Management Program*
Mark Defley, *U.S. Navy*
Jesse Cruz, *Guam Environmental Protection Agency*
Mark Capone, *National Parks Service*
Dr. Peter Schupp, *University of Guam Marine Laboratory*
Dr. Tom Schils, *University of Guam Marine Laboratory*

Background and Rationale

Hermatypic corals provide the living foundation, habitat, and structural complexity for coral reefs worldwide. As such, they are essential to coastal human communities for the services they provide. However, because they exist near their thermal limits, and in nearshore coastal waters subjected to a multitude of human-induced impacts, they are threatened on a global scale. Climate change is now considered an urgent threat to these highly productive ecosystems (McClanahan 2002). Indeed, coral reefs have recently been cited as the most threatened ecosystem on earth from stressors associated with climate change (Mumby and Steneck 2008). Guam's coral reefs are not exempt from these problems, and with the anticipated rapid increase in the island's population due to planned military expansion, stress on coastal reefs is predicted to rise. With the dual needs of healthy coral reefs to support Guam's tourism industry and sustainable sport, artisanal and commercial fishing, Guam reefs will see mounting impacts in the coming years. The need for proactive, practical and targeted management is urgently needed.

This is a working document outlining goals, objectives, priority projects, and performance measures for Guam's Global Climate Change and Reef Resilience Local Action Strategy (LAS) for the next three to five years. Elements within this LAS may change as circumstances which drive our research and management priorities shift (e.g., prioritization of projects, or the identification of new projects). We identify the following major issues which this LAS is designed to address: a) climate change, specifically the impacts of ocean acidification and sea surface temperature warming; b) coral disease; c) nuisance and invasive species, and their impacts on coral reef communities; and d) the resilience of Guam's human communities affected by coral reef loss and degradation. These are discussed below, and provide a structure within which our priority projects are identified (presented in Table 1). We recognize that synergisms between these issues are of major importance and that it is important that flexibility be built into the management plans proposed in this document. We further recognize that priority projects identified in Table 1 may require resources that are currently not available; thus, though a project may be deemed necessary, its implementation may be postponed until resources are available.

Climate Change. Calcifying, reef-building organisms are predicted to respond to increased ocean acidity and warming temperatures by decreasing the rate at which they can deposit $CaCO_3$. This may reduce coral growth rates and reef structural integrity (Kleypas et al. 2006; Hoegh-Guldberg et al. 2007). Influences on photosynthesis, fecundity, and immunodefense are poorly understood. Coral bleaching is most often associated with warming water temperatures and is, therefore, expected to become a more critical source of coral stress and mortality in the near future. Mass bleaching events, which often result in mass mortality and which may be followed by disease outbreaks (Harvell et al. 2001) are predicted to increase in frequency and severity (Hoegh-Guldberg 1999).

The underlying causes of bleaching and responses of the coral host also continue to be an area of ongoing research. However, progress has been made regarding the management and forecasting of bleaching events (see Marshall and Schuttenberg 2006). Existing protocols, therefore, can and should be tested, modified, and applied to Guam reefs. Although coral bleaching is a global phenomenon which is difficult to prevent or manage, two decades of intensive research has yielded information and understanding in certain areas which can be applied to management of such events. The best management option may be to ensure resiliency of our reefs by protecting coral health, improving water quality, developing tools for rehabilitation and protecting sensitive species and key reef communities.

Coral disease. Diseases affecting corals are now thought to be amongst the most critical problems facing reefs today (Harvell *et al.* 2007). While progress in understanding causation, ecological impacts on communities, disease etiology, and the role of environmental drivers continues to be made, the gaps in our knowledge of these areas are still considerable. Management approaches are urgently needed, as recent evidence points to increasing numbers of diseases that have the capacity to alter reef structure, biodiversity and productivity. Current thought focuses on developing a more complete understanding of how and why certain microbes cause disease by attempting to address questions such as: 1) Under what conditions is host health compromised? 2) How does environmental stress affect a host's ability to defend itself against a pathogen? 3) What is the role of climate change and ocean warming in either compromising immunodefense mechanisms or increasing the virulence or range of a pathogen? 4) What organisms may interact with corals to transmit pathogens, thereby aiding in disease spread? and 5) What creates or promotes resiliency in reefs that make corals better able to survive and recover from disease outbreaks, and how does recovery occur? Although many of questions were identified in the first LAS, they remain relevant and should be the focus of continuing efforts in order to develop and test management options.

