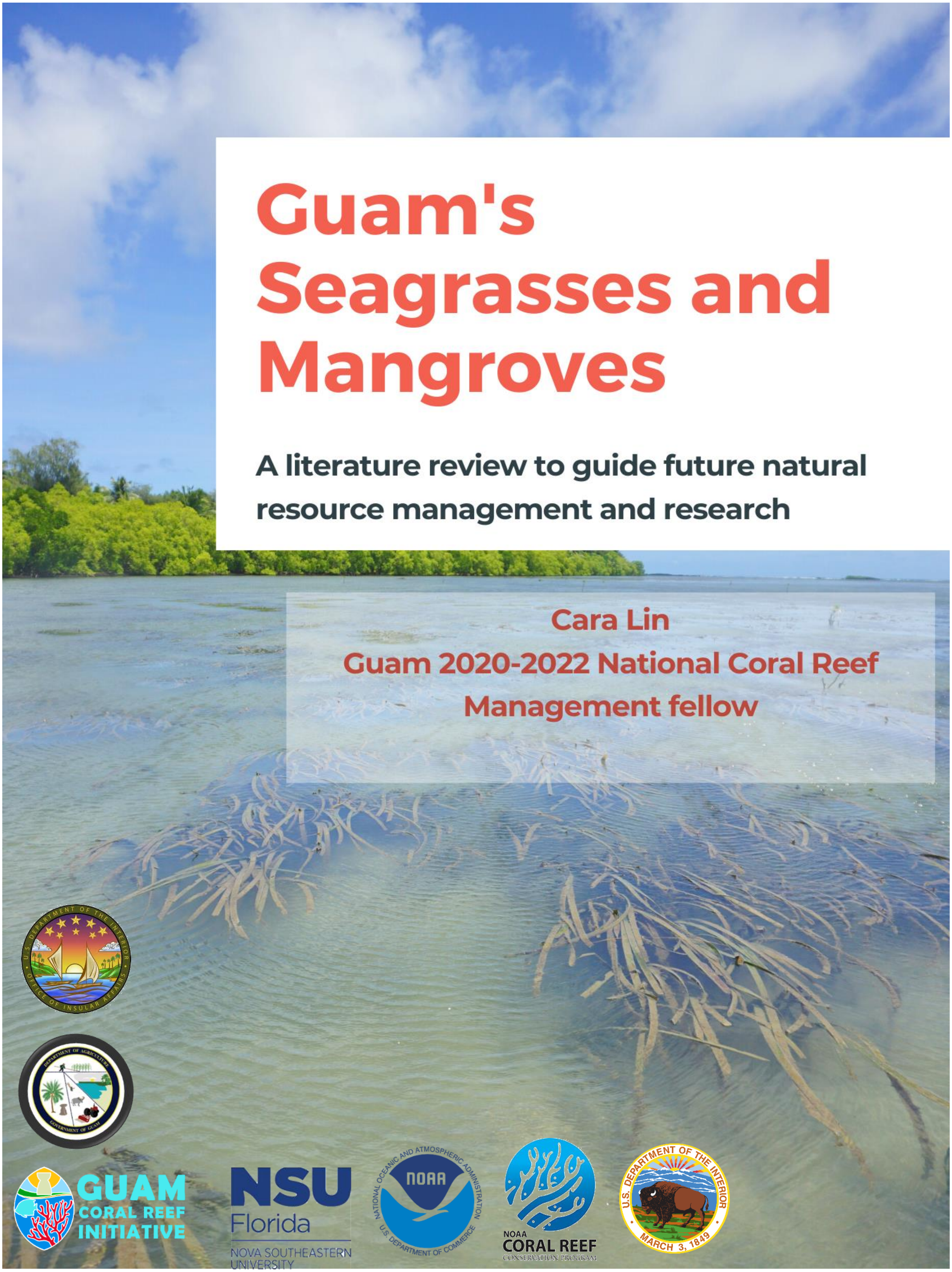

Guam's Seagrasses and Mangroves

A literature review to guide future natural resource management and research

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GUAM CORAL REEF INITIATIVE

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Background and Notes for Use:

This report was developed as part of the Fellowship Work in the Guam National Coral Reef Fellowship Program supported by the National Oceanic and Atmospheric Administration (NOAA, Department of the Interior (DOI), Nova Southeastern University (NSU), and the Guam Department of Agriculture.

The goal of this report is to help provide a foundation of knowledge to understand the state of Guam's seagrasses and mangroves and guide future management initiatives. The report includes broad information, with an emphasis on the Pacific region and Guam to the greatest extent possible. The chapters cover many topics, and may be updated as new information becomes available.

This report may be useful to any government agencies working in Guam's coastal ecosystems, private entities that use Guam's coastal resources, elected and appointed officials, non-governmental organizations, students, research scientists, and grant writers.

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INTRODUCTION

I. What are Seagrasses and Mangroves?

a. Seagrasses

Seagrasses are marine angiosperms that evolved from land plants and can be found in shallow waters around every continent except Antarctica (Green et al. 2003). Seagrasses are characterized by (i) living in an estuarine or marine environment, (ii) the ability to pollinate and produce seeds underwater, (iii) specialized leaves that have a reduced cuticle, lack stomata, and use the epidermis as the primary photosynthetic tissue, (iv) a rhizome (underground stem) that helps keep them anchored, (v) roots that absorb nutrients but also can survive an anoxic environment with oxygenation support from the leaves and rhizome (Larkum et al. 2006). This is in contrast to seaweeds and algae which are very different from land plants and do not have vascular tissue, roots, or flowers like seagrass (Di Carlo and McKenzie 2011). Seagrasses reproduce using seeds and propagules (start life while still attached to the adult plant) and may be considered monoecious (separate plants being male or female), dioecious (same plant but with male or female flowers), or hermaphroditic (both male and female parts on the same flower) (Orth et al. 2007).

b. Mangroves

Mangroves are not defined by a single genetic group but instead by the presence of certain characteristics including: (i) found in intertidal environments (often as pure strands) and not extending into terrestrial communities (ii) morphological specialization and adaptations for the coastal environment such as aerial roots used to survive in anoxic soils, (iii) physiological adaptations for salt exclusion and/or salt excretion; (iv) taxonomic isolation from terrestrial relatives (Wang et al. 2011). Mangroves also reproduce with seeds or propagules and have different reproductive strategies including vivipary (life starts attached to parent and the seedling breaks through the fruit wall), cryptovivipary (life starts attached to parent and the seeding breaks through the seed coat, but not until the fruit falls), normal germination, and vegetative propagation (Kathiresan and Bingham 2001).

II. Mangrove and Seagrass Ecosystem services:

a. Seagrasses and Mangroves valuation estimates:

Seagrasses and mangroves have historically received less attention and protection than coral reefs despite the critical role they play in providing ecosystem services to coastal communities and supporting coral reef resilience. A review that compiled estimates of seagrass ecosystem services valued them in the thousands to tens of thousands of dollars or more per hectare per year, depending on estimation methodology, species, and region (Dewsbury et al. 2016). One study of seagrass beds in Southern Australia estimated that a 16% decline in seagrass could cause a loss of fisheries production equivalent to $235,000 per year (McArthur and Boland 2006). Estimations of mangrove value also show great value per hectare. A meta-analysis of mangrove valuation studies found the average valuation of mangroves for fisheries was $23,613 USD/ha/yr based on 51 studies, and for coastal protection $3,116 USD/ha/yr based on 29 studies (Salem & Mercer 2012). Another study estimated value between $14,166-$16,142 USD/ha/yr for services including raw materials and food, coastal protection, erosion control, fisheries, and carbon sequestration (Barbier et al. 2011). There is also often a mistaken assumption that the value of ecosystem services and spatial extent of the ecosystem have a linear relationship, however this may not be true, and small areas can potentially provide significant value (Barbier et al. 2011, Baker et al. 2015).

b. Seagrass production and associated epiphytes help support food webs and potentially biomass export:

The pathways of energy and carbon in seagrasses form a complex food web that supports many organisms. Seagrasses support organisms that eat: (i) seagrass itself, (ii) seagrass epiphytes and epifauna, and (iii) seagrass detritus (seagrass material enriched by microbial breakdown) (Scott et al. 2018). Small invertebrates (amphipods, isopods, and gastropods) primarily eat seagrass epiphytes, larger herbivores (sea urchins and fish) may shred and take bites of the seagrass blade directly, and the largest herbivores (sea turtles) crop the seagrass (Scott et al. 2018). Seagrass blades may break off due to waves, partial herbivore consumption, or other events and then degrade into detritus, particulate organic carbon, and dissolved organic carbon which can feed microbes, primary producers, and other organisms.

