

Status of seagrasses as indicators of nutrient pollution in Guam

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Abstract

Seagrass beds are among the most valuable but threatened ecosystems. In Guam, the combination of increasing coastal development, poorly-maintained sewage treatment plants, and plans to add up to 40,000 naval troops and support staff have raised serious concerns over the fate of the island's coastal ecosystem including the seagrasses. The purpose of this study was to document the health of the seagrasses and assess dominant sources of N inputs using stable isotope analyses as a baseline for future comparisons. Isotope values ranged from 2.3 to 6.5 (Average: 3.7 ± 0.40 ‰) for $\delta^{15}\text{N}$. The high $\delta^{15}\text{N}$ values indicate the presence of sewage-derived N at several sites, which were strongly correlated with local sewage output sites. However, $\delta^{15}\text{N}$ values were unrelated to seagrass cover suggesting N-limitation in the coastal environment and that the nutrient pollution is not currently negatively affecting the health of the seagrasses. However, it remains to be seen if the military build-up on the island will affect the long-term future of this critical habitat.

Introduction

Seagrasses are valuable but often overlooked species. There are over 60 species of seagrass species worldwide and they cover 0.33 million square km of the ocean (Green and Short 2003). Seagrasses have similar organs and tissue as other flowering plants as well as shoots and roots,

but in contrast to terrestrial plants, they live in marine, highly saline environments (Kuo and Hartog 2006). The main components of seagrass are their shoots and their rhizomes. Seagrass varieties can vary from short, small round leaf-like blades to tape-like blades up to a meter long (Kuo and Hartog 2006). The rhizomes run horizontally under the surface of the sediment, holding the plant in place and distributing roots to capture nutrients. *Enhalus acoroides*, the species analyzed in this study, bears many soft, unbranched roots with a few short hairs and tends to grow most in muddy sediment (Kuo and Hartog 2006). These photosynthesizing shoots and strong roots are the features of the seagrass that strongly contribute to its value.

Seagrasses provide many important ecosystem services. They are the primary food source for dugongs and turtles and are an essential habitat for commercial and rare fish (McKenzie, Yoshida et al. 2010). Seagrass also provide shoreline protection against wave energy and erosion due to the fact that their strong rhizomes hold in sediment and hold shoots as they flow with water movement. Finally, seagrasses, like terrestrial plants, perform carbon sequestration and bury 27.4-44 Tg of Carbon every year (Green and Short 2003; Nellemann and Fonseca 2009). Their total ecosystem value for these services is \$19,004 per ha per year, which is only second globally behind estuaries and swamps (Constanza, d'Arge et al. 1997). Therefore seagrasses, as a home to the fish Guam and other areas of the world depend on for food, as a natural wave energy barrier, and finally as a store of carbon, are extremely important to the marine ecosystem. With growing concerns of global climate change, carbon storage or carbon sequestration is especially important. In a recent report by the United Nations Environment Programme, the importance of “Blue Carbon,” carbon stored in oceans, was established. The oceans bury over half of the

world's biological carbon (Nellemann and Fonseca 2009). Although oceanic vegetated habitats such as seagrass, mangroves, and salt marshes only account for <0.5% of the ocean floor, they account for more than 50% and up to 71% of the carbon stored in the oceans (Nellemann and Fonseca 2009). These extremely productive areas are vital to nutrient cycling systems.

Although critical to the marine ecosystem, the status of seagrasses and other ocean vegetation is dismal. Since the 1940s, the total area of seagrass has declined by more than thirty percent, and the loss rate per year in recent times is about 7% (Nellemann and Fonseca 2009). This is largely due to the fact that seagrasses are a benthic shoreline species subject to degradation in response to natural and human activity (Collado-Vides, Caccia et al. 2007). Growing populations, fisheries, and tourism all affect the shoreline benthic ecosystems. The growing populations, and the waste associated with them especially affect the nutrient loading of seagrass beds and other marine ecosystems. Increased nutrient levels have been shown to intensify the growth of macroalgae and epiphytes, inhibiting the ability of seagrasses to absorb the light they need to perform photosynthesis (Collado-Vides, Caccia et al. 2007). Globally, it has been shown nutrient loading has been the most detrimental cause of seagrass decline (Orth, Carruthers et al. 2006). The response of macroalgae and seagrasses to eutrophication of the oceans varies with regions and environments, which is why studies that look at the local effects of nutrient pollution are crucial.

Seagrasses are a particularly good species to analyze for nutrient pollution due to the fact that they integrate their environment into their shoots and are susceptible to environmental changes

that can be monitored over a period of time (Orth, Carruthers et al. 2006) (Longstaff and Dennison 1999). This time scale is relatively short, and is based on the growth rate of seagrass shoots. A study at Cape Bolinao, Philippines in 2001 showed that *Enhalus* grew at a rate of $3.78 \pm 0.37 \text{ cm}^2 \text{ shoot}^{-1} \text{ day}^{-1}$ (Agawin, Duarte et al. 2001). *Enhalus acoroides*, being one of the largest species of its kind with an average leaf surface of 100 cm^2 and a rhizome diameter of 15 mm (compared to *Halophila* with a average leaf surface of 4 cm^2 and a rhizome diameter of 1 mm), tends to have slower growth rates and higher longevity (Agawin, Duarte et al. 2001). Despite the slow growth of *Enhalus acoroides*, they still are representative of the nutrients around them. Seagrasses take up nutrients through both their roots and shoots and distributes them throughout their system (Larkum, Orth et al. 2006). Therefore, these are ideal plants to monitor nutrient pollution in Guam.

