GUAM EPSCOR REQUEST FOR LETTERS OF INTEREST

The Guam EPSCoR Office will begin to prepare and submit a proposal to the National Science Foundation Established Program to Stimulate Competitive Research (NSF EPSCoR) Research Infrastructure Improvement Grant Program (RII) for funding to conduct coral reef and biodiversity research, expand and utilize cyberinfrastructure capabilities, increase opportunities in science education, outreach and diversity, promote global collaboration in the conduct of research, and expand workforce development capabilities within Guam and the region. Guam EPSCoR will solicit from individuals at the University of Guam, Guam Community College, and within the Guam community Letters of Interests for project proposals that may be integrated into the Project Core to advance the goals and objectives of the new project which are detailed further below.

Letters of Interest are due January 14, 2019 and should not exceed 1 page in length. Submissions should be emailed to Lubuagm@uog.edu with the subject line "RII Track-1 LOI". Letters of Interest will be reviewed by the Guam EPSCoR Office and selected participants will be invited to an initial planning meeting on January 18, 2019.

GOALS AND OBJECTIVES

Emerging science: Resilience is the ability of individuals, populations, and communities to persist after disturbances, returning to their original state. Both global and local stressors affect corals at the level of individuals, at the population level through demography and selection, and at the community level by shifts in species composition toward more resilient species. Climate change increases sea surface temperatures and decreases seawater pH, which affects coral health, leading to a breakdown of the coral-photosymbiont association (coral bleaching) and reduced calcification and growth rates. Historically, coral reef management focused on mitigating local stressors (e.g., terrestrial runoff, coastal development) (National Academies of Sciences, Engineering, and Medicine 2018). Corals already under stress locally are likely to respond differently to the addition of global stressors than unperturbed corals.

The recent research review on coral reef persistence and resilience published by the National Academies of Sciences, Engineering, and Medicine (2018) identified **coral resilience as the result of responses at the individual, population, and species level.** The research of the current EPSCoR RII Track-1 project falls under this umbrella (see background below). With the next proposal, we intend to grow this theme and build on the investments that have been made in this area at the University of Guam (UOG) with the goal of laying the foundation for the Guam Marine Science Research Center (GMSRC) at UOG. Our vision is to establish the GMSRC and make UOG the premier institution for marine and biodiversity research while promoting excellence in student training and greater collaboration with scholars and institutions worldwide.

The theme for the next NSF EPSCoR RII Track-1 proposal will be centered on **describing, understanding, and predicting the effects of global climate change on coral reef ecosystems in Guam and the broader Micronesian region across multiple spatial and temporal scales**. Ecosystems may be understood broadly to encompass those systems that interface with coral reefs.

Activities proposed for the next request for funding through NSF EPSCoR should align with:

- The following of NSF's 10 Big Ideas:
    1. Understanding the rules of life
    2. Harnessing the data revolution
    3. Growing convergence research
    4. Developing mid-scale research infrastructure
    5. NSF INCLUDES
- The report by the Committee on Interventions to Increase the Resilience of Coral Reefs (National Academies of Sciences, Engineering, and Medicine 2018)
- The Guam Coral Reef Resilience Strategy (Guam Coral Reef Initiative, 2018)
- NSF's iDigBio program for the digitization of biodiversity collections

Building for the future: The establishment of a Guam marine science research center at the University of Guam is a primary goal for the development of research capacity on Guam. This center would include construction of a new Marine Laboratory building and the Biorepository Research Collections Building. The existing Marine Laboratory main building would be remodeled to create additional laboratory and office spaces to accommodate new and visiting researchers. The goal is for this new UOG facility to be designated as an NSF-funded National Research Center for coral reef and biodiversity studies. Construction costs will be met by various grants and leveraged funding, with matching funds (20%) from the NSF EPSCoR RII Track-1 (2020-2025) grant devoted towards the construction of the Biorepository building. NSF EPSCoR funding will be used to equip this building and to enhance relevant existing and new laboratories within the new research center.