Analysis of stable carbon isotopes has been especially useful for elucidating the contribution levels of seagrasses, seagrass epiphytes, and other primary producers to food webs, especially since identification of gut contents and visual surveys can be challenging. Stable isotopes of carbon and nitrogen reflect what organisms actually assimilate into their bodies on longer time scales of weeks to months instead of what they simply recently consumed and passed (Kelly 2000). Different primary producers with different photosynthetic pathways will have different ratios of Carbon-12 to Carbon-13 (δ13C), creating a unique carbon isotope signature (Kelly 2000). The signature is maintained as it is ingested by herbivores and passes through other consumers (Kelly 2000). If primary producers (eg. seagrass, mangroves, terrestrial trees, microalgae, macroalgae) can be reliably shown to have different carbon isotope signatures, then those differing signatures can be used to help determine what consumers ate. For instance, say plant A has a δ13C of -15 and plant B has a δ13C of -10. An herbivore that has a δ13C of -15 eats primarily plant A, and an herbivore with a δ13C of -13 eats a mix of plants A and B.

A study by Vonk et al. (2008) in Indonesia found widespread contribution of seagrass biomass itself to animal biomass using carbon isotopes. Seagrasses species were found to have a significantly different δ13C isotopic signature between each other, and from phytoplankton, epiphytes, and *Sargassum* macroalgae. Using this information, further investigation found that roughly 10% of the faunal density assimilated 50% of their carbon from seagrass materials either directly or indirectly. Fauna that obtained 50% of their carbon from seagrass included crustaceans, copepods, amphipods, a sea cucumber (*Synapta maculata*), and herbivorous fish (*Calotomus spinidens, Letpscarus vaigiensis, Hemiramphus far,* and *Amilgobius sp).* In addition to these species, about half of the remaining species had signatures that indicated at least partial use and assimilation of seagrass materials, including some top predators (Vonk et al. 2008). Seagrasses produce a large amount of particular organic matter for a relatively small area (Gillis et al. 2014). In Micronesia, Benstead et al. (2006) sampled 35 species of fish and crustaceans using stable isotope analysis found that seagrasses themselves contributed the most to food webs, followed by seagrass epiphytes, marine mangrove forest, and lastly freshwater swamp forest. However there is likely spatial variation depending on the location and presence of other resources; another study of *E. acoroides* beds in Zanzibar, and other seagrasses in the Gulf of Mexico, and Florida have also found very limited contribution of seagrass biomass and greater contributions other producers such as algae to consumer diet (Kieckbusch et al. 2004, Lugendo et al. 2006, Motamedi et al. 2014).

Based on many isotope analyses, seagrass epiphytes are also an important food source, for smaller invertebrates and fish, and may even be a source of nutrition with greater productivity than seagrass itself. A study of seagrasses in the Philippines found that grazers consumed 20-62% of the periphyton (detritus, diatoms, and filamentous algae) biomass on seagrass surfaces (Klumpp et al. 1992). On *E. acoroides* the periphyton may include many species of red, green, brown, and blue green algae which grows with faster turnover times of 6-8 days instead of 30-100 days as seen in some seagrasses (Klumpp et al. 1992) Sea urchins (*Tripteustes gratilla*), gastropods, and the rabbitfish *Siganus doliatus* have also been found to use epiphytes based on their δ13C values (Vonk et al. 2008). In Fiji epiphytic cyanobacteria were found to serve as the primary food source for amphipods rather than the seagrass itself or seagrass detritus (Yamamuro 1999). Another study of seagrasses in the Gulf of Mexico found that there was intensive foraging of epiphytes by various detritivores at night, and δ13C values supported consumption of epiphytes rather than seagrass material itself (Kitting et al. 1984). The degree to which seagrass contributes to biomass may also simply depend on location. For instance in a study in Australia, carnivorous giant mud crabs (*Scylla serrata*) near seagrass meadows had isotopic signatures showing they had used seagrass and seagrass epiphtyes resources, but crabs furthest from seagrasses had isotopic signatures showing use of terrestrial and mangrove originated materials (Connolly and Waltham 2015).

Seagrass carbon may also exported out of the seagrass beds in the form of consumer or predator fish biomass that moves to the coral reef or even directly to corals. Experimental evidence showed that the coral *Oulastrea crispata* is capable of ingesting seagrass particles and assimilated the nitrogen from the seagrasses into its own tissues (Lai et al. 2013). A study in Zanzibar found that even a top predator such as *Sphyraena barracuda* had assimilated carbon produced by seagrasses at some point in the food chain (Lugendo et al. 2006). A study in the South China Sea, found 70% of total fish abundance in seagrass beds were actually invertebrate feeding carnivores (Lee et al. 2014). In Guam, where seagrasses are extremely shallow, tidal influences may be an especially important factor affecting the availability of seagrass habitats to larger consumers. A study in Indonesia using visual surveys of fish species found seagrass fish assemblages were highly influenced by the tide, with greater fish abundance and richness during high tides (Unsworth et al. 2007). Another study in the South China Sea also found most fish, particularly herbivores, large-sized carnivores, and piscivores preferred deeper areas and flood tides (Lee et al. 2014). This suggested that fish were moving in during high tide to access food resources, including some predators such as *Hemiramphus far, Caranx melampygus and Lutjanus spp*. which made up a larger portion of the high tide fish assemblage (Unsworth et al. 2007). Research of seagrass communities using stable isotopes and surveys in Guam would need be conducted to understand how seagrass production or seagrass epiphytes contribute to Guam's fisheries and seagrass communities.

c. Mangrove production supports detritus based food webs, and may be exported to nearby ecosystems:

Similar to some other coastal and estuarine ecosystems such as salt marshes, mangroves are proposed to be detritus based food webs. Mangrove production generally starts with the breakdown of leaves into detritus by microorganisms, which can then support crabs, filter feeders, and other invertebrates and microorganisms (Kristensen et al. 2008, Kruczynski and Fletcher 2012, Bui and Lee 2014). Mangrove leaves are a difficult source of nutrition to use due to the high tannin and low nitrogen content (Kristensen et al. 2008). Only a few organisms, particularly sesarmid crabs, directly ingest fresh mangrove leaves, and given the choice sesarmid crabs generally prefer yellow or brown leaves that have begun the decomposition process (Thongtham and Kristensen 2005). Leaf litter broken down into detritus by microorganisms have greater palatability due to enriched nutritional content and degradation of feeding deterrent chemicals such as tannins and phenolic compounds (Kristensen et al. 2008). Within the first 10-14 days 20-40% of the organic carbon leaches out of leaf litter which then is incorporated into microbial biomass at varying rates, as low as 45% in more anoxic sediments, and 90% in nutrient replete and oxic conditions (Kristensen et al. 2008). Sesarmid crabs eating leaves will also excrete about half the amount of material they ingest (Thongtham and Kristensen 2005), providing nitrogen rich fecal pellets which are accessible for other organisms to ingest (Kristensen et al. 2008). Crabs can have a significant impact on leaf litter, even a relatively low biomass of sesarmid crabs can remove 30% of leaf litter (Kristensen et al. 2008).

The pathways of carbon in mangroves is complicated by the heavy influence of microbes and inputs from terrestrial and coastal ecosystems. Detritus feeds aerobic microbial communities at or very near the sediment surface (usually less than 2mm), and an anaerobic microbial community below ground (Kristensen et al. 2008). Mangrove communities likely evolved to utilize detritus for energy. A comparison of mangroves in Puerto Rico and Hawaii, where mangroves are native and invasive respectively, found that the community of organisms where mangroves are invasive are not adapted to utilizing mangrove detritus (Demopoulos et al. 2007). Abrantes et al. (2015) found widespread use of mangrove originated materials in invertebrates and fish in areas with moderate mangrove coverage (19%-50%), revealing a large role of detritus based food webs. Other primary producers within the mangrove environment also help feed larger consumers. The microphytobenthos (MPB) is the assemblage of diatoms, cyanobacteria, flagellates, and green algae that lives on the surface of marine sediments (Underwood 2001)and can also play a large role in providing nutrition. Direct consumption of detritus may be less common than consumption of other food sources, such as the MPB (Nagelkerken et al. 2008). Microbial mats may be an important source of production and affect carbon sequestration. A study of Atlantic mangroves found that mangrove materials themselves contributed little to sediment carbon and instead microbial biomass provided 80-90% of the organic carbon to sediments (Wooller et al. 2003). Together these groups contribute to mangrove food webs. A study of carbon and nitrogen isotopes in a coastal system in Australia found that organisms had many overlaps in diet with five food way paths: (i) mangrove-microphytobenthos based, (ii) plankton based, (iii & iv) two different paths originating from seagrass-microphytobenthos based, and (v) seagrass based (Abrantes and Sheaves 2009) (Abrantes and Sheaves 2009). Food webs may also change when productivity of mangroves or other primary producers change during different seasons with greater temperature or rainfall (Abrantes et al. 2015).