Guam is a rarely researched area of the world, despite having a highly diverse population of corals and vast quantities of seagrasses. It is a small isolated island located in the Mariana Archipelago with a land mass of 560 km^2 (Porter, Leberer et al. 2005). A population of about 173,430 (2008) makes it the most heavily populated island in Micronesia (Porter, Leberer et al. 2005; 2010). Seagrasses in Guam cover 2.8 percent of the total reef area and, although Micronesia is known for its unique seagrass diversity, Guam's flora include *Halodule uninervis*, *Enhalus acoroides*, and *Halophila minor*, with *Enhalus acoroides* being the dominant species (Lobban & Tsuda, 2003). These species are crucial to Guam because they provide habitats for the commercial fishing industry. Although agriculture and fishing only make up about 1% of the occupations in Guam, locally caught fish by friends or extended family make up 38% off the fish

consumed by Guam residents (Allen and Bartram 2008). These factors make the preservation of fish habitats extremely important .

The island also has a large area of fringing reefs, patch reefs, submerged reefs, offshore banks, and surrounding reefs. Corals make up almost 30% of the total reef area (Burdick 2005). The variety of reefs along with the idealistic tropical weather are reasons Guam is a large tourist center, which, in turn, is one of the major threats to the marine ecosystem. Over 900,000 tourists visited Guam in 2003 with numbers expected to reach over one million in recent years (Porter, Leberer et al. 2005). Activities that use or impact the reefs and seagrasses include snorkeling, scuba diving, fishing, and jet skiing.

There are a number of preserves around the island to limit the destruction of marine habitats from anthropogenic activities. However, damage is still done at these marine reserves. For example, researchers have noted that snorkelers and scuba divers have caused damage to the seagrasses beds at Piti Bomb Holes Marine Reserve (Porter, Leberer et al. 2005). These disturbances include physical impacts, an increase in turbidity, and decreases in fish abundance and variety (Porter, Leberer et al. 2005). Jet skis, another popular tourist activity, are known to be loud, leak fuel, and damage seagrasses and corals at low tides but this activity is limited to four locations on the island: East Agana Bay, Apra Harbor, Cocos Lagoon, and Tumon Bay (Porter, Leberer et al. 2005). Fundamentally, within and beyond the limits of a marine preserve, there are negative anthropogenic impacts on seagrass and surrounding habitats.

Other threats to the marine ecosystem include coastal development and runoff and coastal pollution. The coastal pollution primarily comes from 19 National Pollutant Discharge Eliminated Systems (NPDES) and non-point sources such as nutrients from septic tank systems and agricultural or chemical pollutants from urban runoff and illegal dumping (Porter, Leberer et al. 2005). The six main Guam Waterworks Authority (GWA) Municipal Wastewater treatment plants are especially marked for nutrient pollution due to the fact that they have treatment procedures suspected of being below standard. The Agana Sewage Treatment plant procedures have been reevaluated in the past few years by the EPA because since 1986 they have had a variance of secondary treatment, the step of the process that uses bacteria to remove organic matter (GWA 2009). This variance allows them to perform less than the required secondary treatment. When they reapplied for this variance, the EPA denied the application in September, 2009 on the basis that (GWA 2009):

- Discharge does not meet mandatory minimum standard of primary treatment;
- GWA has not demonstrated the discharge will attain or maintain water quality to allow recreational activities in and on the water;
- GWA has not demonstrated the discharge is consistently able to attain or maintain water quality to allow protection and propagation of a balanced indigenous population of shellfish, fish , and wildlife;
- The applicant's monitoring data is insufficient to demonstrate compliance with Guam water quality standards;
- The applicant has not developed a program to control toxic pollutants from non-industrial sources

Fundamentally, the EPA established that GWA cannot perform below United States standards anymore for the sake of recreational activities and wildlife. In addition to treatment, the aging pipes that pump the sewage 200 meters past the shore are under suspect. Until GWA improves its wastewater treatment systems, this substandard water is reaching the corals and seagrass beds and risking eutrophication of the ecosystem.

The fact that Guam has this sewage treatment issue alone would make seagrasses an important nutrient pollution tracer. In addition to this, however, Guam is unique in that it has a very low level of agriculture (less than 1% of the economy), the other dominant source of nitrogen in urban runoff (Allen and Bartram 2008). Due to the Guam's low use of land for agriculture, but high inputs from poorly treated sewage waste, the isotopic signature of $\delta^{15}\text{N}$ is less complex and more easily analyzed than a complex system with both outputs of nitrogen. This also means that the effects of nitrogen input are more easily seen without the influence of agriculture.

Finally, Guam is an even more ideal location to study the effects of increases nutrient pollution because as a naval base, there is frequent fluctuation of the population due to increased and decreased demands of naval guard. As of January 2008, the US Government declared that 40,000 troops will be added to the island by 2014 for rapid response in the event of pirates, terrorists, and tsunamis in addition to being a reminder to China that we are here (Harden 2008). Being an island that only currently inhabits about 173,000 people, this would be a rapid increase of roughly 25% of the population. These short term fluctuations make an the ideal circumstance to

study the effects of increased nutrient pollution on the marine ecosystem that traditionally occur over many years.

