UNSIGHTLY ALGAL BLOOMS IN TUMON BAY, GUAM'S PREMIER TOURIST LOCATION: POSSIBLE CONNECTION TO HOTEL LANDSCAPING ACTIVITIES

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ABSTRACT

Tumon Bay is the tourist Mecca of Guam and receives over a million visitors annually. Maintaining the natural beauty of the area is therefore tantamount to maintaining a healthy economy. One problem local hoteliers are faced with is the daily removal of unsightly green alga (*Enteromorpha clathrata*) from the intertidal zone where tourists spend much of their time relaxing. Blooms of this alga have long been associated with the naturally high nitrate levels in intruding groundwater. Recent evidence suggests an increase in the ambient availability of phosphorus associated with hotel landscaping activities may be more important and is considered here.

I. INTRODUCTION

Guam's primary industry is tourism and the lower Tumon basin, on the western side 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 (Fig. 1), a premier location and major attraction to overseas visitors. Maintaining the natural beauty of Tumon Bay is clearly tantamount to maintaining a healthy economy. As a result, considerable effort is made by local hoteliers to preserve the bay's aesthetic appeal, particularly in the intertidal region where vacationers spend much of their time sunbathing and relaxing. This process is both costly and labor intensive. It involves not only the collection of litter and the usual array of marine debris washed in by the tide, but also the daily removal of unsightly green alga that grows prolifically in the intertidal zone. The alga, *Enteromorpha clathrata*, is not a recent invader. On the contrary, it occurs naturally on Guam, although anecdotal evidence suggests its abundance in Tumon Bay has paralleled commercial development in the area over the last 30 years. Today, luxuriant blooms of *E. clathrata* occur year-round along much of Tumon Bay and are considered by many to be a very real threat to the tourism industry. Identifying and controlling the factor(s) driving the growth of this species are, therefore, of importance to the future economy of the island.

In Guam, blooms of *E. clathrata* typically occur on beaches influenced by groundwater intrusion. Members of this genus are well-known indicators of nutrient enrichment derived from natural and anthropogenic sources (Lapointe *et al.,* 1993; 1997; Lapointe and Thacker, 2002). Guam's groundwater comes from a highly conductive limestone aquifer in the northern half of the island and is naturally enriched with dissolved inorganic nitrogen (DIN = NH_4^+ + NO_3^- + NO_2^-), the nutrient popularly believed to be responsible for the algal problem in Tumon Bay (Fitzgerald, 1976; 1978; Marsh, 1977). It is true that Tumon Bay is heavily inundated with emergent groundwater, especially in the intertidal zone where DIN levels are typically in the order of 2-3 mg/l (predominantly as NO_3-N). However, the DIN enrichment theory does not explain why *E. clathrata* has become more abundant on this particular beach in recent years. Some claim it is linked to a decline in herbivorous fish populations as a result of over fishing, although the algal problem has yet to improve significantly since Tumon Bay was declared a marine preserve, with restricted fishing, over five years ago.

An alternative explanation put forward by Denton *et al.* (1998) suggests phosphorus (P) limitations control the growth of *E. clathrata* under normal conditions and that hotel development in Tumon Bay, and concomitant increases in landscaping activities, have increased P availability in the area as a result of poor management practices (i.e., excessive irrigation and over use of chemical fertilizers). The discovery of high soluble reactive phosphorus (RP) levels (up to 482 mg/l) in runoff from the gardens of one of Guam's leading hotels, at the northern end of Agana Bay (Fig. 1) lends support to this hypothesis (Denton *et al.,* 1998). Agana Bay is separated from Tumon Bay by a small peninsula. It is less well developed commercially and doesn't have the same algal problem despite numerous seeps and springs in the area.

In the current investigation, we determined concentrations of NO_3-N, NO_2-N, NH_4-N, RP, total P, and chloride in seeps and springs from the intertidal zone of Agana Bay and Tumon Bay. N and P levels were compared directly with those found in groundwater taken directly from the island's karst limestone aquifer, further inland. Seawater samples were also taken for analysis from discrete locations within Tumon Bay itself to highlight nearshore nutrient dilution and dispersion rates.