Odum and Heald (1975) first suggested the mangrove outwelling hypothesis which proposed the idea that the high productivity from mangroves was exported to other aquatic environments. The amount of export if any, varies widely (Kristensen et al. 2008). Seagrasses and mangroves often occur in proximity and exchange materials and detritus with each other. Using stable carbon isotopes, Hemminga et al. (1994) found that mangroves and seagrasses were tightly coupled systems that exchanged organic particles with changing tides. Chen et al. (2017) found that mangrove organic carbon contributed 34% to 83% to soil organic carbon in seagrass beds. The global average show that mangroves are a source of detritus primarily to closer adjacent areas such as seagrasses and tidal creeks, with little contribution to offshore ecosystems beyond a few kilometers (Kristensen et al. 2008, Nagelkerken et al. 2008, Tue et al. 2017). However, past studies of export have also focused on particulate matter, whereas dissolved organic matter may need to be considered further to understand impacts farther offshore (Lee 1995). A study in Brazil found mangroves were the main source of land based carbon in the open ocean, and estimated that globally mangroves contribute over 10% of the dissolved refractory organic carbon (resistant to degradation, can contribute to long term storage) transported to the ocean (Dittmar et al. 2006). More research would be needed to better understand to what degree “mangrove outwelling” occurs or contributes to long term carbon sequestration.

Seagrasses and Mangroves are a habitat for juveniles and fisheries:

A nursery can be defined as an area where there is higher contribution of juveniles that recruit to the adult population per unit area of that habitat relative to other habitats. (Nagelkerken 2009, Igulu et al. 2014). The previous section focused on the role of seagrasses and mangroves in primary production and support food webs. However seagrasses and mangroves have utility as habitats for both adults and juveniles in other ways beyond serving as a source of food through primary production. Nursery areas may support juvenile populations by providing greater survival, growth, protection from predators and a transition area to the adult habitat (Nagelkerken 2009, McDevitt-Irwin et al. 2016). In some cases food resources might not the major benefit (there are other more nutritious foods allowing faster growth at the coral reef), however protection from predators due to greater turbidity or more structure enhances survival (Heck Jr and Orth 2007, Nagelkerken 2009, McDevitt-Irwin et al. 2016). Seagrass blades and mangrove roots provide a complex 3D habitat that provide refuge (Heck Jr and Orth 2007). A study in the Caribbean found that diurnal fish were likely attracted to seagrasses and mangroves for food, whereas nocturnal fish were attracted to the structure which offered daytime shelter (Verweij et al. 2006). Diurnal barracuda were also found to use structure, but may be using it to facilitate ambush of prey (Verweij et al. 2006).

Overall, in the Indo-Pacific, seagrasses are more accepted as nursery grounds, whereas there is debate over whether mangroves serve as nursery habitats (Faunce and Layman 2009, Nagelkerken 2009, Igulu et al. 2014). A meta-analysis of 14 studies with data on juvenile density in different habitats found Caribbean juvenile density was highest in the mangroves, whereas in the Indo-Pacific it was highest in seagrasses, however it was also found that a more accurate indicator than geographic region would be tidal range, which was a strong driver of the number of reef species that may use mangroves (Igulu et al. 2014). Mangrove roots that are perpetually submerged allow the development of a subtidal community of filter feeders, macroalgae, mangrove and macroalgae associated invertebrates, and allow fish to continuously make use of the mangrove root habitat (Kruczynski and Fletcher 2012). Corals can be found in mangrove environments in Florida and the Caribbean, even growing on mangrove roots themselves (Kellogg et al. 2020, Lord et al. 2020). Distance also can play a role; studies that find nursery functions of seagrasses, mangroves, and coral reefs often studied areas where these environments were in closer proximity (Nagelkerken 2009). Greater separation between mangroves and seagrasses with coral reefs can present predation risk or otherwise affect the linkage between nursery and adult habitat. Other factors may also play a role, such as higher salinity, which was also associated with greater juvenile fish density (Igulu et al. 2014).

There are different types of evidence supporting the role of seagrasses and mangroves as nurseries, including their function separately or as connected systems. Stable isotope analysis once again is a useful tool to investigate an organism's diet down the food chain to the original primary producer. Since isotopes reflect long term diets, ideally, samples would be taken from adults, juveniles, and their food items/stomach contents to separate out time points where mangroves or seagrasses contributed to their biomass (Nagelkerken 2009). A study of carbon isotope signatures of otoliths in Tanzania found that 82% of adult reef *Lethrinus harak* had lived in mangrove (29%) or seagrass (53%) habitats as juveniles (Kimirei et al. 2013). It also found that 99% of adult reef *Lethrinus lentjan* had been in mangrove habitats as juveniles, and a smaller portion (28-35%) of *Lutjanus fulviflamma* had used mangroves and seagrass habitats (Kimirei et al. 2013). Visual surveys in Tanzania also found greater densities of juveniles of fish (*Lutjanus fulviflamma, Lethrinus harak, Lethrinus lentjan, Siganus sutor)* in mangroves and seagrass beds than in deeper water habitats or coral reefs, and vice versa for adults (Kimirei et al 2010). In Japan, *Lutjanus fulvus* migrate from mangrove areas to coral areas and change their resource use as they migrate (Nakamura et al 2008). However this trend varied in time and space, and both adult and juveniles were flexible with their habitat use.

Other methods also compare fish abundance and species richness within different areas, however many studies lack the data needed to conclusively show that an area is a nursery habitat (Nagelkerken 2009). Studies would need to show of juveniles in nursery habitats versus adult habitat, greater density of adults in adult habitats, greater density and migration from the nursery to adult habitats. (Nagelkerken 2009). Dorenbosch et al. (2005) compared coral reef areas with and without adjacent seagrass/mangrove areas and found that the reefs without seagrasses lacked or had very low abundance of 32 out of 26 fish species that have been observed to use seagrasses as nursery habitat . A higher density of the threatened Indo-Pacific humphead wrasse, *Chelinus undulatus* is positively correlated with a higher density of seagrass in the Indian Ocean (Dorenbosch et al. 2006). In Palau, juvenile *C. undulatus* was also found in seagrass areas, although in lower abundance than other potential nursery habitats including low branching corals and macroalgae (Tupper 2007). There is also evidence that when mangroves and seagrasses occur together, they can have greater abundance and species richness (Nagelkerken et al. 2008). Seagrasses and mangroves may also function better together, providing different food or shelter resources. A study of juvenile snappers in the Red Sea sheltered in mangroves but fed on detritus in seagrass beds (McMahon et al. 2011). A study by Unsworth et al. (2008) in Indonesia compared (i) seagrass habitats close to coral reefs and shoreline, (ii) seagrass habitats close to coral reefs and mangroves on land, and (iii) seagrass habitats close to mangroves and far from coral reefs, and found that seagrasses (which contained juvenile coral reef fish) with mangroves nearby had at least double the abundance and species richness of fish compared to seagrass areas without mangroves. Unsworth et al. (2008) noted that many fish found in the seagrass could also be found in the mangroves, suggesting it was an important feeding or sheltering ground.

The utility of seagrasses and mangroves as a habitat for both juveniles and adults will depend on many factors. The depth, size, distribution, and density of seagrass patches affect how well seagrass provides protection against predation and the assemblage of organisms found in the seagrass bed (Heck Jr and Orth 2007, Pogoreutz et al. 2012). Diversity of seagrass in the seagrass bed may also play a role; Pogoreutz et al. (2012) with greater fish diversity occurring at sites with more species of seagrass. Guam's seagrasses have relatively low diversity compared to other regions around the Indo-Pacific however the most common species in Guam, *E. acoroides*, can support greater fish diversity and biomass than other shorter seagrass species (Nakamura and Sano 2004). A study in Indonesia found that the high seagrass blade biomass areas had greater abundance of fauna, especially microbenthic invertebrates and fish compared to low seagrass blade biomass areas (Vonk et al. 2010). Additionally there was an “edge effect”, with greater microbenthic invertebrate abundance towards the interior of the seagrass bed (Vonk et al. 2010). The patchiness and amount of edge habitat available will affect the seagrass community. Pipefish were found to prefer edge habitat for access to food (Macreadie et al. 2010), and scallops were found to face a trade-off between the greater protection of the deeper interior seagrass for greater access to food and higher growth (Bologna and Heck Jr 1999). In addition to flooding mentioned earlier, different factors may also affect the utility of mangroves as a habitat, such as the shading provided by roots, turbidity of the water due to detritus or terrestrial inputs, and surface area available for growth and grazing (Nagelkerken 2009). Ocean currents, location (fringing the ocean as opposed to within tidal creeks) may also affect how accessible mangroves are to juveniles (Faunce and Layman 2009). More research would be needed to study Sasa Bay where there oceanic facing mangroves and intertidal mudflats as to determine if there are nursery functions In southern Guam, there are narrow fringing mangroves with highly turbid water. Despite the lower available area for habitat, fringes often can provide valuable habitat. In an urbanized area of Australia using underwater cameras, Dunbar et al. (2017) showed that even narrow fringing mangroves can be valuable habitat with a high density of fish, including juveniles, using the edge habitat.

As habitats for both juveniles and adults seagrasses and mangroves help contribute to fisheries. Seagrasses are likely underestimated in terms of their fisheries production, since many studies of fisheries in tropical lagoons do not acknowledge presence of seagrasses (Unsworth and Cullen 2010). In Indonesia a study using fisheries data, life history biology, and household interviews found that seagrasses in a marine protected area supported 50% of fish based food, and the primary protein source (Unsworth et al. 2014). A study of coral, mangrove, and seagrass ecosystems in Tanzania found that all three ecosystems provided the same fish catch and income per capita but seagrasses provided the highest fish catches and income at the community level (de la Torre-Castro et al. 2014). In Guam the seagrass parrotfish (*Leptoscarus vaigiensis*) was traditionally harvested in women (Hensley and Sherwood 1993). Seagrasses continue to have a role in Guam’s seafood production and culture -----insert info from community member survey---.