Nutrient enrichment from domestic wastewater has been identified as one of the most important problems impacting nearshore waters and the decline of seagrasses (Lapointe, Tomasko et al. 1994). This nutrient enrichment has been found to increase the growth of attached epiphytes and macroalgae, which reduce available light, limit the availability of dissolved oxygen, and lead to the decline of seagrass growth (Lapointe, Tomasko et al. 1994; Lapointe 1997). Seagrasses have some of the highest light requirements of angiosperms: 25% of incident light just below the surface of the water compared to an average of 1% for most others (Dennison, Orth et al. 1993; Longstaff, Loneragan et al. 1999; Orth, Carruthers et al. 2006). Therefore, an influx of macroalgae and epiphytes would be detrimental to their survival. With substance wastewater treatment and an influx of naval personnel, it is suggested that the seagrass in Guam would indicate nutrient pollution through elevated $\delta^{15}\text{N}$ values, which is analyzed with stable isotope analysis, and decreased health, which is determined by seagrass percent cover.

Stable isotope analysis is being increasingly used to monitor the health status and nutrient pollution sources of various ecosystems. Although there are other factors that increase the N and P content of plants such as light availability and herbivory, isotopic signatures can identify the source of the elements (Fourqurean 2007). The two major types of anthropogenic nitrogen sources are either fertilizers or sewage waste. Wastewater from anthropogenic sources is significantly enriched in $\delta^{15}\text{N}$ due to humans' high trophic level whereas N from fertilizers is

derived from basic atmospheric nitrogen. This is caused by the elimination of the lighter atmospheric nitrogen ($\delta^{14}\text{N}$), and build up of $\delta^{15}\text{N}$ in the tissues and feces (Risk, Lapointe, Sherwood, & Bedford, 2009). It has been suggested from previous studies that there is a 3 ‰ increase for each step up in trophic level (Risk, Lapointe et al. 2009). A study by Udy and Dennison (1997) showed that a $\delta^{15}\text{N}$ signature of 0-2 would indicate an area is unaffected by sewage output and that a signature of 5.1 would indicate raw sewage. Thus, using these parameters, stable isotope analysis can be used to detect the presence of sewage-derived or agricultural N in the tissues of primary producers such as seagrasses whom continually sample their environment. Stable isotope analysis involves finding the ratio of atmospheric N ($\delta^{14}\text{N}$) to enriched N ($\delta^{15}\text{N}$). These isotopes differ based on the higher vibrational frequency of bonding demonstrated by $\delta^{14}\text{N}$, which results in a lower mass (Risk, et al., 2009). These isotope ratio are generated from isotope ratio mass spectrometry (IRMS) in parts per thousand or ‰ (Risk, Lapointe et al. 2009). This method of tracing nutrient pollution is becoming increasingly common in tracking potential sources, and therefore evaluating the influences on species such as seagrass and corals.

Taking into account the poor wastewater treatment and effects of nutrient loading on seagrass growth recorded in recent literature and using stable isotope analysis to trace sewage input, the goal of this study was to study the status of seagrasses in Guam as indicator of the nutrient pollution. It was suspected that:

- $\delta^{15}\text{N}$ N values will be high relative to similar studies
- Increased $\delta^{15}\text{N}$ N levels will correlate with decreased seagrass health

- $\delta^{15}\text{N}$ values with vary according to distances from sources of N

Materials and Methods

Study Area

Enhalus acoroides, the dominant species of seagrass in Guam, was studied at thirteen sites in the summer of 2009. The sites were chosen by presence of seagrass and ease of access along the island (Burdick 2005). Sites with seagrass cover of more than 50 percent were located with Burdick's Guam Coastal Atlas, and cross-referenced with hand-held GPS unit. Water depths at these sites were highly variable with an average of $43.5 \pm 7.2\text{cm}$.