II. MATERIALS AND METHODS

In July 2000, groundwater seep and spring samples were collected at low tide from 9 intertidal sites (mostly 50-100m apart) along the northern half of Agana Bay. Similar samples were collected monthly (June-August 2000) from 70 intertidal sites (~50 m apart) along the entire length of Tumon Bay (Fig. 1). Each sample was withdrawn directly into a pre-cleaned 50-ml polyethylene syringe and passed through a 0.45 µm in-line filter into a 50-ml polypropylene screw-cap tube. All samples were collected in duplicate and chilled immediately.

Groundwater samples from further inland were obtained from 96 of Guam's drinking water production wells (Fig. 1). The samples were collected at the wellhead of about a third of the wells, every three months, over a nine-month period (June 2000-March 2001). The unfiltered samples were captured directly in duplicate 50-ml polypropylene screw-cap tubes and chilled immediately without further treatment.

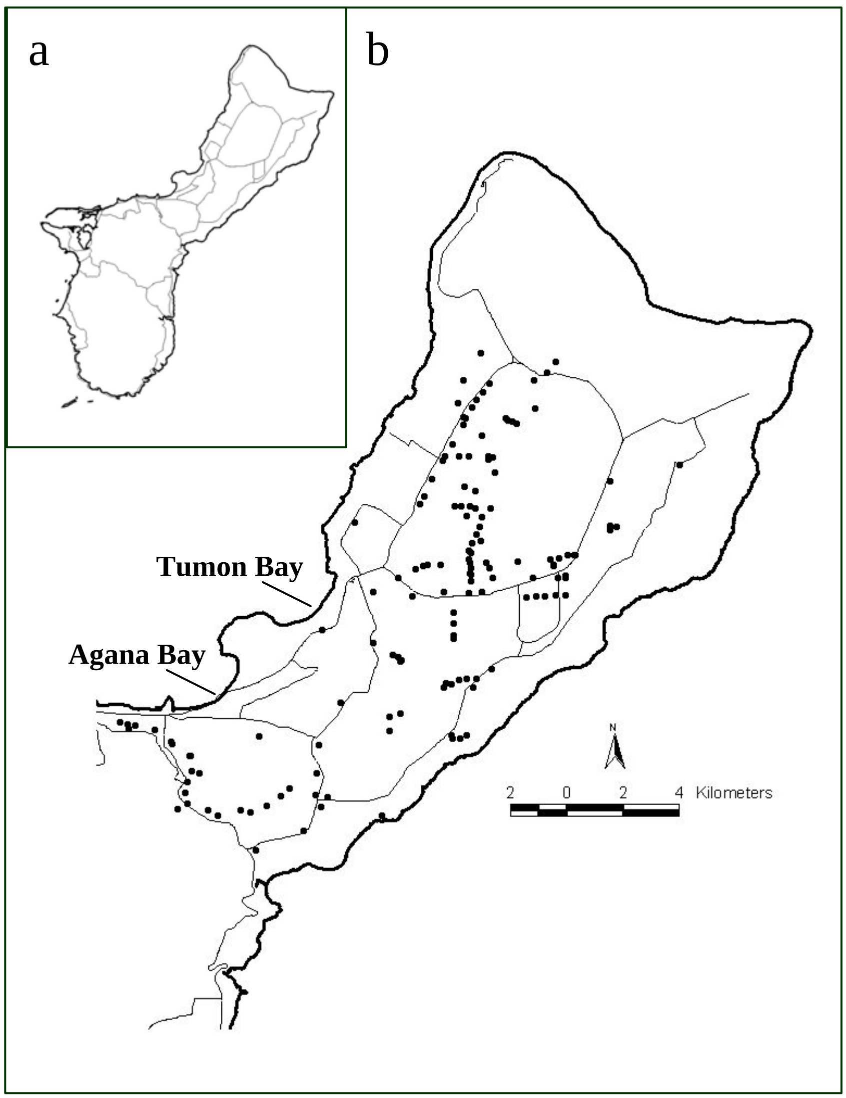

Figure 1: Map of Guam (13°28'N, 144°45'E: inset a) and northern half of the island (b) showing location of Tumon Bay, Agana Bay and the drinking water production wells (closed circles) sampled during this study