Mangroves provide support to fisheries as shown by evidence mostly correlating mangrove area with fisheries catch (Nagelkerken et al. 2008). In a study in Australia, mangrove area and perimeter was correlated with catches of mangrove related species such as prawns, crabs, and barramundi fish (Manson et al. 2005a). In the Gulf of California, mangrove fringes provide $37,500 worth of fisheries per hectare per year of mangroves, and mangrove related fish and crabs account for 35% of small scale fisheries (Aburto-Oropeza et al. 2008). In both the Caribbean and Indo Pacific, a significant portion (30-80%) of commercial fish are associated with mangrove habitats during some portion of their life (Rönnbäck 1999). Mangroves in other areas are also crucial for shellfish, crab, and shrimp fisheries (Rönnbäck 1999). Overall more research is needed to quantitatively demonstrate links between mangroves and fishery yields (Baran and Hambrey 1999, Manson et al. 2005b). In Guam, mangroves support seafood catches of crabs and fish----more details community members from survey---

d. Carbon sequestration:

The carbon stored by seagrasses, mangroves, salt marshes, and other coastal or ocean ecosystems is often described as “blue carbon” (Nelleman et al. 2008). Coastal wetlands often store larger amounts of carbon than expected given for the size of the area due to the type of storage. In seagrass and mangrove ecosystems carbon is stored mostly through accumulation of anoxic sediments stored over millennia with some additional storage in living biomass. In contrast, terrestrial "green carbon" is stored primarily in living tissue with some additional storage in sediments over shorter time periods of decades and centuries (Duarte et al. 2005, Nelleman et al. 2008, Mcleod et al. 2011, Alongi 2012, Fourqurean et al. 2012).

Seagrass are one of the most productive ecosystems and globally store an estimated 4.2 to 8.4 Pg of carbon (Duarte et al. 2005, Duarte et al. 2010, Fourqurean et al. 2012). Carbon burial rate of seagrasses vary but average 138 ± 38 g C m-2 yr-1 (Mcleod et al. 2011). Production of seagrasses themselves contributes approximately 50% to the organic carbon pool (Kennedy et al. 2010), or sometimes less, with greater contributions from other sources like phytoplankton (Kennedy et al. 2004). Globally seagrasses comprise only .2% of the ocean floor, however seagrasses account for approximately 10% of the yearly carbon burial in oceans (Duarte et al. 2005). Guam's *E. acoroides* meadows are estimated to create 10.6 g of dry weight mass per square meter per day, making it among the most productive of seagrasses and capable of sequestering high amounts of carbon (LaRoche et al. 2019). Seagrasses may even export carbon beyond the seagrass bed and into the deep ocean; seagrass shoots have been found on the deep-sea floor (Duarte and Krause-Jensen 2017). Seagrasses will also export part of their carbon to adjacent mangroves (Bouillon and Connolly 2009), and observations of some mangrove areas in Guam also show seagrass on mangrove roots (Lin pers sobs. 2020). Present losses of seagrasses may release massive amounts of carbon, up to 299 Tg per year (Fourqurean et al. 2012). However restored seagrasses are capable of sequestering carbon, and will reach rates similar to undisturbed beds with age, within potentially 12-18 years (Greiner et al. 2013, Marbà et al. 2015). The amount of carbon stored may also depend on other factors such as eutrophication which can lower sequestration rates (Jiang et al 2018), herbivory (Scott et al. 2018), predator induced trophic cascades (Atwood et al. 2015) and turbidity and water depth (Halim et al. 2020).

Like seagrasses, mangroves have a disproportionate effect on carbon sequestration. Mangroves account for approximately 3% of the carbon sequestration by the worlds tropical forests, despite only accounting for <1% of the total area of tropical forests (Alongi 2012). Mangroves also represent on average 14% of the carbon sequestration in marine environments despite accounting for only .5% of coastal area. Mangroves generally have the same net primary production as other forests, however much greater percentages of their production is represented in belowground biomass, including fine roots that grow with rapid turnover to maximize water access, and sloughed root hairs (Alongi 2012). Belowground carbon stocks may account for 49%-98% of total ecosystem carbon stock in mangroves (Adame and Lovelock 2011, Donato et al. 2011). The rapid turnover of roots and slow decay in anoxic sediment allows formation of peat, which may have been an evolutionary mechanism by mangroves for storing nutrients for future use and stabilize the trees in a wavy environment (Alongi 2012). Even smaller short scrub mangroves can have relatively high carbon stocks stored in deep soil (Kauffman et al. 2014). In contrast tropical terrestrial trees typically have a rapid soil decomposition and thin layer of humus (Alongi 2012). A study of peat in Pohnpei comparing decomposition of mangrove leaves and roots also suggested that the production of fine roots was also more important than leaf decomposition for peat formation in this Micronesian mangrove forest (Ono et al. 2015). Despite the presence of tannins which can reduce microbe and herbivore activity, leaves decompose relatively quickly and are washed away by tides compared to roots which reduces their capacity to act as a carbon sink (Ono et al. 2006, Li et al. 2018). Kauffman et al. (2011) measured carbon in aboveground biomass and soil down to 1m and found that mangroves in Palau stored 467 Mg/ha to 1068 Mg/ha from the seaward to landward zone and mangroves in Yap stored 853 Mg/ha to 13585 Mg/ha along the same gradient, which is on the higher end of mangrove carbon sequestration in Asian mangrove forests.

Due to their long term storage of carbon in the ground, loss of mangroves presents an enhanced threat to climate change from (i) loss of future carbon sequestration and (ii) release of greenhouse gases from sediments already accumulated (Alongi 2012). Peat soils from cleared mangroves release carbon dioxide, estimated at 112-392 tC released per hectare, which are current deforestation rates would contribute at least 2-10% of deforestation emissions (Alongi 2012). A study of mangroves in the Dominican Republic found that mangrove areas converted to shrimp ponds only had 11% of the carbon storage as intact mangrove forests (Kauffman et al. 2014). Although peat may destabilize and release greenhouse gases, planting can help ameliorate the situation and young mangroves from mangrove planting projects are capable of sequestering carbon are rates similar to older mangroves (Lunstrum and Chen 2014). Trimming mangroves from 6m to 1.5m can result in a loss of 8.6 tons of carbon/ha/year (Beever III et al. 2013). The amount of carbon stored will depend on the environmental conditions and characteristics of the mangrove forest. In some cases, medium sized mangroves have been found in some instances to have greater rates of carbon storage (Komiyama et al. 2008, Donato et al. 2011, Kauffman et al. 2014). In other instances it has been found that primary production increases with stand age, increasing from 16% sediment carbon burial for a 5 year old forest to 27% for an 85 year old stand (Alongi et al. 2004). The presence of crab burrows and infauna also will affect the amount of CO_2 released (Kristensen et al. 2008). Due to the large amount of anoxic sediments in mangrove habitats, release of methane, a more potent greenhouse gas than carbon dioxide, can also offset the effect mangroves have on mitigating climate change (Rosentreter et al. 2018). Nutrient pollution can exacerbate this by reducing oxygen and increasing methane emissions (Kristensen et al. 2008). As sea level rises, seagrasses may move into areas where mangroves currently exist, which may also affect how much carbon may be sequestered (Donato et al. 2011, Kauffman et al. 2014).

e. Mangroves and seagrasses absorb pollution:

Mangroves and seagrasses both absorb land based sources of pollution, in the form of nutrients, potential toxicants such as heavy metals, and sediment (described in the next section). Seagrasses and mangroves both help absorb nutrients in run-off (Gillis et al. 2014). Experiments that have planted mangroves have around wastewater plants to test for the potential of mangroves to absorb nutrients show that mangroves help absorb nitrogenous wastes, phosphates, and suspended solids (Tam and Wong 1996, Boonsong et al. 2003, Wu et al. 2008, Yang et al. 2008). Naturally occurring mangroves in an estuary in Panama also provide further evidence and act as a nutrient absorption barrier between land and sea (Lin and Dushoff 2004). However, some of the experimental evidence was gathered on relatively short time scales and mangroves have limits to pollution absorption and can be negatively impacted by nutrient enrichment (see section on mangrove biology and ecology). Seagrass and seagrass communities, including epiphyte grazers and filter feeders, also can absorb and buffer the effects of nutrient enrichment to a point, however eutrophication is a significant threat to seagrasses (McGlathery et al. 2007) (see section on seagrass biology and ecology). Run-off may also include bacteria which can cause coral disease. In Indonesia, Lamb et al. (2017) found that 50% less abundance of potential pathogenic bacteria in water samples collected in areas with seagrass meadows. Additional field surveys of over 8000 paired corals (with or without seagrass) found 2x less disease in corals near seagrass (Lamb et al. 2017).