Nuisance and invasive species. Additional sources of coral mortality include predation by the Crown-of-Thorns seastar, *Acanthaster planci* and the corallivorous gastropods *Drupella* spp. and *Coralliophila* spp., and overgrowth of living coral by the encrusting sponge, *Terpios*, and the pelagophyte, *Chrysocystis fragilis*. *Terpios* and *Chrysocystis* can further impact the coral community by inhibiting recruitment via removal of available substrate. Reports of *A. planci* and *Drupella* outbreaks and blooms of *Terpios* and *Chrysocystis* on Guam and elsewhere in the region extend back several decades (Plucer-Rosario 1983, 1987; Birkeland 1990; Moyer *et al.* 1982). However, chronic infestation by these organisms in recent years, in combination with

reduced resilience of Guam's reefs to respond to disturbance, raises questions about the potential influence of anthropogenic activity on the frequency and severity of these infestations. Of great concern is the long-term viability of reef systems with limited recovery capability, influenced by multiple chronic stressors. Management measures to control *A. planci* outbreaks are currently very limited, and usually involve the targeted removal of *A. planci* individuals from small, high-value reef sites. There are currently no known management actions for *Terpios* and *Chrysocystis*. A better understanding of the impact of infestations by these organisms on Guam's reefs and the causes and mechanisms of these infestations is an identified objective, so that effective management actions can be developed and implemented.

Related issues. Finally, we identify other areas of concern that relate to how Guam's coral reefs are likely to respond to climate change in the coming decades, given the projected increase in population. For instance, there is no mechanism in place to respond to acute, potentially catastrophic damage to local reefs from such events as ship groundings, chemical spills and typhoons. Our MPA's are often areas of intense tourism activity; we know little about such impacts on frequented dive sites. However, ample anecdotal and photographic evidence exists of inappropriate diver training, inadequate dive etiquette and destructive diving practices that directly impact prime dive sites. Sensitive areas, such as thicket-forming *Acropora* stands, are particularly vulnerable, given their morphology and susceptibility to bleaching.

We know nothing about how our human population is likely to respond to, or be affected by, the continuing degradation and loss of our coral reefs. The human communities of Guam depend heavily on coral reefs, both economically and culturally. Increases in bleaching events will most likely occur as a direct result of global climate change and warming temperatures. Tourism relies on pristine, high-quality reefs, and a large-scale bleaching event could have devastating impacts on this industry, a mainstay of the local economy. In preparation for such an event, it is imperative that local threats are minimized, in order to provide an optimum environment for coral reef recovery.

Further, it is imperative that we develop proactive approaches to rehabilitate degraded reefs and foster resiliency where possible. We build into this LAS strategies for testing and applying both of these concepts into our management framework. Rehabilitation and mitigation projects have been a focus of research in Guam for decades (Birkeland et al. 1979; Richmond et al. 1997; Rojas et al. in review), and should continue to be so as part of the overall management plan.

Synergisms. Interactions between these identified issues present additional challenges for managers. For instance, limited evidence suggests a role of corallivores in disease spread. The fireworm *Hermodice carunculata,* and gastropods *Drupella cornus* and *Coralliophila abbreviata* have all been implicated as vectors in disease spread in the Mediterrean, Red Sea and Caribbean, respectively (Sussman *et al.* 2003; Antonius and Riegl 1997; Williams and Miller 2005, respectively). The calcareous macroalga *Halimeda opuntia* has been found to harbor the pathogen causing White Plague on its surface; contact with potential host corals can transmit the disease (Nugues *et al.* 2004). Such examples illustrate mechanisms of disease behavior within reef communities that provides information of direct use to managers, but also underscore the unique nature of individual host-predator-pathogen relationships. Such evidence has not yet been documented for any disease affecting Indo-Pacific reefs; this LAS lists this gap as a priority

project area. In addition, reports from the Caribbean have documented disease outbreaks on corals that survived bleaching events (Harvell *et al.* 2001; Miller *et al.* 2006). Current thought is that corals stressed from a bleaching event may be immunocompromised and less able to defend themselves against pathogen exposure. This may be exacerbated in areas with poor water quality or other stressors. Therefore, those that may have survived bleaching may subsequently succumb to disease.