Rationale

Guam and the broader region depend on coral reefs. Our reefs host a diverse biota, provide coastal protection, economic stability in a tourism-based economy and ensure food security in the region by supporting local fisheries. Climate change is predicted to have severe impacts on coral reefs and in turn will have lasting effects on the ecosystem services provided by these reefs; this will have profound and lasting impacts on societies across the region. Managing local reef stressors remains an important task

but is unlikely to ward off the impacts of global climate change, increasing sea surface temperatures, and changing ocean chemistry. Global coral bleaching events are predicted to occur annually by 2050 and are likely to lead to wide-spread and persistent reef declines (Frieler et al., 2013). The reliance of humans on an ecosystem at risk of collapse requires understanding the mechanisms of coral reef responses to a changing climate and their possible adaptation to changing conditions (cf., National Academies of Sciences, Engineering, and Medicine 2018). Predicting the scale of expected impacts of coral reef decline will be necessary to develop meaningful intervention strategies to mitigate biodiversity loss and impacts of coral reef declines on our society.

Marine genomics and oceanography will play central roles in developing the research theme for the next proposal, building on the previous research efforts and investments in infrastructure made under the current NSF EPSCoR RII Track-1 award – faculty and post-doctoral fellow hires, development of the Biorepository to document biodiversity and house biological tissue collections, significant upgrades in our capacity for molecular genetics research, oceanographic equipment, and computational infrastructure.

Dispersal patterns and environment associations of individual species, populations and communities of reef organisms can describe and explain present-day diversity while also providing the foundation for predicting the future diversity of coral reefs. A better understanding of the impacts of changing reef ecosystems will require development and implementation of analytical methods that cross disciplinary boundaries (e.g., integrating existing ecological monitoring data, population ecology, oceanography, and mathematics). Understanding the mechanisms of acclimatization and adaptation of reef organisms to a changing climate has the potential to inform mitigation and remediation strategies. The latter creates direct links to restoration efforts already underway in Guam and promotes research into ecological engineering solutions to mitigate impacts of climate change (e.g., selecting appropriate sites, species, individuals for restoration; restoration informed by a mechanistic understanding of coral regeneration and growth).

While climate change has direct effects on reefs, its effects on terrestrial ecosystems fit under the theme of the next proposal, as changes in terrestrial ecosystems may exert pressures on reef systems (e.g., declines in vegetation leading to erosion; spread of alien species that lead to destabilization of native ecosystems). Considering the dependence of Guam and the broader region on reefs for economic stability, studies that investigate effects of predicted climate change on human populations and the economy may potentially fit under this umbrella as well (e.g., predicting the effects of climate change on the migration of people).

The UOG Biorepository is tasked with documenting the biodiversity of Guam and the broader region, and bringing collections and their management into the 21st century by employing protocols, techniques and tools promoted by the NSF-funded iDigBio project (www.idigbio.org). Biorepository activities in the new project will include the following:

- Richard H. Randall Coral Collection: curation, digitization, imaging and long-term storage

- Rebuilding the Richard Dickinson Memorial Mollusk Collection: collection, curation, digitization, imaging and long-term storage
- Rebuilding the Collection of Fishes: collection, curation, digitization, imaging and long-term storage
- Barcoding marine fishes of the Mariana Islands: intertidal to mesophotic coastal species with an analysis of their biogeographical relationships
- Barcoding insular freshwater and estuarine fishes of Micronesia with an analysis of their biogeographic relationships
- Rebuilding the Collections of Invertebrates: collection, curation, digitization, imaging and storage

PROJECT ELEMENTS IN SUPPORT OF RESEARCH ACTIVITIES INCLUDE:

Cyberinfrastructure Development

Development and implementation of strategies and networks to increase research capacity.

Education, Outreach and Diversity (EOD), and Workforce Development

Between 2020-2025, Guam EPSCoR proposes to expand *Education, Outreach, and Diversity* (EOD) activities in the Guam Ecosystems Collaboratorium. The "Guam Green Growth" or G^3 Initiative will be established. G^3 will build capacity and develop the local workforce in four (4) **NICE** areas, further stimulating Guam's competitive research capabilities. The G^3 initiative will contribute to creating a new sustainable green economy for the jurisdiction, which has traditionally been supported by tourism and government spending.