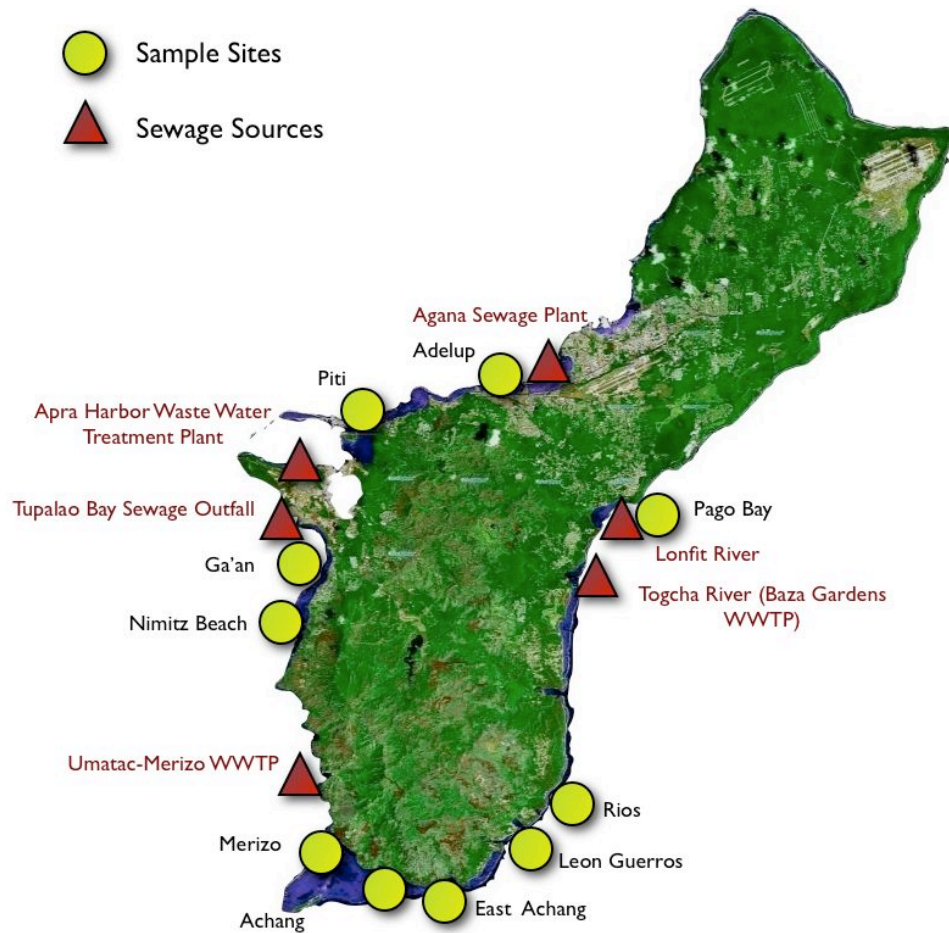


Figure 1. Sample site and sewage output sources

Seagrass Survey

Methods suggested in the *Manual for Scientific Monitoring of Seagrass Habitat: Western Pacific Edition* were used to analyze the health of *Enhalus acoroides* and take samples. Ten quadrats (50 cm x 50 cm) were randomly generated at each site. The estimated density was taken based on cover of sand at the base of the shoot rather than an overhead appearance. The average shoot length was also measured at each of these quadrats as an indicator of seagrass health. At quadrats 1, 5, and 10, a sample shoot of average length was taken for N and C isotope analysis (i.e. n=3). The blades were placed in pre-labeled plastic bags. At each quadrat, a photo was taken to cross reference density measurements off-site and for future questions of seagrass observations. Coring

was attempted with a standard PVC corer, but due to the thickness of the *Enhalus acoroides* rhizomes and muddy substrate, this did not prove feasible for this study.

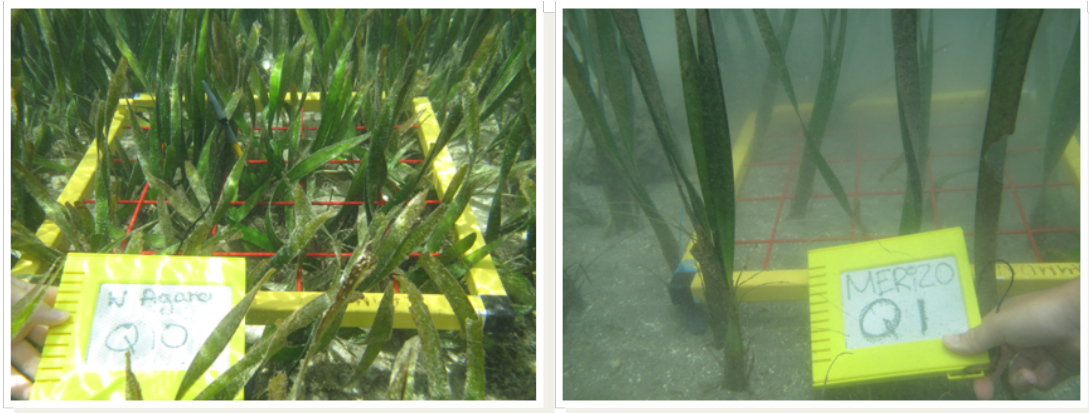


Figure 2. Examples of 55% density and 5% density in seagrass samples.

The samples taken at each site were carefully cleared of sediments and epiphytes and wrapped in an aluminum foil case. Then they were dried at 40°C for 48 hours on site at the University of Guam Marine Lab, packed and refrigerated for storage and then transport to American University. These isotope samples were ground to a powder and then weighed to $0.03 \text{ mg} \pm 0.01 \text{ mg}$ at American University for analysis at the Cornell University Stable Isotope Lab. `

Results

Seagrass Health

Seagrass cover ranged from approximately 9.4 to 49.9 % with a mean of 28.6 ± 4.6 percent.

Length of seagrass blades ranged from 13–65 cm and was related to the depth of the water ($R^2 = 0.683$, $p = 0.006$).

$\delta^{15}N$ Levels

Isotope values varied among sites ($\delta^{15}N$ range 2.3-6.5‰; $\delta^{13}C$ -6.3 to -10.1‰). The highest $\delta^{15}N$ value was documented at Pago Bay with 6.5 ± 0.42 ‰. Adelup, the second highest $\delta^{15}N$ level at 5.26 ± 0.038 , is the site most adjacent to the Agana sewage treatment facility cited by the EPA for substandard treatment procedures. All sites compared to the unaffected level of 2‰ are not significantly different (One-Way ANOVA p-value: 0.91), but the two sites of Pago and Adelup were significantly different (One-Way ANOVA p-value: 0.01) from the level of 2‰.