The complexity of issues affecting Guam coral reefs necessitate coordination and collaboration between the various Local Action Strategy working groups. For example, local dive and tourism operators are in the process of being trained to protect their reefs (and, hence their livelihoods) from destructive diving and recreational use through efforts of the Recreation Use and Misuse LAS working group. The Overfishing LAS addresses fishing activities such as SCUBA spear fishing, a highly efficient and extractive technique that has resulted in an almost total removal of top predators and other functional groups from Guam reefs (J. McIlwain, pers. comm.). Furthermore, the Land-Based Pollution LAS working group is aiming to reduce sedimentation and non-point source pollution, in an effort to improve water quality.

The previous Local Action Strategy

The previous LAS was the first of its kind for this working group, and identified the following objectives and targets:

- *To complete an island-wide baseline survey of Guam's reefs to determine current total disease prevalence, specific diseases present, host species affected, and severity of impacts to the reef communities.* We have completed 12 surveys at selected sites around Guam, and we continue to do so as time and resources permit. A mean total disease prevalence value of 17.4% is what we feel represents the current baseline (Myers and Raymundo in prep; Burdick *et al.* 2008). This is higher than many other sites in the region; the Northwest Hawaiian Islands, for instance, exhibited a mean total disease prevalence of 0.5% (Aeby 2006). We have identified certain sites with significantly higher total disease prevalence than other sites, suggesting that some reefs may act as hot spots for disease, and potential outbreak sites.

- *To establish long-term monitoring sites on selected reefs.* Currently, there are four sites that are monitored quarterly along replicate permanent transects. Temperature data are collected from two of these sites, and preliminary data suggest a link between seasonally warm temperatures and increased disease prevalence (Myers and Raymundo in prep).

- *To establish a protocol for rapidly identifying and assessing disease epizootics, bleaching episodes and predator outbreaks.* A workshop, held at the University of Guam in March 2007, trained local and regional managers and scientists in disease outbreak protocol. A second workshop, which will target additional local and regional personnel, is planned for March 2009. This second workshop will build on experience gained from implementing and testing the original protocol, and will follow a meeting to be held in Hawaii in February 2009 to revise the current approach to assessing epizootics.

- *To establish a local coral impacts working group in Guam.* Personnel who attended the first disease workshop constitute the current working group, in addition to individuals from appropriate agencies whose experience and expertise warrant their involvement; their names are listed above. In addition to disease outbreak training, these individuals will be receiving training in damage assessment, scheduled for November 2008.

All of these objectives have been met, largely through funded research from the Coral Reef Initiative. It is appropriate, therefore, to reevaluate the current state of our local and global understanding, and to identify new goals and objectives which bring our state of knowledge forward. Below, we state our targeted goals and objectives for this new LAS.

Goals and Objectives of the Current LAS

The broad goal of the current LAS is to ***better manage Guam coral reefs to enhance resilience and recovery processes.*** This goal will be met by the priority objectives described below. Table 1 summarizes these objectives in the context of the broad issues discussed above.

- *To develop and implement response plans for bleaching, disease and predator outbreaks, and acute events (ship groundings, chemical spills).* Currently, there are no plans available on Guam to respond to these sudden, potentially devastating events. As each event has a different cause, may target different species, and impacts a reef community in a unique way, response plans need to be equally unique and targeted. This is expected to involve workshops to train local managers and scientists in protocols that have been developed and tested (such as the upcoming damage assessment and disease outbreak assessment workshops), and tests of approaches that have been attempted elsewhere, such as reef closures, quarantines, removal activities, etc. We identify an urgent need to develop and test individual plans for each of these types events within three years. In addition, we recognize the need for an ongoing flexibility by which we can carry out response activities as needed.