Various studies have been conducted on the phytoremediation capabilities of mangroves and seagrasses. Mangroves sediments are anaerobic, reduced, and rich in sulfide contain fine particles and organic matter which enables them to effectively capture heavy metals (Pb, Zn, Cu, Cr, Cd and Ni) (Zhou et al. 2011, Paz-Alberto et al. 2014, Chowdhury et al. 2017). Mangroves around a landfill were found to have helped reduced heavy metal pollution into nearby waters (Machado et al. 2002). However some of these contaminants are absorbed into the mangroves and remobilized into the environment when mangrove leaves drop (Almahasheer et al. 2018). Mangroves also may have some remediation capabilities for organic pollutants such as petroleum hydrocarbons and polycylic aromatic hydrocarbons (Moreira et al. 2011, Verâne et al. 2020) Although there is research showing that mangroves are fairly tolerant to heavy metals (Peters et al. 1997, MacFarlane and Burchett 2002) there are also many studies demonstrating bioaccumulation, negative effects of organic and inorganic toxicants on the health of mangroves and mangrove community (Lewis et al. 2011). Therefore the ability of mangroves to absorb pollution should be seen as an additional benefit to help mitigate impacts and not a solution. Since bioaccumulation of toxic compounds can occur, testing of seafood from mangroves can also test their food safety. There is less research showing the value of seagrasses in absorbing pollution. There is some evidence that seagrasses and seaweeds are capable of absorbing heavy metals (Sudharsan et al. 2012), however research also shows that that seagrasses are negatively impacted by pollutants (Prange and Dennison 2000, Mayer-Pinto et al. 2020).

f. Seagrasses and Mangroves also help prevent coastal erosion through wave attenuation:

Coral reefs, seagrasses and mangroves are a sustainable and cost effective part coastal erosion management by reducing wave energy approaching the shore, preventing coastal erosion through sediment accretion and stabilization, and offering protection from storms (Gracia et al. 2018). A study modeling different habitat combinations of coral reefs, seagrasses, and mangroves based on habitats in Belize found the combination of 3 habitats provided more protection than any single or any pair of habitats on their own (Guannel et al. 2016). Mangroves in particular were found to offer higher levels of protection and reduced wave height by more than 70%, however mangroves may also depend on the coral reef and seagrasses to help slow down water enough for young mangroves to establish (Guannel et al. 2016). There is sometimes a mistaken assumption that ecosystem services have a linear relationship with spatial extent of the ecosystem, however this may not be true. For mangroves there is a quadratic decrease in wave height relative to the inland extent of mangroves, and seagrasses also have a non-linear relationship with wave height influenced by the depth of the water (Barbier et al. 2008). *Rhizophora* mangroves in particular offer greater protection than other genera of mangroves due to the increased structure offered by the shape of their prop roots (Horstman et al. 2014, Srikanth et al. 2016).

Seagrasses also have a documented ability to reduce wave energy. A study using artificial replicates of *Enhalus acoroides* in a 1:30 scale model estimated a 50% reduction in wave height (John et al. 2015). Additionally, the consolidated sediment structure built up by seagrass roots can also add a level of protection(Christianen et al. 2013, James et al. 2020). Even smaller seagrasses can help attenuate waves. A study of Indonesia meadows of *Halodule uninervis* (also a species found in Guam), had significant value in coastal protection by stabilizing sediment despite small biomass and heavy grazing by sea turtles (Christianen et al. 2013). Despite the low above ground biomass, the belowground biomass in the form of root structures stabilized sediment and accreted sediment into elevated banks structures that helped attenuate waves (Christianen et al. 2013). A meta-analysis and flume study found that a combination of seagrass and calcified macroalgae such as *Halimeda sp.* help maintain beaches through a dual benefit of providing carbonate sediment and stabilization of that sediment (James et al. 2019).

g. Seagrasses and Mangroves trap sediment particles, preventing sedimentation of coral reefs and coastal erosion:

Seagrasses and mangroves both help decrease sediment in the water column (Gillis et al. 2014) which can help support coral reef health. Tropical seagrasses effectively capture sediment particles by reducing wave energy and providing surface area for particles to attach to. Seagrass epiphytes or seagrasses themselves may even release chemical substances that help trap particles (Gacia et al. 2003). A study in the Philippines found that seagrasses reduced particles in the water column, with 4x less particles than unvegetated areas (Agawin and Duarte 2002). Up to 5% of particles were trapped directly via adhering to the surface of seagrass blades (Agawin and Duarte 2002). Even in storm conditions, particle concentrations increase over the general area but are lowest deep inside the seagrass meadow (Granata et al. 2001).

Not only do seagrasses trap sediments coming from other sources, but they produce and trap sediment produced by themselves. Seagrasses create inorganic and organic particles that deposit into the seagrass bed as sediment contributing a minor to moderate amount of sediment trapped (15-42%) (Kuramoto and Minagawa 2001, Gacia et al. 2003, A'an et al. 2016). Organic material forming "marine snow" in seagrass beds consist of fecal pellets and phytodetritus (A'an et al. 2016). Long lived seagrass, such as *E. acoroides* and seagrass epiphytes (which have higher productivity than the seagrass themselves), also contain relatively large amounts of calcium carbonate which contributes to carbonate sediments (Gacia et al. 2003). This can have an effect on carbonate chemistry; a review showed that nearby seagrass meadows can increase the seawater pH by .38 units and scleractinian coral can calcify up 18% greater, depending on factors such as amount of tidal flushing and water depth (Unsworth et al. 2012).

Mangroves roots actively capture silt, clay and organic particles generated from different ecosystems (seagrasses, terrestrial sources) and organic sediments produced by mangroves themselves (Alongi 2012). The amount of sediment inputs will vary depending on the characteristics of the area. A stable isotope study in Thailand found mangrove material consisted about 23% sedimentary organic material (Kuramoto and Minagawa 2001). A separate stable isotope analysis found that organic matter captured from upstream rivers and adjacent waters contributed more to mangrove carbon sinks than their own mangrove production (Li et al. 2018), which also demonstrates the effectiveness of mangroves in trapping LBSP. Microbial mucus and the salinity of sea water helps promote flocculation and settling of the particles during slack tide (Alongi 2012). A study in Palau comparing two river catchment areas, one pristine and one impacted by farming and development, found that although mangroves only comprised 3.8% of the catchment area in both catchments, the mangroves trapped approximately 30% of river sediment (Victor et al. 2004). A study in the Solomon Island found that Bumphead Parrotfish (*Bolbometopon muricatum*), important for local fisheries and labeled vulnerable by the IUCN, were only found in lagoon reefs that were forested with mangroves on the shoreline (Hamilton et al. 2017), suggesting an important role in mangroves preventing sedimentation. However logging in the area and impacts to mangroves caused sedimentation of reefs resulting in 24 times less juveniles found in logging impacted areas (Hamilton et al. 2017). However mangroves alone can only absorb a certain amount of sediment, and poor land planning or development practices can overwhelm the abilities of mangroves to cope (Victor et al. 2004).

Mangroves actually require active input and accretion of sediment to prevent erosion. On average mangroves accrete 5 mm of soil per year, frequency of tidal inundation is the greatest factor influencing rate of accretion (Alongi 2012). More frequent tidal inundation allows for greater input of sediment, and fringing mangroves along the shore experience greater rate of sediment accretion than those higher in the intertidal zone (Alongi 2012). Other factors may affect mangrove vertical accretion such as growth of roots and growth of microbial mats and algae (Alongi 2012). In Micronesia, natural subsidence also affects net elevation rates (Krauss et al. 2010). Without enough sediment input mangrove coastlines may experience erosion. An example of this is the Mekong River Delta in India, where dams and other human activities reduced sediment input, preventing the necessary sediment accretion to prevent erosion (Besset et al. 2019). Understanding the rate of accretion is key to understanding whether mangroves will be able to prevent erosion and keep up with sea level change.

