USGS

WATER RESOURCES RESEARCH GRANT PROPOSAL

Title: Nutrient Levels in Freshwater Seeps, Springs and Subterranean Flows of Tumon Bay and their Potential Impact on the Growth and Proliferation of the Green Alga *Enteromorpha clathratus*

Focus Categories: NU, NC, SW, ECL, HYDGEO

Keyword Numbers: Algae, Beaches, Groundwater Quality, Nutrients, Percolation

Duration: June 2000 to May 2001

Fiscal Year 1999 Federal Funds: $27,906

Non-Federal Funds Allocated: $40,000

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Congressional District of University Performing the Research: N/A

Statement of Critical Regional Water Problems

The lower Tumon basin, on the western shore of northern Guam, is the tourist Mecca of the island. Some 25 hotels are located in this area together with a vast array of shopping outlets, restaurants, and recreational facilities. The entire commercial complex borders Tumon Bay, a premier location and major attraction to overseas visitors. In fact, Tumon Bay and its associated developments represent the lifeblood of the tourist industry on Guam. Maintaining the natural beauty of Tumon Bay is, therefore, tantamount to maintaining a healthy economy and has become a top priority in recent years. To this end, an appreciable effort is made by beachfront hotels to preserve the aesthetic appeal of Tumon Bay, especially the intertidal area where vacationers spend much of their time sunbathing and relaxing. This process is both costly and labor intensive. It not only involves the removal of litter and the usual array of marine debris washed in by the tide, but also an over abundance of unsightly green alga that grows prolifically along much of the intertidal region. The alga, *Enteromorpha clathratus*, is not a recent invader. On the contrary, it occurs naturally on Guam although its increased presence and abundance along the shore of Tumon Bay appears to have paralleled the commercial developments that have occurred in the area over the last 30 years. Today, luxuriant stands of *E. clathratus* occur year-round in Tumon Bay and are a chronic eyesore to the majority of people that frequent the area. The hotel and tourist businesses on Guam regard *E. clathratus*, not only as a nuisance, but a very real threat to the tourism industry. Understanding and controlling the underlying variables responsible for the prolific growth of *E. clathratus* in Tumon Bay is, therefore, of paramount importance to the future economy of the island.

It is popularly believed that nutrient enrichment is the primary cause of the algal problem in Tumon Bay, although some claim it is linked to a decline in herbivorous fish populations. It seems probable that both factors are important, although there is no hard evidence to support either. Certainly, the nutrient enrichment theory has credence, and a number of possible sources have been suggested, including stormwater runoff, leaky sewer pipes, and groundwater intrusion (Matson 1996). Of these, the latter is frequently cited as the most likely cause due to the high incidence of permanent seeps and springs in Tumon Bay, and the naturally elevated nitrate levels in Guam's groundwater (Matson 1991a). Denton *et al.* (1998) disputed the idea that nitrate from groundwater was the critical element controlling the growth of *E. clathratus* in Tumon Bay and suggested that phosphorus from fertilizers was a more likely candidate. This conclusion was prompted by the discovery of extremely high inorganic phosphorus levels (up to 486 mgl^{-1}) in irrigation runoff from the Palace Hotel overlooking Agana Bay. These findings implied that similarly charged runoff from beachfront hotels in Tumon Bay could well be the principal driving force behind the luxuriant growths of *E. clathratus* in the area today. In support of this argument, Denton *et al.* (1998) point out that natural levels of available phosphorus in Guam's surface waters are usually less than 1 μgl^{-1} and, hence, are sufficiently low enough to limit the growth of most aquatic plants. Thus, a small increase in the ambient availability of this element could have a dramatic effect on the productivity of local algae, providing all other nutrients are nonlimiting. It is known for example that levels in excess of 25 μgl^{-1} can cause nuisance growths of algae and other aquatic plants (U.S. EPA 1986). Denton *et al.* (1998) also drew attention to the fact that runoff from hotels fronting Tumon Bay is not discharged into storm drains or storm sewers, but permeates slowly into the intertidal zone, via an underground network of infiltration chambers. Nutrient enriched runoff infiltrating this region of the beach would, therefore, create the perfect milieu for algal growth and development.