- *To provide scientific and management support and recommendations that can guide the evaluation and construction of useful policy and law to local government.* Currently, Guam does not have a set of laws and policies to hold responsible entities which cause catastrophic damage to its reefs (i.e., chemical spills, ship groundings, etc.). In addition, there are other key areas affecting coastal resources management where local legislation and policy are lacking. This LAS will attempt to address these insufficiencies, so that responses to such events can involve accountability and mitigation. This will involve research of Guam law, research into management policies and laws that have been adopted by other countries to handle such events, an examination of Guam's current and past experiences with such events, and coordination with local politicians and lawmakers. We will continue to make the results of our various projects available to the Guam community and specific stakeholders and local government, with the purpose of providing necessary information to guide policy and law.

- *To better understand the role of environmental drivers in coral health, disease, and bleaching.* Temperature, elevated nutrients, silt, pollutants and toxins are potential stressors to corals, which may affect their ability to fight disease and recover from bleaching. With the projected increase in Guam's population, we anticipate further degradation of water quality from these sources in

the coming years. It is essential to improve our understanding of specific effects of these stressors, in order to increase our ability to identify sensitive reefs and species, predict potential events, and determine the most effective protection and/or remediation measures where and when they may be needed. Coordination with the Land-Based Pollution and Public Awareness LAS working groups is essential. These activities require some basic research and monitoring, and are expected to be ongoing over the next several years.

- *To address knowledge gaps in our understanding of invasive and nuisance species.* Specifically, *A. planci, Terpios* sp., *Chrysocystis fragilis*, *Drupella* spp. have caused significant coral mortality on Guam reefs and in the wider Indo-Pacific region, and inhibit coral recruitment through the occupation of suitable substrate. To date, we have little information that can be applied to management, such as the impacts of these infestations (the geographic extent, severity, preferred host or target species) and the mechanisms of infestation (mortality rates of hosts, spread rate, temporal or seasonal variation). Management strategies also need to be developed, and these should include addressing land-based issues that may affect either the spread of these species or the ability of the coral host to defend against them.

- *To address the issue of human community resilience in the presence of reef loss and degradation.* In addition to working toward minimizing local threats to coral reefs, as outlined above, the resilience of Guam's human coastal communities must be examined. Are Guam's human coastal communities resilient in the face of a devastating events resulting in massive coral mortality? What are the social, economic, and political impacts of increased frequency of such events? Answering these questions will require use of the social science tools and data, specifically from the disciplines of anthropology, geography, sociology, demography, and economics. While there has been an economic valuation study on Guam's reefs (van Beukering et al. 2007), the social and economic ramifications of reef degradation due to bleaching and disease are unknown. Results of that coral reef economic valuation have provided comprehensible evidence to politicians and the general public of the need for appropriate legislation and protection. Addressing human community resiliency will supplement the coral reef valuation study and also help justify financial support for projects such as the implementation of additional areas of conservation (based on ecological resiliency factors) or the feasibility study of a coral nursery. Furthermore, such data will assist coral reef managers in understanding the human communities' values and perceptions, a crucial step in achieving necessary positive behavior changes to minimize local threats. The cultural value of Guam's coral reefs remains poorly understood. Yet, their continued loss is already perceived by many residents (pers. comm. to L. Raymundo). How Guam's population is likely to be affected in the coming years deserves some attention, and we recognize it as a priority objective.

- *To develop and test approaches for mitigation and rehabilitation of key reef areas.* These areas should be identified as those that either a) contain particularly sensitive species, such as reefs dominated by the genus *Acropora,* or b) are particularly productive or diverse. *Acropora* thickets in many areas around Guam have experienced high mortality rates, speculated to be attributed to a variety of sources that include Crown-of-Thorns outbreaks, bleaching, and disease. *Acropora* nurseries and outplanting activities may assist in restoring selected populations. Larval recruitment appears to be highly variable, but declining; this phenomenon requires further investigation. Efforts may target identifying localized areas of high vs. low

recruitment, laboratory or nursery rearing of recruits, transplantation, and identifying environmental factors which may be driving low recruitment or low recruit survival. Coordination with the Land-Based Pollution Working Group will be useful in examining questions of water quality impacts. These areas of research and monitoring require longer time commitments, and would be expected to take several years.