Daily seawater samples were also collected from within Tumon Bay over a period of four months (February-May 2001). The samples were taken directly in front of 9 bayside hotels and one beach bar, at the surf zone and further offshore (~50 m), in waist deep water (~1 m). Seven of the sites were adjacent to emergent springs, five of them major. All samples were filtered and treated in the same manner as described earlier.

In the laboratory, samples were stored overnight at $4^{o}C$ and analyzed the next day using a four-channel, automated, flow injection ion analyzer (Lachet, Australia). Relatively unstable RP, NO_2-N and NH_4-N were analyzed first followed by NO_3-N and chloride using the manufactures recommended QuickChem® methods. Total P was determined later following persulfate oxidation.

III. RESULTS

N and P levels determined in the different water types are summarized in Table 1 together with DIN:RP molar ratios. RP concentrations in spring and seep samples from Agana Bay ranged from 12.7-30.6 µg/l (overall geometric mean: 19.0 µg/l). The highest concentration occurred at the northern end of the bay closest to the hotel where high RP levels in surface runoff had previously been identified (Denton *et al.*, 1998). Runoff from the hotel grounds drains into a retention pond located on the peninsula that separates Agana Bay from Tumon Bay. The P enriched spring sample was collected from the base of this rocky peninsula. NO_3-N concentrations for the Agana Bay sites ranged from 1.3-4.0 mg/l (overall geometric mean: 2.5 mg/l) and accounted for 97-100% of DIN. Once again, the highest concentration was found at the northern end of the bay closest to the hotel.

RP accounted for >95% of total P in almost all spring and seep samples taken from Tumon Bay. Values exceeded the Guam Environmental Protection Agency water quality standard of 25 µg/l for category M-1 (excellent) marine waters (GEPA, 2001) in only 6% of the total number analyzed. Levels in the nine major springs entering Tumon Bay ranged from 14.0-25.4 µg/l (geometric mean: 17.1 µg/l). Two adjacent springs had significantly higher RP levels than the other springs monitored (Fig. 2) and clearly represent aquifer source waters that are chemically different from those feeding the other springs along the beach. It is noteworthy that *E. clathrata* was especially abundant in this region of the bay.

Compared with spring water, RP levels in seeps were considerably more variable in both space and time, with levels ranging from 1.3-31.9 µg/l (geometric mean: 14.1 µg/l). Such variability did not correlate with salinity fluctuations and may reflect losses as a result of biotic uptake in the slower moving pore waters, on the one hand, coupled with redox mediated releases of iron bound P from oxygen depleted beach sediments, on the other. Episodic nutrient inputs associated with landscaping activities along the waterfront may also be a contributing factor here, since excess irrigation water moving through the shallow soil profile is more likely to show up on the beach as seepage rather than as a fast flowing spring. It is worth noting here that runoff from the 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.