In the study proposed here, we will look closely at the nutrient loading of freshwater seeps, springs and subterranean flows within the intertidal region of Tumon Bay. This study will be the first comprehensive survey of its kind and will address a critical water quality priority area recently established by the Institute's Advisory Council. Partial funding for a major piece of equipment for the project is also being sought from Duty Free Shoppers (DFS, Guam) and Guam Hotel and Restaurant Association (GHRA) – see budget. In a separate study, we are planning to assess and evaluate current landscaping practices in the Tumon Bay area with a view towards implementing corrective management strategies.

Statement of Results, Benefits, and/or Information Expected

The study will determine the level and distribution of primary nutrients (nitrogen, phosphorus, iron, manganese and silica) in freshwater sources entering the intertidal region of Tumon Bay. Such a program is an essential first step towards confirming the nutrient enrichment theory and identifying the principal sources supplying nutrients into the bay. It will also provide the necessary groundwork for a more intensive follow-up study to identify seasonal norms and fluctuations in nutrient levels entering the bay, as well as episodic inputs related to landscaping activities. These studies are fundamental to the management and sustainability of Tumon Bay.

Nature, Scope, and Objectives of the Research

The nature of the proposed study is primarily one of assessment monitoring. In scope, the project will consider a range of primary nutrients within the area under investigation, and from adjacent control sites to the north. The objectives of the study are as follows:

1. To determine the presence and abundance of nitrogen (as nitrate and nitrite nitrogen), phosphorus (as orthophosphate phosphorus), iron, manganese, and silica in freshwater seeps, springs, and subterranean flows within the intertidal region of Tumon Bay.
2. To delineate concentration gradients of the above nutrients along the beach and identify areas of temporary and chronic enrichment if they exist.
3. To determine which nutrients are present in excess and which are limiting relative to needs of *E. clathratus* for optimum growth and photosynthesis.
4. To initiate the provision of a sound database with which future levels may be compared and evaluated and which is vital to the sustainable development of Tumon Bay.
5. To identify permanent monitoring sites for future surveillance work

Methods, Procedures and Facilities

Freshwater samples will be collected for nutrient analysis from the permanent seeps and springs within the intertidal region of Tumon Bay. The locations of these have been precisely mapped and digitized into a P.C. ARC/INFO map coverage (Jenson *et al.* 1997, Jocson *et al.* 1999). Subterranean freshwater flows will be sampled from pits dug in the upper intertidal region. These will be placed at regular intervals (~50 m) along the entire length (3 km) of Tumon Bay. Additional sampling of these interstitial waters will occur as necessary down-gradient from each of the beachfront hotels, and in areas where the growth of *E. clathratus* is especially prolific. The undeveloped beaches to the north of Tumon Bay will serve as control sites. Standard field measurements (temperature, pH, redox potential, dissolved oxygen, salinity, and conductivity) will be taken at each site prior to sample collection.

Water samples will be collected in 50-ml polypropylene syringes and immediately filtered (0.45 μm) into 60 ml polyethylene bottles. Sample preservation methods will include acidification and/or storage on ice as appropriate. Duplicate samples will be collected at each site. All analyses will be undertaken within 24 h of collection in accordance with U.S. EPA protocols.

The analytical work will be carried out at the Water and Environmental Research Institute (WERI), Water Quality Laboratory, at the University of Guam, where adequate support facilities, infrastructure, essential chemicals, and basic items of equipment necessary for the study are present. The analytical procedures will follow U.S. EPA approved methods described in the American Public Health Association's *Standard Methods* Manual. Quality control and quality assurance procedures will be rigidly adhered to.