Table 1. Status of Enhalus acroides: $\delta^{15}\text{N}$, Density, and Distance from Sewage Outfall

Site	$\delta^{15}\text{N}$	SE	Shoot Density (%)	SE (Density)	Distance from Sewage Outfall (km)
Achang	2.303		0.018	12.8	2.740
Adelup/W Agana	5.255		0.038	32.5	6.760
E Achang	3.012		0.476	32.6	1.293
E Agana	4.743		0.205		
Gaan	4.478		0.140	49.9	7.491
Leon Guerro	2.576		0.264	15.9	3.271
Merizo	3.292		0.394	9.4	1.518
Nimitz	3.267		0.353	25.2	2.365
Old Agat	2.774		0.158		
Pago	6.500		0.417	41.7	5.991
Piti	3.054		0.456	47.5	3.745

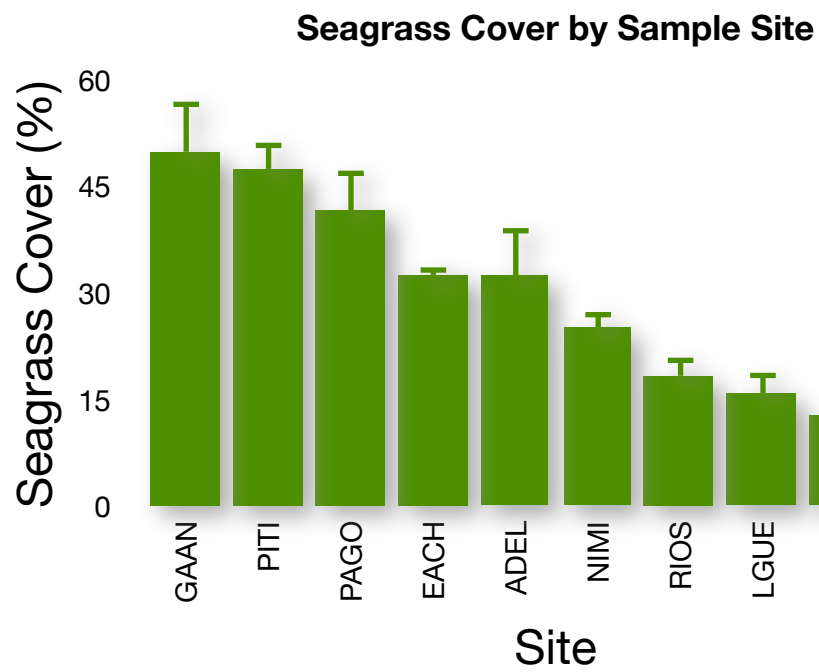


Figure 3. Seagrass density at sample sites.