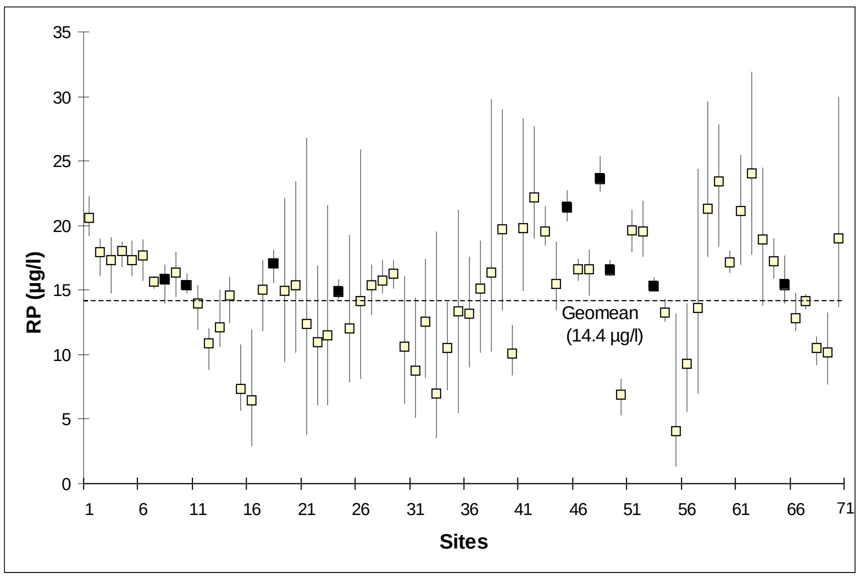

Figure 2: Geometric mean RP levels in seeps (open squares) and springs (filled squares) from Tumon Bay, Guam. Vertical bars indicate range of monthly values for June-August 2000. Dashed line represents the geometric mean of all data sets.

NO_3-N levels in the spring samples from Tumon Bay ranged from 1.5-3.2 mg/l (geometric mean: 2.2. mg/l) and again accounted for almost all of DIN in the great majority of the samples analyzed. Detectable levels of NH_4-N (3.5-10.0 µg/l) and NO_2-N (1.3-9.0 µg/l) were found in 15% and 33%, respectively, of all samples analyzed. NO_3-N levels in seep samples were far more variable and ranged from <0.001-7.9 mg/l (geometric mean: 1.2 mg/l). Only 1.5% of all samples had NO_3-N concentrations <0.1 mg/l. Detectable levels of NH_4-N (1.1-387 µg/l) and NO_2-N (0.9-414 µg/l) were found in 41% and 74%, respectively, of all samples analyzed.

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Table 1: Nitrogen and Phosphorus Concentrations (µg/l) in Groundwater and Shallow Nearshore Waters in Guam

Location	Sample Type	n	Sampling Events	Statisitic	RP	NH_4^+	NO_3^-	DIN	DIN:RP (molar ratio)
Agana Bay	Intertidal Seep	2	1	Range	15.4 - 18.2	<1.06	2071 - 2566	2076 - 2566	59 - 62
				Mean	16.7	-	2305	2308	60
Agana Bay	intertidal Spring	7	1	Range	12.7 - 30.6	<1.06 - 23.4	1335 - 4014	1372 - 4014	28 - 110
				Mean	19.8	nc	2520	2535	56
Tumon Bay	Intertidal Seep	65	3	Range	1.3 - 31.9	<1.06 - 387	0.53 - 7942	7.2 - 8357	0.1 - 288
				Mean	14.1	nc	1226	1677	57
Tumon Bay	Intertidal Spring	9	3	Range	14.0 - 25.4	<1.06 - 10.0	1546 - 3241	1560 - 3241	36 - 94
				Mean	17.0	nc	2164	2202	57
Tumon Bay	Surf (mixing) Zone	10	50	Range	0.17 - 13.3	<1.06 - 216	7.6 - 2540	7.6 - 2540	0.8 - 248
				Mean	2.17	nc	130	235	39
Tumon Bay	50 m Offshore	10	50	Range	0.08 - 7.46	<1.06 - 29.7	0.92 - 1325	0.92 - 1325	0.3 - 469
				Mean	1.32	nc	120	174	64
Northern Guam	Production Wells	97	3	Range	6.7 - 38.5	<1.06 - 30.7	793 - 5779	793 - 5786	20 - 201
				Mean	13.4	nc	2362	2537	86

Mean = geometric mean; nc = not calculable; dashes indicate no data

RP levels in the production wells ranged from 6.7-38.5 µg/l (geometric mean: 13.4 µg/l). Only five wells yielded values in excess of 25 µg/l and only one scored above 35.0 µg/l. Four of these wells were located in the Yigo-Tumon Trough, a natural valley formed by the basement volcanics to the northeast of Tumon Bay (Jenson *et al.*, 1997). It is noteworthy that much of the groundwater entering the bay comes from this particular subbasin. The geometric mean RP level for the 50 wells sampled within this region was 13.1 µg/l compared with 13.9 µg/l for all remaining wells analyzed island wide. Frequency distribution histograms of all well and beach data sets are plotted together in Fig. 3. It can be seen that the latter are somewhat displaced to the right suggesting the aquifer may not be the only source of RP into the bay.