1) **N- Natural Resources**: Guam EPSCoR has demonstrated success in building capacity to support the understanding and management of the jurisdiction's natural resources amid global environmental changes. Guam EPSCoR supported dozens of graduate research assistantships (GRAs) and summer research experiences (SREs) for undergraduates in the marine and environmental sciences. Educational outreach activities extend the science of the Guam EPSCoR to thousands more in the community. The NSF INCLUDES Pilot: Growing STEM, leverages the success of Guam EPSCoR's EOD activities and creates a pathway from high school to terminal STEM degrees for Pacific Islander students. These efforts to build capacity for improved understanding and management of natural resources will continue in the new EPSCoR initiative.

2) **I- Information Technology**: The Guam Science & Technology Committee indicated that Guam needs to build capacity in information technology to support the booming telecommunications industry. Guam EPSCoR will support internships and training opportunities such as coding camps. Guam EPSCoR

will coordinate efforts with Silicon Village, an organization of telecommunications professionals working together to address capacity needs.

Guam EPSCoR will build scientific interest and understanding throughout the community by contributing to the establishment of Guam's first and only STEM Center. The center will be created in a former NASA Apollo tracking station that the U.S. Navy is expected to lease to the University of Guam. A Challenger Learning Center (www.challenger.org) will be a core feature of the center to take participants on a simulated Marianas Trench mission. Guam NASA EPSCoR resources will be leveraged for this effort.

3) **C-Circular Economy**: Guam EPSCoR will spark the creation of a circular economy in the jurisdiction to improve island sustainability. Circular Economy principles are 1) design out waste and pollution, 2) keep products and materials in use, and 3) regenerate natural systems. Guam relies heavily on imports to meet the needs of society. Over 100,000 shipping containers arrive at the Port of Guam each year, while nearly 15,000 barrels of petroleum products are used each day. As the island has limited space to continue digging holes to create new landfills, improved waste reduction and management strategies are crucial.

   Circular Economy concepts will be stimulated throughout the community. Examples of circular economy initiatives include, converting green waste into compost, waste to energy, food waste to animal feed, aquaponics, and harnessing renewable energy (sun, wind, and ocean).

4) **E- Energy Independence**: Guam EPSCoR will build capacity for the jurisdiction in new renewable energy technologies, microgrid technologies, and energy policy. New UOG partnerships with the Arizona State University's Global Institute of Sustainability and School of Engineering will be leveraged to stimulate action for energy independence in Guam and the broader Micronesia region. Guam EPSCoR will support a new faculty line in engineering/planning/sustainable development to lead these efforts.

Partners of this effort will include the Guam Economic Development Authority, UOG Center for Island Sustainability, UOG Sea Grant, UOG Office of Information Technology, UOG School of Business and Public Administration, Bank of Hawaii Center for Entrepreneurship and Innovation, Small Business Development Centers throughout Micronesia, Silicon Village, Guam Power Authority, Guam Solid Waste Authority, and Arizona State University Global Institute of Sustainability.

Through EOD and Workforce Development initiatives, Guam EPSCoR will be a leader for informing policy, building local STEM capacity, and implementing solutions to island challenges.

The Collaboratorium: promotion of international research collaborations.

PROPOSED ADDITIONAL COMPONENTS OF THE NEW PROJECT

Guam EPSCoR encourages the submission of Letters of Interest for proposals that may be integrated into the core project from the following suggested areas of research, development and engagement:

- Ocean acidification and responses by reef organisms
- Coral health under stress
- The role of algae in the resilience and maintenance of reef systems
- Changing reefs and changing peoples in Micronesia
- Remote sensing and reef research
- Robotics and reef research
- Diatoms of Micronesia (Biorepository collections)
- Terrestrial and Marine Insects of Micronesia (Biorepository collections)
- Flora of Micronesia in the University of Guam Herbarium (Biorepository collections)
- Marine Flora of Micronesia in the UOGML collection (Biorepository collections
- Promoting scientific research opportunities at the community college level
- Other proposed activities will be considered in relation to their relevance to the core project

RESEARCH BACKGROUND

Research under the current EPSCoR RII Track-1 grant relies on genomic and oceanographic tools to study coral reef resilience under the following paradigm: **Coral resilience is the result of responses at the individual, population, and species level.**