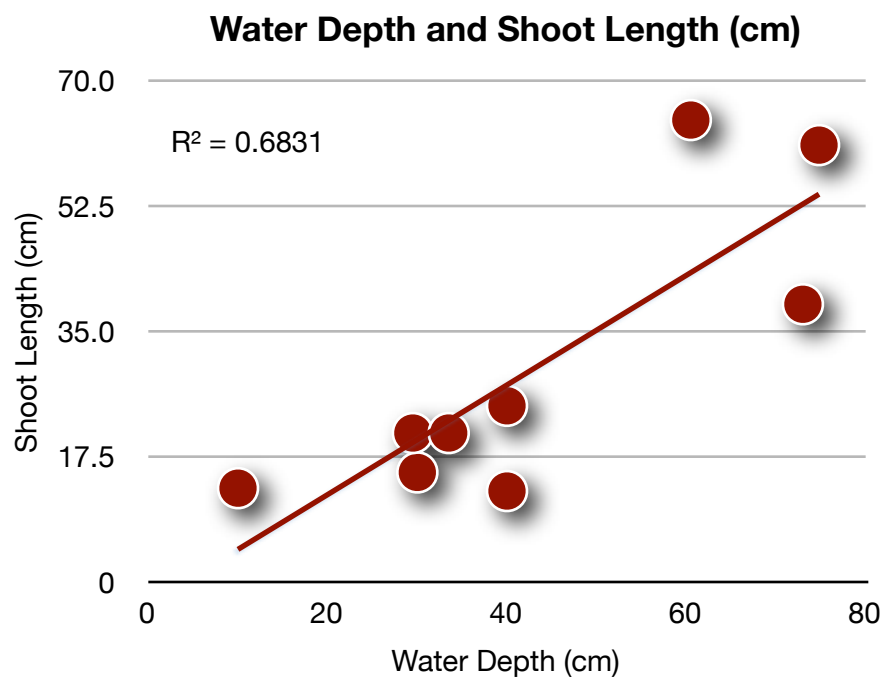


Figure 4. Seagrass shoot length samples vs water depth

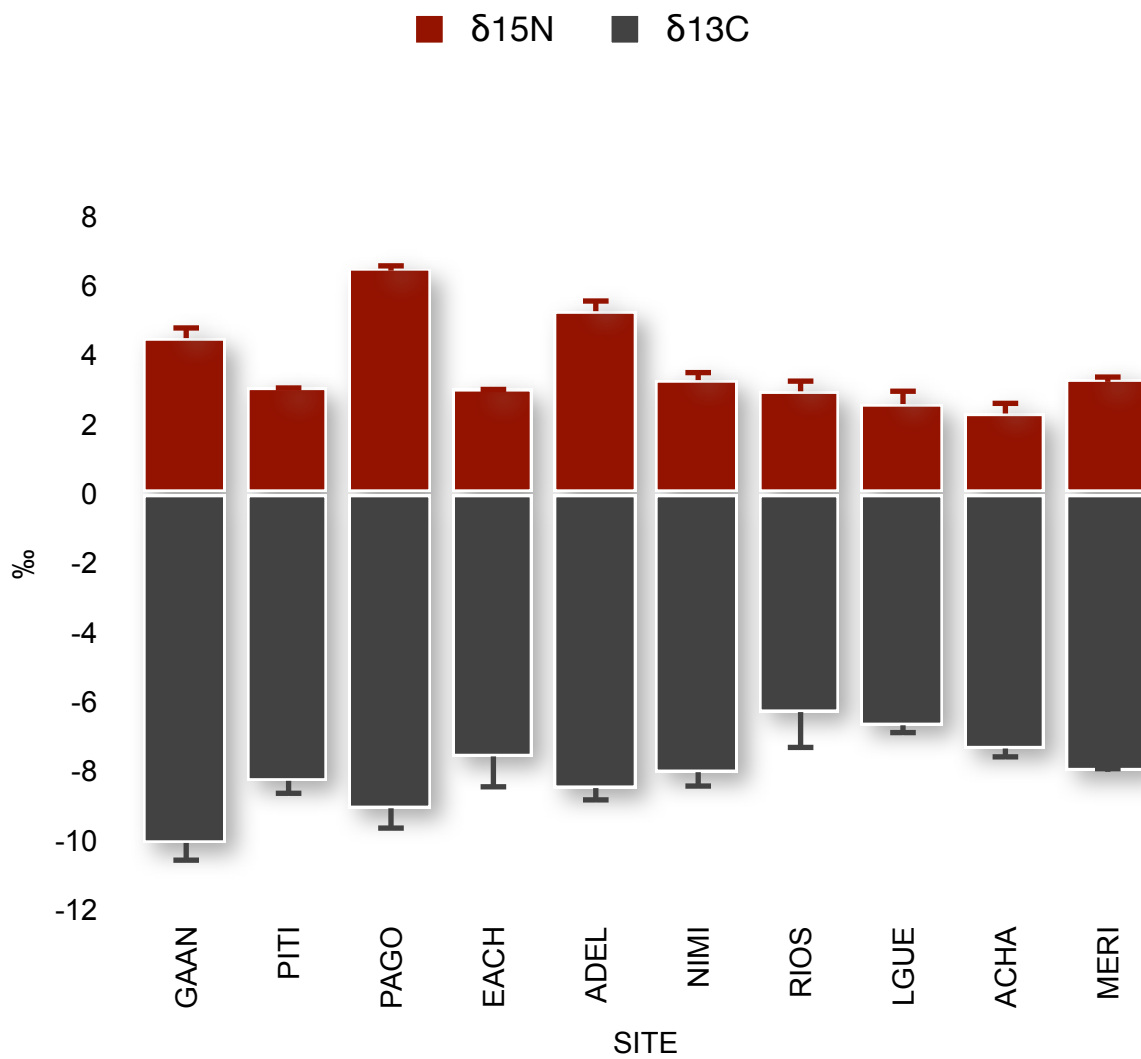


Figure 5. $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ levels at sample sites.

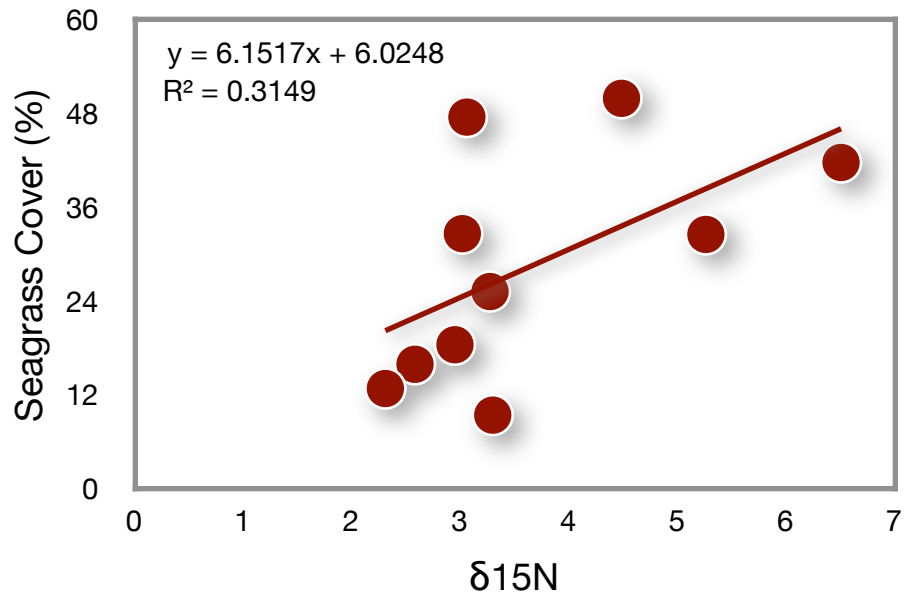


Figure 6. Relationship between $\delta^{15}\text{N}$ value (x-axis) and seagrass density as an indicator of health (y-axis) at sample sites.