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SEAGRASS BIOLOGY AND ECOLOGY

CONTENTS:

I. Seagrass species found in Guam:

Lobban and Tsuda (2003) compiled an updated inventory, reporting ten seagrass species that can be found in Micronesia, three of which may be found in Guam: *Enhalus acroides, Halophila minor,* and *Halodule uninervis*. However, a recent report of the Manell-Geus Habitat Focus Area also recorded *Halodule pinifolia* as a species in that the area (Raymundo et al. 2018). *H. pinifolia* and *H. uninervis* may be difficult to differentiate due to their similar and highly variable morphology as discussed below (El Shaffai 2011). There are genetic studies that suggest both that these two *Halodule* species are the same species (Waycott et al. 2014 as cited by Shaffai 2011), as well as separate species (Wagey and Calumpong 2013). There is also evidence for potential hybridization of the two species(Ito and Tanaka 2011), which could add an additional challenge to define them as separate species.

a. Identification & Morphology:

- ***Enhalus acoroides:*** one of the largest of seagrasses (>1m), has blades with edges rolled inwards up to 1.5-2 cm wide (Meñez and Phillips 1983, El Shaffai 2011). The rhizome is also large, with long black fibrous bristles and thick roots up to 1 cm in diameter. (Meñez and Phillips 1983, El Shaffai 2011). LaRoche et al. (2019)'s study of *E. acoroides* meadows in Guam showed that nearly 90% of its biomass was underground.
- ***Halodule uninervis:*** morphologies may vary with wide or narrow leaves (2-5mm) that may be found under different environmental conditions such as depth and light availability, with the narrow leaf type typically found in shallow waters (Hedge et al. 2009, El Shaffai 2011). At the tip of the leaf there are 3 protrusions, 2 lateral "teeth" and a central "tooth" that unlike *H. pinifolia* is not split (El Shaffai 2011). The rhizomes are very fine, barely reaching 2mm in diameter. The leaf blades reach up to 15 cm in length and are 2-5 mm wide (Meñez and Phillips 1983).
- ***Halodule pinifolia:*** morphologically distinguished from *H. uninervis* at the leaf tip where *H. pinifolia* has a black central vein that splits, as well as very fine serrations along the entire leaf tip edge. The leaf blade is also flat, less than 20 cm long (El Shaffai 2011), up to 1.5cm (Meñez and Phillips 1983).
- ***Halophila minor:*** is easily distinguished by its ovate leaf blades that grow in pairs, typically, 6-12 mm long, 2.5-6 mm wide (El Shaffai 2011). The leaves are smooth (no hairs) also have 10-28 branched cross veins (El Shaffai 2011).

b. Life strategies- climax and pioneer species:

Enhalus acoroides

E. acoroides tends to live in shallow areas very close to shore and it can tolerate a wide range of salinities (Kock and Tsuda 1978, Short and Duarte 2001, El Shaffai 2011). *E. acoroides* can also be found growing in a wide range of substrates including silty, sandy, and muddy substrates (Meñez and Phillips 1983, Green et al. 2003). LaRoche et al. (2019) reported *E. acoroides* in Guam to be predominantly found in carbonate sediments at depths <0.5m on top of limestone.

E. acoroides is a slow growing climax species, which may make it vulnerable and take longer to recover after disturbances (Green et al. 2003). In a removal experiment in the Philippines, *E. acoroides* was one of the last species to reestablish, after several other species (including *H. uninervis*) reestablished first (Rollon et al. 1999). Rollon et al. (1999) estimated it would take 10 years or more to fill the $1m^2$ space that was experimentally removed. Another study of seagrass recolonization in the Philippines showed that this long recovery time may be due to *E. acoroides* reestablishing primarily through sexual reproduction (Olesen et al. 2004). Compared to *E. acoroides*, *H. uninervis* recolonization accounted for a higher percent of the recently recolonized seagrass areas, likely due to it expending more energy on asexual reproduction and growing quickly along rhizomes (Olesen et al. 2004). On average the rhizome grows only by 3 cm per year in *E. acoroides,* as opposed to 101 cm *in H. uninervis*, or higher in some *Halophila* species (Marbà and Duarte 1998, Duarte et al. 2007).

Since sexual reproduction is a major form of growth for *E. acoroides,* fragmented meadows can present an additional challenge. Another study of *E. acoroides* in the Philippines found density dependent relationship of fruit production, with a dramatic increase in the percentage of female flowers with fruit at around 50% seagrass cover (Vermaat et al. 2004). Vermaat et al. (2004) suggested that a certain density of *E. acoroides* also might be needed to effectively trap pollen in the water.

Halodule uninervis

While *E. acoroides* may be considered a slow growing climax species, *H. uninervis* is considered a fast growing pioneer species. *H. uninervis* can be found growing in reef flats in sheltered and exposed areas (Meñez and Phillips 1983, Short and Duarte 2001). *H. uninervis* has been found in different sediments including sandy, silty, muddy, and areas with coral rubble (Hedge et al. 2009) and reported to be able to quickly colonize thin or thick sediments (Birch and Birch 1984).

Halodule pinifolia

H. pinifolia can be found growing on a variety of environments, in more sheltered areas, coral reef platforms, and in more wave-beaten sites (Meñez and Phillips 1983). H*. pinifolia* has shown experimental tolerance to low light conditions, suggesting it may be capable of living in more turbid waters (Longstaff and Dennison 1999).

Halophila minor

Halophila minor can be found also in a variety of sandy, muddy, or coral based sediment. In other areas it may be found with other species such as *Halophila ovalis.* It has also been found in patches with other seagrass species in deeper waters down to seven meters (Kuo et al. 2006).

c. Reproductive biology and ecology:

The amount of seed production, length of seed dormancy, germination, and seed dispersal may depend on a multitude of factors. Levels of disturbance can affect the amount of flowering, with observations suggesting that increased stress may actually lead to increased flowering (Orth et al. 2007, Cabaco and Santos 2012). In general, larger seagrasses (such as *E. acoroides*) use a strategy of "resistance" and survive disturbance by having large carbohydrate reserves, whereas smaller seagrasses (such as *Halophila* and to a lesser extent *Halodule*) use a strategy of "recovery" and rapidly regrow from seedbanks and faster growth rates (Unsworth et al. 2015). Different environmental factors (light, temperature, oxygen levels, and especially salinity) can impact dormancy periods (Orth et al. 2007). Seeds from more genetically diverse populations may also be more likely to germinate (Williams 2001). Dispersal of seeds will depend on factors such as wind and currents, and animal activity (Orth et al. 2007). The topographic features and complexity (amount of pits and burrows) will also affect how rapidly a seed is buried, eaten, or washed away to unsuitable areas (Lacap et al. 2002, Orth et al. 2007). Once settled, seeds are not guaranteed to survive. Seedling recruitment can be low and is limited by wave action, grazing, bioturbation, and other factors (Statton et al. 2017). Priority in conservation could be given to beds that are more productive and serve as a source of seeds for other areas (Orth et al. 2007).

Enhalus acoroides:

E. acoroides is limited to shallow areas due it its reproductive requirements. *E. acoroides* reproduces via ephydrophily, meaning pollination occurs at the surface of the water, as opposed to hyphydrophily, which occurs underwater (Ackerman 2007). Male *E. acoroides* flowers detach and float to the surface and drift to female inflorescences which are still attached by a peduncle to the seagrass underwater (Ackerman 2007). After pollination the peduncle becomes coiled and retracts (Kuo and Den Hartog 2007). The male flower is taken, pollen is transferred, and the infructescence (an aggregate fruit) develops underwater until it detaches and floats up (Shimokawa et al. 2019). The length of exposure of the female inflorescence at the water surface is critical for pollination and creation of seeds, and shallow areas have more fruits (Rollón et al. 2003). In the Philippines Rollón et al. (2003) observed flowering throughout the year with shoots flowering on average .5 to 3.4 times per year. Rollón et al. (2003) also found a greater amount of peduncle scars on rhizomes than actual flowers, suggesting that early abortion was common. A study of seagrass restoration techniques searched for *E. acoroides* in Guam in 1977 and 1978 (missing author information, document shared by Brent Tibbatts). The authors found flowering male plants in September 1977 and in June and July 1978, a few days before the full moon, although no annual cycles were determined because the surveys were not timed regularly. Surprisingly, the authors did not observe any female flowers or seeds. The lack of knowledge on *E. acoroides* reproductive cycle and output is a major knowledge gap that could help determine causes of decline and support future restoration efforts.

Lacap et al. (2002) found that the floating fruits are buoyant for a median of 7 days, and seeds have a shorter period of buoyancy (at most 14h). Rollón et al. (2003) estimated 27 seedlings establish per square meter. Male flowerlets disperse at the water surface over potentially large distances; Lacap et al. (2002) estimate pollen dispersal could occur on spatial scales 10km. The fruits are roughly 6 cm long with a spinous surface and release 2-6 angular seeds (Kuo and Den Hartog 2007). Different fauna might also affect distribution or survivorship of seeds. Once seeds sink, they may continue to travel for 2 to 5 days before hairs start to anchor the plant into the sediment (Lacap et al. 2002). *E. acoroides* seeds have a fleshy/membranous seed coat and no distinct dormancy period (Orth et al. 2007). Lacap et al. (2002) also observed that alpheid shrimps, symbiotic gobies and ophiuroid brittlestars manipulated seeds, and shrimps and gobies brought seeds into their burrows.

Halodule uninervis:

H. uninervis reproduces via a unique method where singled-seeded spherical fruits are released below the surface of the marine sediments, a strategy also known as geocarpy (Inglis 2000). *H. uninervis* seeds have a hard outer coat and can remain dormant in sediments and form seed banks of thousands of seeds (Inglis 2000, Orth et al. 2007). *H.* uninervis seeds have been observed under lab conditions to survive over 41 months (McMillan 1991). Male plants produce single male flowers, and female plants produce a pair of female flowers (Bujang et al. 2006). Halodule has naked flowers on short pedicels close to the ground however little is known about the pollen transfer process (Ackerman 2007). The *H. uninervis* fruit matures within a leaf sheath (Kuo and Den Hartog 2007). However the amount of seeds stored can vary greatly (Orth et al. 2007). In urban coastal areas of Singapore, Ong et al. (2020) found only five H. uninervis seeds out of 185 sediment cores, which is much lower than the what Inglis (2000) found in Australia (1426 seeds in one bank and 2716 seeds in another). Ong et al. (2020) also found that none of the 5 the seeds were viable, which suggests that those particular H uninervis beds have much lower resiliency since there is not a seed bank to rely on.