Related Research

Hydrogeological investigation of Tumon Bay has been ongoing at WERI for the past several years (Jenson *et al.* 1997). Maps of the springs and seeps in Tumon Bay were compiled by Jocson (1998) and recently published by Jocson *et al.* (1999). Modeling simulations of discharge into Tumon Bay (Jocson 1998, Jocson *et al.* 1999) provide a basis for estimating total flow into the bay, so that some estimate of unobserved flux into the tidal zone can be made. The hydrogeological work to date will enable workers to initiate field data collection for this project with a thorough knowledge of the locations and relative importance of the groundwater discharge sources in the bay.

Surprisingly little work has been directed towards identifying the parameters that control the growth of *E. clathratus* in Tumon Bay. In fact, the only study to date was that undertaken by FitzGerald in the early 1970s (FitzGerald 1976, 1978). This researcher examined the relationship between several environmental variables and the biomass of *E. clathratus* at three sites in Tumon Bay. He concluded that surf conditions, water flow, and grazing by herbivorous fish were the main cause of fluctuations in standing crop. FitzGerald also suggested that nutrients, particularly nitrates, in percolating groundwater were the primary growth stimuli.

The latter hypothesis was based on the fact that luxuriant growths of *E. clathratus* were frequently encountered near freshwater seeps that contained near optimum levels of nitrate for the growth of this species (2.1 mgl^{-1}). It was generally accepted that limitations in nitrogen rather than phosphorus controlled the growth of algae in the marine environment (Correll 1998). Consequently, FitzGerald paid little attention to the phosphorus levels in the seep waters examined (7-8 μgl^{-1}) possibly because they were over two orders of magnitude below that considered optimum for *E. clathratus* (1.22 mgl^{-1}). In the light of current knowledge, however, he may have viewed things differently. For example, threshold levels of phosphorus, above which macroalgae blooms have been observed on coral reefs elsewhere, are around 3 μgl^{-1} (Lapointe *et al.* 1993, 1997, Bell 1992). Although the equivalent threshold level has yet to be determined for *E. clathratus,* it could conceivably be lower than the seep levels measured by FitzGerald during his study. Also, it is now well known that phosphorus limitations in coral reef waters are frequently more severe than nitrogen limitations, in controlling algal growth and productivity (Smith 1984). In fact, several studies have shown that phosphorus enrichment alone can stimulate tropical marine algal productivity in the field (Lapointe 1985, 1987, 1989, Lapointe *et al.* 1987, Schaffelke and Klumpp 1998).

Shortly after Fitzgerald concluded his study, Marsh (1977) carried out a fairly extensive nutrient analysis of marine waters in Tumon Bay, in an attempt learn more about the phytoplankton blooms that periodically occur there to this day. He noted that the blooms started at the beginning of the wet season, and reasoned that nutrients (especially phosphorus) accumulated within the watershed during the dry season and were flushed into the bay with the first heavy rains. Marsh also concluded that groundwater inputs into Tumon Bay constituted a significant source of nitrogen for the reef ecosystem, but that this was not the case for phosphorus. Unfortunately, no analytical data was provided in his report.

Another significant outcome of Marsh's study was the discovery of occasionally high phosphorus concentrations (up to 388 μgl^{-1}) in runoff from the parking lots and landscaped areas of two of the seven hotels that fronted Tumon Bay at the time. Surprisingly, Marsh failed to make any connection between these data and the high growth rates of *E. clathratus* reported earlier in Tumon Bay by FitzGerald (1976). However, he did note that the Guam Environmental Protection Agency had occasionally observed similarly high levels of phosphate in hotel runoff, although again, no data was given. The likelihood remains, however, that hotels in the Tumon basin have been a prominent source of phosphorus enrichment to the bay waters over the last quarter of a century.

It is possible that Marsh considered drainage water from hotels to be a sufficiently variable and unreliable source of nutrients to *E. clathratus.* However, the recent work of Schaffelke and Klumpp (1998) now suggests otherwise. Apparently, marine algae have the capacity to rapidly accumulate and store phosphorus in their tissues under conditions of short-term nutrient enhancement. These nutrient stores are then used to sustain enhanced growth and net photosynthesis rates for about a week once conditions return to normal. Schaffelke and Klumpp (1998) noted significant increases for both biological parameters in *Sargassum baccularia* exposed to weekly, 1-h pulses of phosphate (60 μgl^{-1}) over a four-week period. Clearly then, episodic nutrient inputs, associated with hotel landscaping activities, may very well play a highly significant role in maintaining the chronic algal problem that is present in Tumon Bay today.