Our aim is to understand and describe the mechanisms of resilience in corals in the face of global and local stress, with coral bleaching being our focal global stressor. Local stressors investigated in our projects include terrestrial runoff caused by a poor watershed usage (recurrent arson wildfires and popular off-roading activities) and coastal development (pollution and tourism). Identifying mechanisms of resilience has the potential to incorporate/engineer resilience into mitigation strategies. For example, Guam Ecosystem Collaboratorium (GEC) researchers work on examining the genetic diversity of corals reared in Guam's coral nursery for restoration purposes. Linking population genetics to environmental tolerances of corals, for example, has the potential to select resilient individuals for reef restoration (National Academies of Sciences, Engineering, and Medicine 2018).

The overarching hypothesis above can be broken down into three components: resilience is driven by the ability of the coral holobiont to acclimate to stress; differences in population resilience are driven by connectivity and local adaptations; and interspecific differences in resilience are shaped by species-specific traits and responses to environmental stress.

1) Resilience is driven by the ability of the coral holobiont to acclimate to stress.

a) **Acclimation to stressors comes at an energetic cost, affecting the health of the coral holobiont**. To address this issue, we use gene expression to investigate the response of the coral holobiont to bleaching stress across a depth gradient in Pago Bay, relying on oceanographic data collected from a subset of the Pago Bay sensor network to identify micro-habitat differences, (a clear link between oceanography and genetics). Similarly, we perform gene expression experiments across a sedimentation gradient in Fouha Bay as a local stressor interacting with seasonal bleaching stress (see previous page). Further, the photophysiology of corals in these experimental systems is studied using PAM fluorometry while tissue lipid content and reactive oxygen species will be determined in collaboration with Dr. D. Baker at the University of Hong Kong, strengthening the collaborative network of the GEC.

b) **Repeated exposure to stressors (and survival) promotes acclimation via cellular-level responses.** Past studies have shown the importance of coral's thermal history in aiding acclimatization, increasing capacity for mitigating cellular-level stress (Weis, 2010). In fact, corals that were periodically subjected to a specific stress, such as high temperatures, have shown that they can acquire a higher resilience toward this particular stress in the future (Putnam and Gates 2015, Brown et al. 2002, Brown and Cossins 2011). We are investigating coral acclimation capabilities and mechanisms of genetic plasticity through gene expression and epigenetic studies. For example, we are documenting a rapid acclimation response of the coral holobiont to heat stress, using gene expression in controlled experiments and in parallel possible long-term acclimation via epigenetic mechanisms. Since acclimation may vary across individuals and species, experiments are performed on several species (genera *Acropora* and *Porites*).

c) **The abiotic environment may mitigate stress and promote acclimation at different spatial scales.** Water flow in particular may mitigate the impact of sea surface temperatures surpassing bleaching thresholds, as suggested by increased mortality of near-shore patches of staghorn *Acropora* corals during recent bleaching events in Guam (Raymundo et al. 2017). Building on this observation, we sampled staghorn *Acropora* corals from different flow environments *in situ* and conducted experiments in flow tanks to investigate how water flow may mitigate the rapid gene expression response that allows corals to acclimate to increased temperatures (identification of field sites and construction of flow tanks were facilitated by the GEC oceanographer); we found that increased water flow leads to gene front-loading, aiding in acclimation (Fifer 2018; Fifer et al. in prep). In collaboration with the Okinawa Institute of Science and Technology (OIST, Japan), GEC researchers measure the production of reactive oxygen species in corals exposed to thermal stress under different water flow regimes, adding relevant physiological data to our gene expression datasets. Lastly, building on the Pago Bay sensor network, reciprocal transplant experiments across depths are planned for the summer of 2019 to study the acclimation potential of *Acropora surculosa* originating from different micro-habitats.