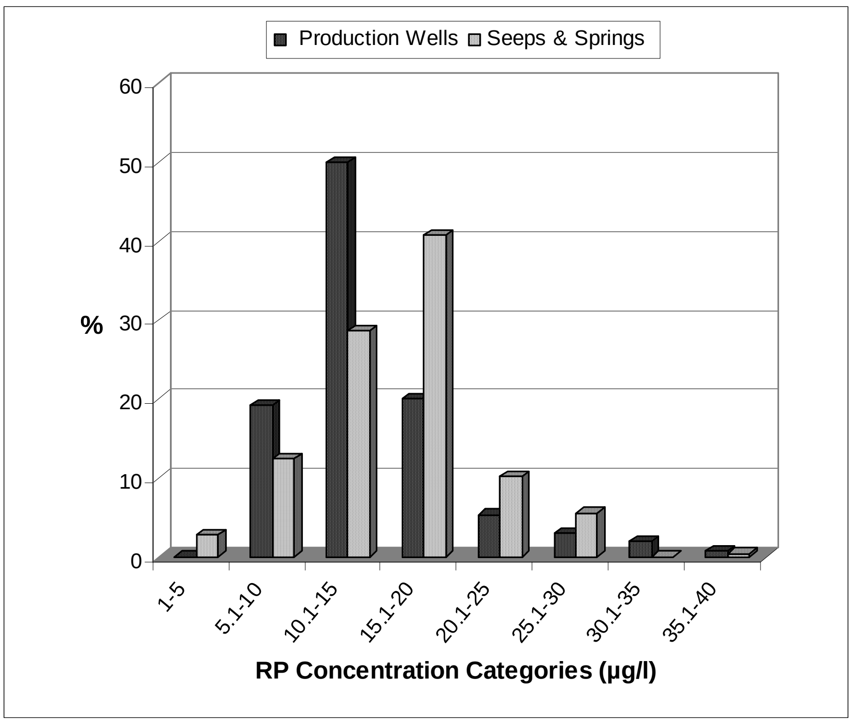

Figure 3: Frequency distribution histograms for RP levels in Tumon Bay seeps and springs and in Guam's drinking water production wells.

NO_3-N accounted for >99% of DIN in all well water samples analyzed with concentrations ranging from 0.79-5.78 mg/l (geometric mean: 2.36 mg/l). NH_4-N was detected in 35% of the samples at a concentration range of 1.7-30.7 µg/l whereas NO_2-N was consistently below an analytical detection limit of 0.7 µg/l.

The analysis of seawater from the bay showed that emergent groundwater is rapidly diluted and dispersed at the surf zone. Plots of salinity against nutrient concentrations (Fig. 4) indicate that both RP and NO_3-N behave conservatively in the mixing zone, affected only by the physical process of dilution with seawater. Although there are numerous sub-tidal springs in Tumon Bay, dilution is essentially complete within ~50 m of the shoreline where RP and DIN concentrations are predominantly <3 µg/l and from 100-400 µg/l respectively. Occasionally, very low levels of RP (<0.2 µg/l) and DIN (<10 µg/l) were recorded in this region. Such samples (<5%) were considered to be representative of oligotrophic oceanic waters that wash over the reef crest into the bay at high tide.

NH_4-N was detected in 10% of the surf zone samples (1.5-216 µg/l) and 4% of those taken further offshore (1.5-29.7 µg/l). Occurrences were most frequently coincident with obvious algal decomposition in nearby sediments. NO_2-N levels were consistently below the limits of analytical detection.