Specific investigations into the nutrient chemistry of groundwater seeps and springs, and the brackish interstitial waters of Tumon Bay are limited largely to the work of Matson (1991a and b, 1996). In his earlier studies, Matson examined several aquifer beach seeps and springs along a section of Tumon Bay between the Reef and Okura Hotels. He reported average nitrate-nitrogen levels of 1.39-1.74 mgl^{-1}, which is not unusual for Guam's groundwater. However, average reactive (available) phosphate levels ranged from 17.1-40.3 μgl^{-1} - appreciably higher than FitzGerald's earlier data (7-8 μgl^{-1}) for seep waters from the same general area. Unfortunately, no control sites were incorporated into the study.

Matson's later study focused on interstitial waters from the six intertidal sites in Tumon Bay. This time, even higher levels of reactive phosphorus were measured (37.2-55.8 μgl^{-1}) whereas nitrate-nitrogen levels remained fairly typical of local groundwater discharges (0.74-4.14 mgl^{-1}). Once again, the study suffered from a lack of comparative data from suitable control sites.

The general conclusions from the limited available date presented above is that significant nutrient enrichment is indeed occurring in the intertidal zone of Tumon Bay, and is almost certainly contributing to the algal problem that currently plagues the area. Sources of these nutrients (particularly phosphorus) are as yet undefined, although significant contributions from hotel landscaping practices are strongly suspected. However, contributions from urban runoff, domestic wastewater leaks and discharges, and contaminated groundwater sources from further afield (e.g. Harmon Sink) cannot be ruled out at this stage. Further degradation of Tumon Bay seems almost inevitable in the light of continued hotel development in the area. The recent initiative to beautify Tumon as part of the Governor's Vision 2001, is also likely to contribute additional nutrient burdens to the coastal waters, unless preventative measures are implemented. The proposed research program described herein is seen as a first step towards achieving this goal, and will provide the necessary database to gauge the effectiveness of future management practices in the area.

Professional Publication Plan

The study will appear as a WERI Technical Report. It is also planned to publish the study in a reputable scientific journal (e.g., *Marine Pollution Bulletin, Ground Water, Journal of Hydrology, Marine Ecology Progress Series, Pacific Science, Micronesica*)

Literature Cited

Bell, P.R.F. (1992). Eutrophication and Coral Reefs – Some Examples in the Great Barrier Reef Lagoon. *Water Research,* 26: 553-568.

Correll, D.L. (1998). The Role of Phosphorus in the Eurtrophication of Receiving Waters: A Review. *Journal of Environmental Quality*

Denton G.R.W., L.F. Heitz, H.R. Wood, H.G. Siegrist, L.P., R. Lennox (1998). Urban Runoff in Guam: Major Retention Sites, Elemental Composition and Environmental Significance. *WERI Technical Report No. 84,* 72 pp + appendices.

FitzGerald, W.J. (1976). Environmental Parameters Influencing the Growth of *Enteromorpha clathrata* (Roth) J. Ag. in the Intertidal Zone of Guam. *Botanica Marina*, 21: 207-220.

FitzGerald, W.J. (1976). Environmental Parameters Influencing the Growth of *Enteromorpha clathrata* (Roth) J. Ag. in the Intertidal Zone of Guam. M.S. Thesis, University of Guam, 43 pp.

Jenson, J.W., J. M. U. Jocson and H.G. Siegrist (1997). Groundwater Discharge Styles from an Uplifted Pleistocene Island Karst Aquifer, Guam, Mariana Islands. *Proceedings, Sixth Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst*, April 1997, Springfield, Missouri. Balkema/Rotterdam/Brookfield Press. P. 15-20.

Jocson, J. M. U. (1998). *Hydrologic Model for the Yigo-Tumon and Finegayan Subbasins of the Northern Guam Lens Aquifer, Guam*. Masters Thesis, University of Guam, 95 pp.