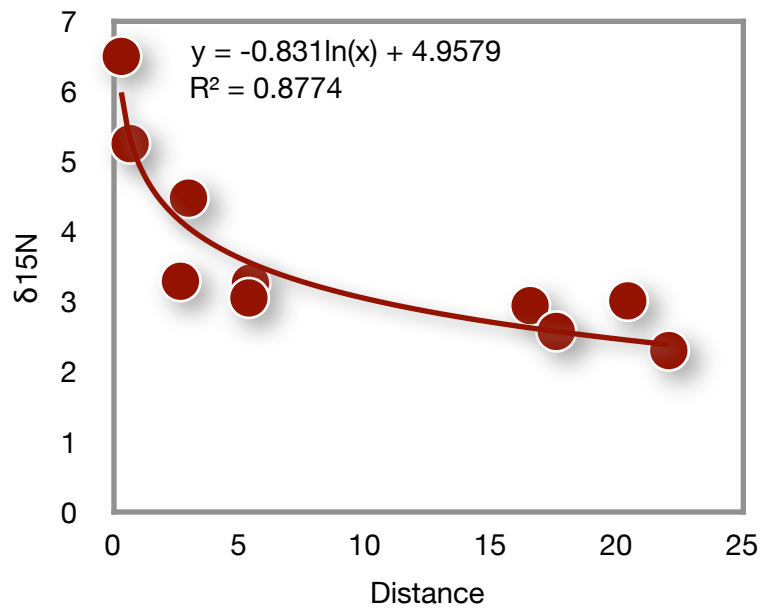


Figure 7. Relationship between distance from nearest sewage output (x-axis) and $\delta^{15}\text{N}$ value at sample sites.

Discussion

Nutrient loading from sewage treatment plants is a common source of anthropogenic nitrogen. However, in Guam, where there is little agriculture, the other dominant source of anthropogenic nitrogen, it should be simple to correlate the status of seagrasses with the sources of nutrient loading. Knowing the poor sewage treatment practices of Guam, it was suspected that these would negatively influence the health of the seagrasses, as well as the coral ecosystem. This study documented the current health of seagrass and found that overall, the health is good. With an overall percent cover range of 9.4 to 49.9 % and average of 28.6%, the health of seagrass in this study was comparable to tropical seagrass beds elsewhere. For example, a study of *Thalassia hemprichii* between 2001 and 2007 determined a range of 30-50% cover and is in a relatively healthy state (Coles, McKenzie et al. 2007). The percent covers established in this study indicate relatively good health for Guam's marine biome despite the poorly treated sewage in the area. Although Guam seagrasses are comparable to other studies, these studies also show that this percent cover average is lower than historical levels of seagrass cover in intertidal zones (Coles, McKenzie et al. 2007).

Enhalus acoroides is known to reach up to 1 m in height, which means some of the sites with shorter shoots are either new or have suffered from damage since none reached above 70 cm. An interesting point to make is that according to the Guam Coastal Atlas, there was a large area of seagrass at cover points of 10-50% and 50-90%, but we did not find this large seagrass bed. This could have been due to researcher error, but this is also a location in between the Agana Sewage Outfall and the main tourist center, Tumon Bay. This location could likely be the area of Guam

most susceptible to nutrient loading and damage. It would be valuable to research the changes in the location overtime and why we were unable to find such a large seagrass bed with our Guam Coastal Atlas.

The $\delta^{15}\text{N}$ values determined in this study varied in relation to similar studies done with seagrass. They are comparable to those of a study in Spain published by Fourqurean, but higher than a previous study in Florida, an area less affected by poor wastewater practices (Anderson and Fourqurean 2003; Fourqurean 2007). Study samples overall had an average $\delta^{15}\text{N}$ $3.68 \pm 0.37\text{‰}$ whereas Fourqurean found averages of 3.7‰ for *Posidonia oceanica* and 3‰ for *Cymodocea nodosa* (Fourqurean 2007). In a study by Anderson and Fourqurean in Florida, averages of *Thalassia testudinum* $\delta^{15}\text{N}$ ranged from 1.14 ± 0.20 - $2.08 \pm 0.41\text{‰}$ (Anderson and Fourqurean 2003). Determined in a study in Moreton Bay, Australia, $\delta^{15}\text{N}$ values of remote, unaffected areas are around $\delta^{15}\text{N}$ 2.4‰ or less and that 5.1‰ indicates raw sewage influences (Udy and Dennison 1997). The highest $\delta^{15}\text{N}$ value of this study was documented at Pago Bay with $6.5 \pm 0.42\text{‰}$, indicating the input of enriched (i.e., sewage-derived) N from Pago River. Adelup, the site with the second highest $\delta^{15}\text{N}$ level $5.26 \pm 0.038\text{‰}$ also indicates sewage influences on the seagrass. Adelup is the closest site to the Agana Sewage Treatment Plant, the GWA location cited for below standard treatment of wastewater. Although some sites have relatively normal $\delta^{15}\text{N}$ levels compared to other studies, it is obvious that some sites have levels that indicate nutrient pollution from sewage sources.