Halophila minor:

H. minor, similar to the other two species is also dioecious (distinct male and female plants) that produces solitary flowers (Ackerman 2007). Its male flowers have 1.5mm long tepals (structures that cannot be distinguished as petals or sepals) and anthers 2.5-3.5mm long. Female flowers have 3 styles with 8-12mm long and fruits 2-3.5mm in diameter. (Kuo et al. 2006). *H. minor* flowers from June to September and fruits in August and September (Kuo et al. 2006). There is much less information on reproduction of this particular species. In general *Halophila* fruits are fleshy and globose, and produce seeds with dormancy periods that also undergo geocarpy (Ackerman 2007). Flowers are small (male with tepals 1.5mm, and female flowers with styles 8-20mm) and fruits approximately 2-3.5mm in diameter (Short and Coles 2001).

II. The seagrass community:

a. Overview of the importance of Seagrass Community Ecology:

Seagrasses support a large diversity of life, although their importance may be obscured slightly by studies and reports that describe the "reef flat" or "lagoon" environment in general, without specifying whether that is seagrass, sandy, shallow coral reef, or rubble areas. Seagrass community ecology is complex, with interactions and connections between different species of seagrass, macroalgae, plankton, benthic microalgae, and epiphytes on the seagrass blades, herbivores large and small, predators, and detritivores (Fortes 1990, Vonk et al. 2008).

Understanding seagrass herbivory is important, as it may affect the seagrass bed and the ecosystem services provided (Scott et al. 2018). Less heavily grazed beds with a thick canopy of climax species may be a better nursery for organisms to hide in and be better for sediment trapping, however a more moderately grazed bed may have greater diversity of seagrass and seagrass fauna, higher nutrient absorption, and greater carbon sequestration (Scott et al. 2018). Herbivores can also affect seagrass bed dynamics. Near the reef there are often seagrass "halos" of bare sand that occur due to sea urchins and other animals leaving the reef to feed on seagrass at night (El Shaffai 2011). Grazers can help reduce the amount of organic matter, reducing the likelihood of hypoxia (Valentine and Duffy 2007). Grazers can also increase the turnover of leaves, preventing overgrowth of potential pathogens such as slime molds (Valentine and Duffy 2007). Larger animals such as dugongs and stingrays can mechanically disturb the bed and alter species compositions (Valentine and Duffy 2007, El Shaffai 2011). Small invertebrates may not only be grazers, but also have other roles. Mobile invertebrates have recently been discovered to play a role as underwater pollinators for a seagrass species found in the Atlantic, *Thalassia testudinum* (Van Tussenbroek et al. 2016). Invertebrate bioturbators can resuspend sediment which deposits onto seagrasses and helps aerate anoxic sediments (Lamers et al. 2013).

Predators can also impact the behaviors or density of other lower trophic levels, which can impact seagrasses. For example Hughes et al. (2013) used a combination of 50 years of time series data, spatial comparisons, and mesocosm experiments to show how the presence of sea otters indirectly promoted the expansion and growth of eelgrass in California through a trophic cascade. The sea otters ate intermediate predators such as crabs, which allowed mesograzers such as sea slugs and isopods to flourish and eat epiphytes, which subsequently helps seagrasses grow more efficiently. Ultimately, the recovery of the sea otter apex predators allowed the seagrass beds to be more resilient to the effects of nutrient input (Hughes et al. 2013). A follow up study focused on the edge of the seagrass bed instead of the interior. On the edge of seagrass beds, Hughes et al. (2016) found that sea otters actually also supported growth of macroalgae which traditionally is seen as a competitor with seagrass. However, the macroalgae supported epiphyte grazers that then helped seagrass to grow and expand at the edge. These are just some examples of how complex community dynamics can affect the growth and health of seagrass beds.

b. Guam's seagrass community- fish and invertebrates:

There are several species of fish that can be found in Guam's seagrass areas. Perhaps the most well known are the rabbitfish, *Siganus spinus* and *Siganus argentus*, which are caught for food both as juveniles (*manahak)* and as adults (*sesyon*)(Tosatto 2013). Although *S. spinus* and *S. argentus* can be found in seagrass beds they most likely are using that as shelter and their diet likely consists primarily of macroalgae (Tsuda and Bryan 1973). Rabbitfish may also be important for preventing macroalgal overgrowth that can harm coral reefs and seagrasses (Rasher et al. 2013). Bryan (1975) captured *S. spinus* from various locations in Guam and found macroalgae preferences for food to be in the order of: (1) *Enteromorpha compressa*, (2) *Murrqyella periclados*, (3) *Chondria repens*, (4) *Boodlea composita*, (5) *Cladophoropsis membranacea*, (6) *Acanthophora spicifera*, and (7) *Centroceras clavulatum*. A UOG study by Paul et al. (1990) determined juvenile and adult food preferences of *S. argentus* and categorized preferences as low, medium, and high*.* Paul et al. (1990) found high preference by adults for several types of green algae (*Chlorophyta*), including *Caupera racemosa, Chlorodsmis fastigiata, Cladophoropsis membranacea, Enteromorpha clathrate*, and *Valonia fastigiata.* Juveniles also had high preferences for *C. racemosa and C. membranacea.* Paul et al. (1990) also tested preferences for consuming seagrasses and found juveniles had medium preference for both *E. acoroides* and *H. uninervis*, and adults had low preference for *E. acoroides* and medium preference for *H. uninervis.*

There are also other numerous fish species found in the seagrass. A UOG technical report by Randall et al. (1975), (results reprinted in (Jones et al. 1975)), compiled past records of fish found in seagrass areas of *E. acorodies* and *H. uninervis* of Cocos lagoon and found fish from 13 different orders were observed including wrasses, goatfish, rabbitfish, parrotfish, and others. Another later survey by Randall and Sherwood (1982) including transects and observation of seagrasses in Cocos Lagoon also reported sightings of some similar species as well as many other species not reported in Randall et al. (1975). Full lists can be found in appendix A. Randall and Sherwood (1982) also reported that fish density was variable, and noticeably higher in *Halodule* beds than *Enhalus* beds, mostly the result of rabbitfish in the *Halodule* beds, and overall fish densities were not significantly different compared to the 1974 study. More recently, DAWR has run seagrass surveys between the 1990s and last decade, for fish in different areas around the island including Achang Bay, Piti, and Pago Bay which can also been found in appendix A (provided by Brent Tibbatts 2020). These surveys have shown goatfish, butterflyfish, emperorfish, wrasses, and scarids mostly <15cm in length. The diversity of fish in *E. acoroides* likely supports fisheries, however more research would be needed in Guam to more precisely understand that role.

Although less well documented, and difficult to find since many can be small and cryptic, invertebrates can also be found in Guam's seagrass beds. Guam has a rich diversity of sea cucumbers, Michonneau et al. (2013) reported *Bohadschia marmorata* in seagrass beds in Piti. The more common sea cucumber, *Holothuria atra,* can also be found in seagrass beds (Kerr et al. 1993). Eldredge (1979) also reported finding the bivalves, *Quidnipagus palatum* and *Ctena* spp. in relative abundance in seagrass beds in Cocos Lagoon. Eldredge et al. (1977) also reported the sea hare, *Phyllaphysia taylori*, as very common on *E. acoroides* blades in Agat Bay surveys. Research has also shown that *E. acoroides* may be a primary food item for the common sea urchin, *Tripneustes gratilla* (Kasim 2009), which was also reported in Cocos lagoon (Hartwell et al. 2017).

c. Guam's seagrass community - epiphytes:

Epiphytes are an important part of the seagrass ecosystem as a food source (see ecosystem services section) and have complex poorly understood potentially positive and negative effects on the health of the seagrass. Epiphytic cyanobacteria have been observed to contribute to nitrogen fixation, and other epiphytes can act as a sink of available nitrogen (Borowitzka et al. 2007). Epiphytic calcareous red algae (also known as crustose coralline algae) can help form sediment (Borowitzka et al. 2007).