Jocson, J. M. U., J. W. Jenson and D.N. Contractor. (1999). An Integrated Numerical Modeling Study and Field Investigation of the Northern Guam Lens Aquifer. *WERI Technical Report No. 88,* (in press).

Lapointe, B.E. (1985). Strategies for Pulsed Nutrient Supply to *Gracilaria* Cultures in the Florida Keys: Interactions Between Concentrations and Frequency of Nutrient Pulses. *Journal of Experimental Marine Biology and Ecology,* 93: 211-222.

Lapointe, B.E. (1987). Phosphorus- and Nitrogen-Limited Photosynthesisand Growth of *Gracilaria tikvahiae* (Rhodophyceae) in the Florida Keys: An Experimental Field Study. *Marine Biology,* 93: 561-568.

Lapointe, B.E. (1989). Macroalgal Productionand Nutrient Relations in Oligotrophic Areas of Florida Bay. *Bulletin of Marine Science,* 44: 312-323.

Lapointe, B.E., M.M. Littler and D.S. Littler (1987). A Comparison of Nutrient-Limited Productivity in Macroalgae from a Caribbean Barrier Reef and from a Mangrove Ecosystem. *Aquatic Botany,* 28: 243-255.

Lapointe, B.E., M.M. Littler and D.S. Littler (1993). Modification of Benthic Community Structure by Natural Eutrophication: The Belize Barrier Reef. *Proceedings of the 7th International Coral Reef Symposium,* 1: 323-324.

Lapointe, B.E., M.M. Littler and D.S. Littler (1997). Macroalgal Overgrowth at Fringing Coral Reefs at Discovery Bay, Jamaica: Bottom-Up Versus Top-Down Control. *Proceedings of the 8th International Coral Reef Symposium,* 1: 927-932.

Marsh, J.A. Jr. (1977). Terrestrial Inputs of Nitrogen and Phosphorous on Fringing Reefs on Guam. *Proceedings: Third International Coral Reef Symposium,* Miami, Florida. Pp. 331-336.

Matson, E.A. (1996). Terrestrial Groundwater Sources of Fecal Indicator Bacteria in Guam. A Comparison of Densities of Pollution Indicator Microorganisms in Recreational Coastal Waters and their Contaminated Influent Groundwaters of Guam. In: Phase II of Project Completion

Report WRRC-96-03 entitled *Applicability of New Marine Water Quality Standards in Guam* (Principal Investigator: R.S Fujioka. Co-investigators: C. Sian-Denton and M. Borja). Pp. 1-20. Prepared for U.S. EPA under Cooperative Agreement # CR820809-01-0, August 1996. Available from the Water Resources Research Center, Honolulu, Hawaii.

Matson, E.A. (1991a). Nutrient Chemistry of the Coastal Waters of Guam. *Micronesica*, 24: 109-135

Matson, E.A. (1991b). Water Chemistry and Hydrology of the "Blood of Sanvitores", A Micronesian Red Tide. *Micronesica,* 24: 95-108.

Mylroie, J. E., J. W. Jenson, *et al.* (1999). Karst Geology and Hydrology of Guam: Key Questions and Priorities. *WERI Technical Report No. 89,* (in press).

Schaffelke, B. and D.W. Klumpp (1998). Short-Term Nutrient PulsesEnHance Growth and Photosynthesis of the Coral Reef Macroalga *Sargassum baccularia. Marine Ecology Progress Series,* 170: 95-105.

Smith, S.V. (1984). Phosphorus Versus Nitrogen Limitation in the Marine Environment. *Limnology and Oceanography,* 29: 1149-1160.

Taborosi, D. S. (1999). An Inventory of Karst Features on Guam. *Karst Modeling Symposium,* Charlottesville, VA.

U. S. EPA (1986). Quality Criteria for Water 1986. U. S. Environmental Protection Agency, *EPA 440/5-86-001,* Office of Water Regulations and Standards Washington, DC 20460