Literature Cited

Aeby, G. S. 2006. Baseline levels of coral disease in the Northwestern Hawaiian Islands. Atoll Research Bulletin 543:471-488.

Antonius, A., and B. Riegl. 1997. A possible link between coral diseases and a corallivorous snail *(Drupella cornus)* outbreak in the Red Sea. Atoll Research Bulletin 447:1-9.

Birkeland, C., R. H. Randall, and G. Grimm. 1979. Three methods of coral transplantation in the thermal effluent area at the Tanguisson power plant. Tech. Rep. #60, Univ. of Guam Marine Laboratory.

Birkeland, C., and J. S. Lucas. 1990. *Acanthaster planci*: Major Management Problem of Coral Reefs. CRC Press, Inc., Townsville, Australia.

Burdick, D., V. Brown, J. Asher, M. Gawel, L. Goldman, A. Hall, T. Leberer, J. Kenyon, E. Lundlad, J. McIlwain, J. Miller, D. Minton, M. Nadon, N. Pioppi, L. Raymundo, B. Richards, R. Schroeder, P. Schupp, E. Smith, and B. Zgliczynski. 2008. The State of the Coral Reef Ecosystems of Guam. pp. 413-456. In: J. Waddell (ed.), The State of the Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2008. NOAA Tech. Mem. NOS NCCOS X. NOAA/NCCOS Center for Coastal Monitoring and Assessment Biogeography Team. Silver Spring, MD.

Harvell, D., K. Kim, C. Quirolo, J. Weir, and G. Smith. 2001. Coral bleaching and disease: contributors to 1998 mass mortality in *Briareum asbestinum* (Octocorallia, Gorgonacea). Hydrobiologia 460:97-104.

Harvell, C. D., E. Jordan-Dahlgren, Merkel, S.M., Rosenberg, E., Raymundo, L.J., Smith, G., Weil, E., Willis, B. 2007. Coral diseases, environmental drivers, and the balance between coral and microbial associates. Oceanography 20(1): 172-195.

Hoegh-Guldberg, O. 1999. Climate change, coral bleaching and the future of the world's coral reefs. Marine and Freshwater Research 50:839-866.

Hoegh-Guldberg, O., P. J. Mumby, A. J. Hooten, R. Steneck, P. Greenfield, E. Gomez, C. D. Harvell, P. Sale, A. Edwards, K. Caldiera, N. Knowlton, C. M. Eakin, R. Iglesias-Prieto, N. A. Muthiga, R. H. Bradbury, A. Dubi, and M. E. Hatziolos. 2007. Coral reefs under rapid climate change and ocean acidification. Science 318:1737-1742.

Kleypas, J. A., R. A. Feely, V. J. Fabry, C. Langdon, C. L. Sabine, and L. L. Robbins. 2006. Impacts of Ocean Acidification on Coral Reefs and Other Marine Calcifiers: A Guide for Future Research. NSF, NOAA, USGS, St. Petersburg.

Marshall, P., and H. Schuttenberg, eds. 2006. A Reef Manager's Guide to Coral Bleaching. GBRMPA, Townsville, Australia.

McClanahan, T. 2002. The near future of coral reefs. Environmental Conservation 29:460-483.

Miller, J., R. Waara, E. Muller, and C. S. Rogers. 2006. Coral bleaching and disease combine to cause extensive mortality on reefs in the US Virgin Islands. Coral Reefs 25:418.

Moyer, J. T., W. K. Emerson, and M. Ross. 1982. Massive destruction of scleractinian corals by the muricid gatropod, *Drupella*, in Japan and the Philippines. The Nautilus 96(2):69-82.