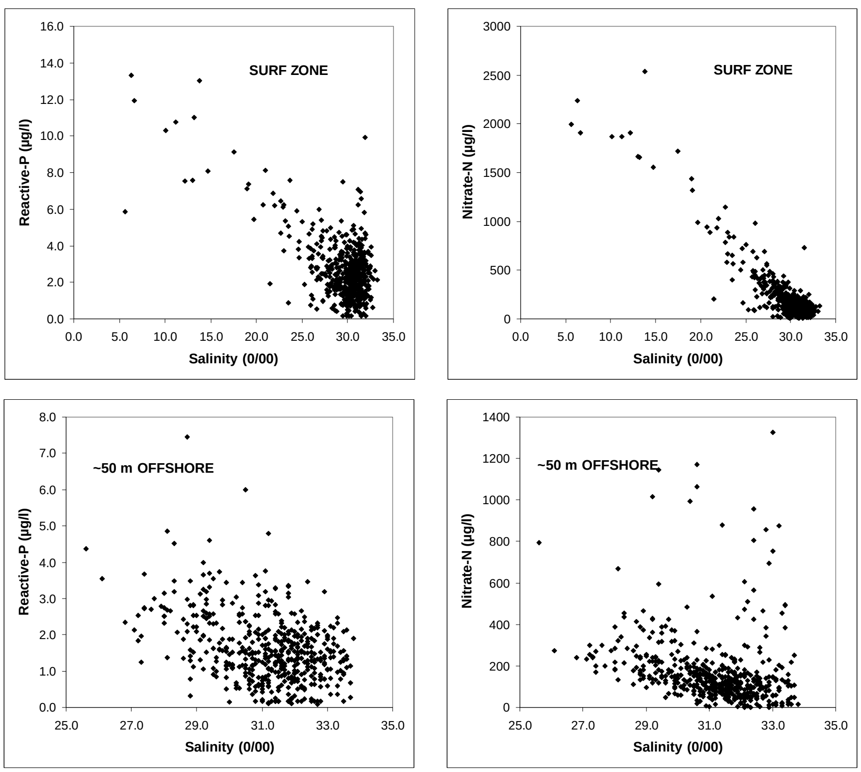

Figure 4: Daily concentrations of RP and NO_3-N plotted against salinity of seawater from the surf (mixing) zone and ~50 m offshore in Tumon Bay (February-May 2001)

IV. DISCUSSION

Coastal waters receiving groundwater inputs from limestone watersheds are typically DIN enriched (Matson, 1993; Lapoint, 2004). The comparatively high DIN levels found in groundwater entering Tumon Bay are, therefore, not unusual. It has been suggested from field observations that DIN threshold concentrations required to promote macroalgae blooms in coral reef waters are in the order of ~70 µg/l (Lapointe, 1997; 1999; Lapointe and Thacker, 2002). Considering that algae require N:P molar ratios of ~10:1 (Bell 1992), corresponding threshold concentrations for RP are estimated to lie somewhere between 1.5-3.0 µg/l (Lapointe, 2004). These critical values are certainly within the range of concentrations determined for each nutrient in nearshore waters of Tumon Bay during the present study. In fact, 80% of samples taken ~50 m offshore contained DIN concentrations >70 µg/l. In contrast, only 8% had RP levels in excess of 3 µg/l and 49% yielded values of less than 1.5µg/l. Thus, while N is generally present in oversupply in this region of the bay, RP levels are frequently limiting. This could explain why *E. clathrata* does not extend far beyond the intertidal zone. It also highlights the dramatic effect relatively small anthropogenic inputs of RP could have on the distribution and abundance of this species within the bay. The dense blooms of *E. clathrata* observed near the two RP enriched springs (Fig. 2) may well serve to illustrate this point.