2) Differences in population resilience are driven by connectivity and local adaptations.

a) **Populations with high levels of genetic connectivity are more resilient to environmental stress.** While both local and global stressors may lead to local mass mortalities, high connectivity among populations represents an important source for beneficial alleles and recruits that can promote fast recovery. Here, the GEC research team performs island-wide population genetic assessments of three *Acropora* and one *Porites* species to evaluate their recovery potential. The larval stages of different coral species may spend different lengths of time in the water column, affecting their ability to disperse. Larval dispersal potential was studied in the Marianas using a combination of sea surface current modeling based on ocean drifter data and larval transport models (Kendall & Poti 2014; Kendall & Poti 2015). Acoustic Doppler Current Profilers (ADCP) will be deployed at sites sampled for population genetics during the summer 2019 spawning season to characterize current velocities and directions at these sites. Using both the Kendall & Poti (2014, 2015) models and our smaller scale ADCP data, we will be able to discern if population genetic diversity is a result of predominantly local recruitment or recruitment from off-islands sources (e.g., the broader Micronesian region). This effort will directly link population genetics and coastal oceanography. Relying on explicit larval transport models will also allow designing sampling strategies for future population genetics research to identify source and sink populations across larger geographic scale.

b) **High levels of genetic diversity across populations allows local stressors to act as environmental filters, leading to locally adapted resilient populations.** Population genetic analyses of corals (genera *Acropora* and *Porites*) across environmental gradients are conducted by GEC researchers and students at multiple sites in Guam, both on the fore- and back-reef. These data allow us to detect possible allele frequency shifts across habitats. Understanding the effects of environmental filtering on coral resilience will directly impact management decisions. For example, resilience can be built into restoration efforts by identifying appropriate source colonies for specific restoration target sites.

3) Interspecific differences in resilience are shaped by species-specific traits and responses to environmental stress.

a) **Species with higher population connectivity are more resilient than species with lower levels of population connectivity.** Under 2a, we described our framework of how population connectivity affects coral resilience at the level of individual species. Comparing population genetic patterns across multiple species sampled from the same sites allows us to address if differences in genetic diversity and connectivity may (partially) explain the differences in resilience observed between different coral species on Guam

b) **Resilience of coral communities is driven by community composition.** Some coral communities will be more resilient than others due to differences in taxonomic composition of communities. The Pago Bay sensor network will provide the data to parameterize a numerical model of

oceanographic processes in Pago Bay. The long-term coral reef monitoring project led by GEC biorepository data manager Burdick documented the bleaching and mortality of corals in Pago Bay through the 2017 bleaching event using photo-transects. Using a nested model of the larger Pago Bay oceanographic model, we will use hindcasting to evaluate if differences in coral community resilience are the result of taxonomic composition or environmental differences between sites. The coral reef monitoring project will revisit the Pago Bay transects to document recovery of coral communities and we will perform a follow-up analysis, correlating the oceanographic model with recovery rates of communities, thus co-opting and leveraging existing time-series datasets and analyses.

c) **Species-specific traits explain differences in resilience between taxa.** Numerous coral traits are available through the Coral Trait Database (Madin et al. 2016) and may serve as the foundation for investigating the covariation of traits and resilience established through the long-term coral reef monitoring efforts in Guam. Phylogenetic comparative methods [e.g., Felsenstein's (1985) phylogenetic independent contrasts] represent a viable approach for investigating covariation of traits while accounting for the non-independence of species connected by evolutionary history and by extension non-independence of traits. To fully leverage existing coral trait data, it is vital to establish the identity of coral species (on Guam and elsewhere) and their relationships to each other. We will accomplish this goal using genetic barcoding and phylogenetic/ phylogenomic analyses of Guam's coral fauna. Comparative trait analyses will begin in Project Year 5. The specimens and notes contained in the Randall coral collection that will become part of the biorepository will be a vital resource for this effort.

FOR MORE INFORMATION:

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The Established Program to Stimulate Competitive Research (EPSCoR) is designed to fulfill the mandate of the National Science Foundation (NSF) to promote scientific progress nationwide. A jurisdiction is eligible to participate in the NSF EPSCoR Research Infrastructure Improvement Grant Program (RII) if their most recent 3-year level of NSF research support is equal to or less than 0.75% of the total NSF Research and Related Activities (R&RA) budget. Through this program, NSF establishes partnerships with government, higher education, and industry that are designed to effect sustainable improvements in a jurisdiction's research infrastructure, Research and Development (R&D) capacity, and hence, its R&D competitiveness. (National Science Foundation)

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