Mumby, P. J., and R. S. Steneck. 2008. Coral reef management and conservation in light of rapidly evolving ecological paradigms. TREE 23:555-562.

Myers R. and Raymundo L.J. in prep. Guam reefs show a link between the dominant genus *Porites* and disease prevalence. Invited paper to be submitted to Diseases of Aquatic Organisms.

Nugues, M. M., G. W. Smith, R. J. van Hooidonk, M. I. Seabra, and R. P. M. Bak. 2004. Algal contact as a trigger for coral disease. Ecology Letters **7**:919-923.

Plucer-Rosario, G. 1983. Effect of Substrate and Light on Growth and Distribution of *Terpios*, an encrusting sponge which kills corals. University of Guam (Master's Thesis) 39pp.

Plucer-Rosario, G. 1987. The effect of substratum on the growth of *Terpios*, an encrusting sponge which kills corals. Coral Reefs 5:197-200.

Richmond, R. H., S. L. Romano, S. Leota, and T. Taitano. 1997. Coral cultivation for reef restoration, restitution, and the aquarium trade. American Zoologist 37:71A.

Rojas, P.T., Raymundo, L.J. and R. Myers. (in review). Coral transplants as rubble stabilizers: a technique to rehabilitate damaged reefs. Proc. 11th Int'l. Coral Reef Symp. Ft. Lauderdale, Fla.

Sussman, M., Y. Loya, M. Fine, and E. Rosenberg. 2003. The marine fireworm *Hermodice carunculata* is a winter reservoir and spring-summer vector for the coral-bleaching pathogen *Vibrio shiloi*. Environmental Microbiology 5:250-255.

van Beukering, P., W. Haider, M. Longland, H. Cesar, J. Sablan, S. Shjegstad, B. Beardmore, Y. Liu, and G.O. Garces. 2007. The economic value of Guam's coral reefs. Technical Report 116. The Marine Laboratory, University of Guam. Mangilao, Guam. 120 pp.

Williams, D. E., and M. W. Miller. 2005. Coral disease outbreak: pattern, prevalence and transmission in *Acropora cervicornis*. Marine Ecology Progress Series 310:119-128.

Table 1. Three-year Local Action Strategy Planning Document, 2009-2011

Focus Area: *Climate Change and Reef Resilience*

Goal: To better manage Guam's coral reefs to enhance resilience and recovery processes

Objectives:	Identified Priority Projects	Estimated Budget:	Timeline:	Who will do the work:
Global Climate Change				
Establish current baselines and investigate consequences of climate change (ocean acidification and global warming) in coral reef ecosystems of the Western Pacific	Collect baseline data on the ecophysiology of indicator species of benthic calcifiers	50,000 (yr1) 35,000 (yr2)	2 yrs	DAWR, NPS, NOAA, UOGML, HIMB (HI)
	Collect baseline data on existing variability in oceanographic conditions of coral reef habitats (*e.g.*, pH, temp. fluctuations, "ocean thermostat" mechanisms)	45,000 (yr1) 25,000 (yr2)	2 yrs	DAWR, NPS, NOAA, UOGML, HIMB (HI)
	Investigate effects of changes in pH and temp. on ecophysiology, growth rate, calcification, and morphology of calcifying reef biota	60,000 (yr1) 30,000 (yr2)	2 yrs	DAWR, NPS, NOAA, UOGML, HIMB (HI)
	Investigate resilience of calcifying flora and fauna contributing to reef accretion under different ocean acidification scenarios.	60,000 (yr1) 30,000 (yr2)	2 yrs	DAWR, NPS, NOAA, UOGML, HIMB (HI)
	Develop a response plan for bleaching in 2009. Prepare a document outlining the protocol, and test this protocol in 2010.	10,000	3 mo	Reponse team including GCMP, DAWR, NMFS, UOGML, invited trainer(s)
	Identify areas that are either highly resistant or susceptible to bleaching for targeted management, protection or rehabilitation	15,000	1 yr	DAWR, UOGML, NPS, NOAA
Coral Disease				
Increase understanding of the causes, spread, and impacts of the six known diseases affecting Guam reefs	Second workshop to train personnel in coral disease assessment, monitoring, and outbreak response	25,000 (funding approved by NOAA for 2009)	4 wks (includes prep time)	Reponse team: GCMP, DAWR, NMFS, NPS, UOGML, trainers