Studies on the Australian Great Barrier Reef suggest that algae do not do particularly well in waters where RP concentrations are less than 0.1 µg/l (Furnas *et al.*, 1995). Likewise, DIN concentrations of <10 µg/l are equally limiting to algal growth (Lapointe, 2004). Based on the current study and some earlier data from Guam (Nadeau and Denton, in prep), it would appear that oceanic waters circulating the island are limiting in both nutrients. The absence of conspicuous macroalgae growth seaward of the reef crest, in Tumon Bay and elsewhere around the coast, supports this contention.

The question remains as to whether hotel landscaping activities, or other anthropogenic source of RP, have exacerbated the green algae problem in Tumon Bay in recent years. The findings presented here reveal very little overall difference between average RP concentrations in emergent seeps and springs, and levels present in the aquifer further inland. This infers nutrient contributions from waterfront sources were insignificant at the time of our study. Nevertheless, the possibility of discrete pulses of nutrient enriched waters entering the intertidal zone of the bay from adjacent landscaped areas remains, and seems highly likely, in light of current management practices that exercise little control over excessive irrigation and fertilizer applications. Past evidence tends to support this line of thinking. For example, Marsh (1977) discovered occasionally high RP concentrations (up to 388 µg/l) in runoff from the parking lots and gardens of two of the seven hotels that fronted Tumon Bay at the time of his study. Surprisingly, this researcher failed to make any connection between these data and the prolific growth of *E. clathrata* 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 RP in hotel runoff, although no data was given.

More recently, Matson (1991) examined several aquifer beach seeps and springs at the northern end of Tumon Bay between two major hotels. He reported average NO_3-N levels of 1.39-1.74 mg/l, which is not unusual for Guam's groundwater. However, average RP levels ranged from 17.1-40.3 µg/l, appreciably higher than the 7-8 µg/l recorded by FitzGerald (1976) several years earlier. In a later study, Matson (1996) focused on interstitial waters from an additional six intertidal sites in Tumon Bay. This time, even higher levels of RP were measured (37.2-55.8 µg/l) whereas NO_3-N levels remained fairly typical of local groundwater discharges (0.74-4.14 mg/l).

It could be argued that the intermittent flows of drainage water from hotels are too variable to provide a reliable source of nutrients for sustained *E. clathrata* growth. However, the recent work of Schaffelke and Klumpp (1998) indicates that marine algae have the capacity to rapidly accumulate and store P in their tissues under conditions of short-term (1 h) 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. 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.

Current US EPA doctrine dictates that RP levels in excess of 25 µg/l can promote nuisance algal growth (US EPA, 1986) in aquatic systems. Unfortunately, this threshold value is based largely on experiences in freshwater rather than the marine environment where RP is naturally less abundant. In all probability, most marine algae are better adapted to nutrient impoverished environments than their freshwater counterparts and, as such, can be induced to grow to nuisance proportions at RP levels much lower than 25 µg/l. The fact that sustained RP concentrations of 1.5-3 µg/l have been shown to initiate macroalgae blooms in coral reef waters elsewhere in the world certainly lends weight to this argument and suggests that the current RP standard (25 µg/l) for Guam's cleanest marine waters (GEPA 2001) should be lower than it is today. This notwithstanding, the threshold concentration of RP necessary to induce blooms of *E. clathratus* remains to be determined and may be higher than other marine algae given the preference of this species for brackish waters. In any event, it is clear that RP levels presently found in groundwater entering Tumon Bay occasionally exceed 25 µg/l (Fig. 2) and leave little room for additional contributions from fertilizers, or any other potential sources of this nutrient.

Approximately 40 million gallons of fresh water flow from the aquifer into Tumon Bay each day (Jocson, 1998). Thus, a little over 2 kg of P entering the bay from anthropogenic sources would effectively double daily inputs from the aquifer alone (assuming background RP concentrations average ~14 µg/l). Hotel managers are, therefore, advised to pay close attention to the landscaping activities that go on in their grounds in order to eliminate, or at least minimize excess fertilizer and water applications to their lawns and gardens.

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