Counter to the expectation, seagrass cover was not negatively related to $\delta^{15}\text{N}$. In fact, there was a weak positive relationship, suggesting that seagrass primary production is N-limited. Although there was not a correlation between increased $\delta^{15}\text{N}$ levels and reduced seagrass health as suspected, this is not completely surprising. Tropical benthic communities are nutrient limited and therefore would experience increased growth with more nitrogen sources. In addition to the natural of tropical ecology, *Enhalus acoroides* has been shown to be especially N-limited (NSR, CM et al. 1996; Touchette and Burkholder 2000; Burkholder, Tomasko et al. 2007). Even knowing these two factors, continuing research on these topics is extremely important for finding the tipping point in which anthropogenic nutrient loading becomes detrimental to these ecosystems.

There was a very strong relationship between sewage output sources and $\delta^{15}\text{N}$ values (Figure . This indicates that isotope analysis of seagrasses can aid in the tracking of sewage sources. Sites were determined by the report of *The State of Coral Reef Ecosystems of Guam*, which includes nineteen National Pollutant Discharge Elimination Systems (NPDES). The NPDES include wastewater treatment plants, power plants, and fuel facilities (Porter, Leberer et al. 2005). Some were obvious, such as the Agana Sewage plant, but others, such as the Pago Bay river outfall were not. Pago Bay had the highest $\delta^{15}\text{N}$ value despite being 3.4 km upcurrent from the nearest sewage outfall. The significance of the site is that it is on a major river outfall from the hills of central Guam. Thus, a combination of construction and rural septic tank system runoff is an important source of N inputs into coastal environments.

The identification of the sewage sources is especially important because the sewage outfalls are not immediately at the shore. For example, they are 200 m away from the shore at the Agana Sewage plant, but nutrient loading from anthropogenic sources can have effects on the growth and productivity of seagrasses for up to seven km (Lapointe, Tomasko et al. 1994). With the correlation to sewage output sites, it is clear that these outfalls are affecting the seagrass as indicated by their elevated $\delta^{15}\text{N}$ values. Despite the hypothesis, N pollution is not currently having a negative impact on health of the seagrasses. However, the fact that we could correlate the $\delta^{15}\text{N}$ values with distance from known sewage outfalls shows that we can track the sources of nutrient loading. This is important so that in the event of a negative impact on seagrasses (such as dramatic population growth), these point sources can be targeted for mitigation and subsequent monitoring.

This study could benefit from including additional factors. For example, light is an important parameter for the growth of seagrass and nutrient absorbance. In fact, seagrasses have some of the highest light requirements of all angiosperms, which is why they are located in shallow benthic communities. Light levels were not examined during this study, and in further research, clarity of water, light, and time of day should all be recorded when taking samples.

Rhizome biomass is another important indicator of the health of the seagrass that was not measured in this study. Although rhizomes do not function in N uptake as much as the shoots, their size and expansion in the sediment could indicate health status (Touchette and Burkholder 2000). Rhizomes of the species *Enhalus acoroides* are especially thick and large, and therefore

difficult to core with a standard PVC corer.

In addition to light and rhizome biomass, epiphyte growth was not formally studied in this research. Studies have shown that N increases epiphyte growth and decreases the productivity of seagrass communities (Lapointe, Tomasko et al. 1994). Notes were taken regarding the high bacteria levels at Pago Bay and increased epiphyte growth in near Agana Bay. However, murkiness of the water is not necessarily a deciding factor because Achang, a reserve location with the lowest nutrient loading levels, had some of the least clear water during our work. This is especially interesting considering that there were mangrove forests along this bay that both control erosion and nutrient cycling (Zhang, Liu et al.). The mangrove forests could explain the low $\delta^{15}\text{N}$ levels relative to other location and reflect similar literature on this topic.

The seagrasses and other marine biomes in Guam would benefit from a long term study of the changes in nutrient pollution as more naval troops arrive with families or as standards of the wastewater treatment improve. The influx of naval troops without rapid improvement of the wastewater treatment could introduce a tipping point of nitrogen enrichment of the seagrass and thus lead to the decline in the seagrass health. However, if wastewater treatment improves before the influx of troops, there actually might be a decline in seagrass health with reduction of N-inputs. Finally, rapid increases in population and sewage treatment improvements could result in no changes from this baseline study. Monitoring these changes in the ecosystems of Guam over the next few years could provide key insights on specific eutrophication effects of tropical biomes. Without a doubt, preservation and prevention would be less costly and more ecological

than restoration of the seagrasses, which has only had a 30% success rate worldwide (Orth, Carruthers et al. 2006). The ecosystem services these species provide are imperative to benthic marine ecosystems, the economies of fisheries, and the coasts they inhabit.

Conclusion

The results of this study shows that the current status of seagrasses in Guam is comparable to other regions. Although nutrient pollution from local sewage output was not shown in this study to negatively impact the seagrass, continual monitoring of seagrass health is essential to ensure the continuation of the important ecosystem services provided by these marine plants.

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