and identify three main environmental drivers of bleaching and disease in Guam.	Examine a potential role of fish populations in influencing recovery from or resistance to bleaching or disease impacts by comparing coral health and fish assemblages inside and outside preserves.	100,000	3 yrs	UOGML, Contractor, NOAA
	Examine correlations between temperature and coral disease - the influence of increased temperature on disease progression, infection rates, transmissibility of the various diseases affecting Guam corals.	60,000	2 yrs	UOGML, NOAA
	Investigate the role of vectors, reservoirs, and environmental stressors in transmission and impacts of the diseases affecting Guam reefs	25,000/yr	3yrs	UOGML, DAWR, NOAA, NPS
	Link site-specific disease/ bleaching monitoring with site-specific water quality monitoring and land-based sources of pollution.	none needed; coordination with other monitoring activities	1 yr	DAWR, UOGML, NPS, NOAA
Nuisance and invasive species				
Quantify the extent of this problem for the various identified species affecting Guam reefs and investigate and test management approaches	Establish baseline levels and a subsequent monitoring program of selected reef areas for presence of invasive species	40,000	3 yrs	DAWR, UOGML
	Develop and test response plan for predator outbreaks, based on protocols developed elsewhere (sodium sulfate injection, targeted removal)	40,000	1yr	Reponse team including GCMP, DAWR, NMFS, UOGML, invited trainer(s)
	Management of *Acanthaster* by investigating the source of the larval supply: do Guam *A. planci* starfish originate from a local population or from surrounding islands?	80,000	2 yrs	UOGML
	Research causes of, impacts of, and control methods for *Drupella spp.*	25,000	1 yr	DAWR, UOGML
	Research causes of, impacts of, and control methods for *Terpios sp.*	25,000	1 yr	DAWR, UOGML

	Research causes of, impacts of, spread and distribution of, and control methods for *Chrysocystis fragilis.*	35,000	2 yrs	DAWR, UOGML
Synergisms				
Prioritize at least five sites by for management action based on resilience principles.	Identify links with other LAS's via meetings with navigators of other relevant LAS's to coordinate grant writing efforts	none needed	6 mos	CDBCC working group members
	Survey sensitive areas (high *Acropora* cover; Tumon Bay or other areas of high coral mortality; Cocos lagoon) & develop a monitoring protocol to use a subset of these areas as an early warning of habitat impacts.	60,000	2 yrs	UOGML, Contractor, NOAA
	Compile and standardize data from existing and past monitoring efforts, for analysis of spatial and temporal patterns that focus on MPA performance. Prepare a statement/report for local stakeholders on current status and effectiveness of protection.	30,000	1 yr	DAWR, UOGML, GCMP
	Engage stakeholder community in monitoring and reporting of impacts to reefs, focusing particularly on coastal communities affected by management activities.	20,000	1 yr	DAWR, UOGML, GCMP; link with Public Awareness LAS
Recovery and rehabilitation				
Increase understanding of the causes of coral mortality on Guam and investigate approaches to stimulate recovery and rehabilitation	Run a workshop for damage assessment protocol (NRDA) for local managers and working group members	funding available from NOAA	2 weeks (November 2008)	Reponse team: GCMP, DAWR, NMFS, UOGML, NRDA/NOAA trainers
	Establish baseline levels of coral recruitment at target sites around Guam, linked with water quality monitoring, to investigate potential links between water quality and recruitment variability. Identify threshhold levels of sediments and nutrient load	45,000/yr	3 yrs	NPS, UOGML, Contractor, NOAA

	for coral recruitment and survival of recruits in spawning and brooding corals			
	Conduct a feasibility study on establishment of coral nurseries, including identification and delineation of coral grow-out and outplanting areas, key species, and methods for propagation and rearing.	25,000	1 yr	DAWR, UOGML, NPS, NOAA, UOG