There have not been many studies of epiphytes in Guam's seagrasses, and studies can be difficult due to the huge diversity of epiphytic life. The crustose coralline algae *Hydrolithon farinosu* and *Neogoniolithon brassica-Florida* have been reported to be found on *E. acoroides* near Pago river mouth and reef channel (Tsuda 2004). Other studies of seagrass in the Indo-Pacific might help provide information about the epiphyte community. Purvaja et al. (2018) surveyed *E. acoroides* in Palk bay (between Sri Lanka and India) and found epiphyte communities included Polychaeta (segmented worms), Nematoda (round worms), Harpacticoida (copepods), Navicula (diatom), Foraminifera , Gyrosigma (diatom). Other epiphytes could include encrusting sponges, sea anemones, tunicates, and Bryozoans (Purvaja et al 2017). Hartati et al. (2018) observed the tip, middle, and base of seagrass blades and found 32 different genera of microalgae in just 20 samples of *E. acoroides*. A study of *E. acoroides* in Papau New Guinea found that 66 algal species, mostly in shallower locations, and epiphytes contributed 3-17% of the total annual mean above ground plant biomass or 2-9% of the total above ground production. (Brouns and Heijs 1986). However epiphyte communities can be transient and change between seasons (Borowitzka et al. 2007). Epiphytes will also vary depending on the location on the leaf, environmental conditions, and species of seagrass (Borowitzka et al. 2007). Further research on Guam's seagrass epiphyte communities can help us better understand how seagrass might serve as food, and how epiphytes might affect the ability for seagrasses to still get sunlight or oxygen.

d. Guam's seagrass community –macroalgae:

Macroalgae can also be an important feature of seagrass beds. In some areas, such as Florida Bay and Everglades, many different green, red, and brown, fleshy, and calcareous macroalgae species live closely and interspersed among seagrass bed (Kruczynski and Fletcher 2012). Although to a lesser extent, Randall et al. (1975) also reported within "Biotype 1E", which was dominated by *Enhalus acoroides*, many other marine plants including other red, brown, and green macroalgae. Due to its larger size, *E. acoroides* likely is less impacted by macroalgae overgrowth compared to *H. uninervis* (Camacho and Houk 2020). Macroalgae might outcompete seagrasses in areas with high nutrient input such as near mangrove islands where birds roost (Collado-Vides et al. 2007, Kruczynski and Fletcher 2012). Phase shifts from seagrass to algae dominated systems is often seen as a sign of seagrass degradation (Unsworth et al 2015). As seagrasses degrade to sandy or algae dominated systems, colonization of sediments by bioturbators, deposit feeders, and burrowers that can prevent reestablishment of seagrasses after loss (Cadier and Frouws 2019). More monitoring of macroalgae, seagrass density, and seagrass species, will help determine whether seagrass habitats are degrading.

III Seagrass decline globally and in Guam:

A global review of 215 studies found that seagrasses have lost 30% of their past global extent since 1879, and suggested that the rate of loss may be increasing, from previously 0.9% per year before 1940 to now 7% a year since 1990 (Waycott et al. 2009). The Western Pacific has been historically understudied, but Short et al. (2014) also found declines and changes in species in composition (from climax species to pioneer species in locations where there was large losses) in 10 sites from the Federated States of Micronesia, Republic of Palau, Indonesia, Australia, Philippines, Malaysia, and Australia. *E. acoroides* in particular declined in 4 of the 6 study sites it was present, including in Palau and a pristine site in Kosrae with no detectable stressor. In Kosrae, *E. acoroides* was replaced with C.

rotundata and T. hemprichii (Short et al. 2014). These records of *E. acoroides* declines despite obvious local stressors suggest this species is sensitive, might self-shade, and may be susceptible to climate change impacts (Short et al. 2014). A more extreme measure to consider in the future if *E. acoroides* continues to decline due to climate change, is to introduce other more resilient species that are found in the pacific. Guam also has experienced seagrass losses, below is a time line of studies that included some measure of seagrass coverage:

<table>
<tr><th>Study</th><th>Year(s) (of data not publishing date)</th><th>Method used</th><th># of sites</th><th>Whole island area estimate</th><th>Change found</th></tr>
<tr><td rowspan="2">Burdick (2006)</td><td>2001-2004</td><td>IKONOS imagery (0.82-m resolution) & ground truthing</td><td>Whole island/ 1049 ground validation points/241 accuracy assessment points</td><td>310 ha ($3.1\ km^2$)</td><td>N/A</td></tr>
<tr><td colspan="5">Additional notes: Seagrass cover was separated into 3 bins, 10% - <50%, 50% - <90%, and 90%-100%.</td></tr>
<tr><td rowspan="2">Pinkerton et al. (2015)</td><td>2009, 2011, 2013</td><td>10 Random quadrats (50 x 50 cm)</td><td>10 sites around the island</td><td>N/A</td><td>No changes between 2009-and 2013 on an island level, changes on more local scales</td></tr>
<tr><td colspan="5">Additional notes: More dramtic downward trends were found at adelup and Ga’an and dramatic increasing trends at Nimitz and East Achang. Lowest cover was at Merizo and Achang all three years.</td></tr>
<tr><td rowspan="2">(Raymundo et al. 2018)</td><td>2018?</td><td>GPS used while walking the perimeter</td><td></td><td>N/A</td><td>N/A</td></tr>
<tr><td colspan="5">Additional notes: Report also has density (shoots/sqm), blade length (cm), and mean % epiphyte cover from .25 m^2 quadrat data laid ever 10m across the width of the bed. Both E. acoroides and H. pinifolia were recorded</td></tr>
<tr><td rowspan="2">(LaRoche et al. 2019)</td><td>2003/2004 vs 2015</td><td>Worldview-2 images (0.46-m resolution) compared with Budrick 2005 IKONOS imagery & ground truthing</td><td>For 2015 ground truthing, GPS was used while walking the perimeter of Leon Guerrero, Achang East, Piti and Agana West.</td><td>266 to 184 ha</td><td>22% decrease</td></tr>
<tr><td colspan="5">Adiditional details: Out of the nine sites around southern Guam measured, six declined in seagrass, two had moderate increases (by 20 and 27%), and one a minimal increase (3%). Losses at the 6 sites had a large range, with the lowest being 11% at Pago, and the highest sites being at 94% at Cocos lagoon, 82% at Agana East.
*technically based on 92% of the seagrass beds on island, not the whole amount identified</td></tr>
</table>

Maps showing areas outlined by the various studies can be found in Appendix B. Additionally, a public google maps with compiled observations from UOG technical reports and other studies can be found at https://www.google.com/maps/d/u/0/viewer?mid=164m56BrfmNnZCpjip_TzfKg4H9hbDOjP&ll=13.368161578219793%2C144.71929029999998&z=11

The cause of Guam's seagrass decline is uncertain. It is likely that trends in seagrass and any loses are driven by multiple factors including natural variation, changes in community dynamics, pollution, climate change, and potentially other unknown factors.

IV. Natural Variables and Stressors:

Tropical seagrasses live in a naturally challenging environment. Particularly in Guam, seagrasses live in very shallow water where they are exposed to high UV radiation and drastic temperature fluctuations. Natural variations due to tidal variations, solar radiation, and daytime temperature regimes can affect the extent of seagrass beds (Unsworth et al. 2012). Unsworth et al. (2012) found that seagrass extent in a 250 ha *E. acoroides* bed in Australia that had declined by 54% over 11 years was significantly negatively correlated with tidal exposure and solar radiation. The size of the lagoon, amount of area with shallow water suitable for seagrasses can also affect the extent of seagrasses (Houk and van Woesik 2008).Living nearshore, seagrasses are also exposed to varying salinities dependent on input from rivers and rainfall, and must anchor themselves in wave energy. A major contributing cause to massive seagrass die offs in Florida Bay was hypersalinity events due to the rerouting freshwater input from the everglades (Kruczynski and Fletcher 2012, Johnson et al. 2018).

Typhoons and storms are another natural stressor, although their frequency or intensity might be changing due to climate change (Knutson et al. 2010). Some common ways typhoons can impact seagrasses include: (i) direct physical damage, (ii) resuspending sediments, which can increase turbidity for relatively long periods, (iii) changes in salinity due to increased rainfall (Yang and Yang 2014). However there is a lot of variation in how seagrasses can be impacted by storms. Australia lost over 1000 km^2 of seagrass after two floods and a cyclone event when seagrasses died due to being uprooted in shallow areas, and light deprivation caused by high turbidity in deeper waters (Preen et al. 1995). In contrast, seagrasses in other areas have survived intense storms. For instance, *Thalassia testudinum* seagrass bed communities and structures were unaltered in a study in the Caribbean after Hurricane Irma, a category 5 storm (James et al. 2020). experienced This difference is likely due to differences in the depth, since the water column helps buffer the energy (Kim et al. 2015). Another study of typhoon impacts showed more nuanced impacts, the typhoon reduced seagrass biomass but not density, and that out of three designated areas, two were reduced in seagrass coverage after the typhoons, and one actually increased (Yang and Huang 2011).

Hydrodynamics also influence seagrass growth, survival, distribution, and reproduction, with an intermediate flow rate being optimal for growth (Nelson and Brown 2009). Lower flows tend to reduce self-shading from canopy formation, reduce the amount of sediment resuspension and increase further settlement of particles, and allows greater potential for nutrient absorption due to the increased residence time of water (Koch 2001). However faster flows with lower water residence time may decrease exposure to toxins, reduce deposition of sediment on leaves, and reduce the formation of boundary layers that limit diffusion (Koch 2001). The last major typhoon in Guam was hurricane Omar in 1992. Research using satellite imagery at the time may be able to determine if there were impacts from past storms in Guam. Since Guam's seagrasses are so shallow, they are at greater risk to storm damage. Researching the reproductive capabilities and seed bank storage of seagrasses in Guam will help determine if they are able to bounce back from future storms.

V. Anthropogenic stressors:

a. Disturbance by trampling and watercraft:

Guam's large tourism industry includes snorkeling and diving experiences in shallow areas that may require passing seagrasses to get to the coral reefs and result in trampling. The impact of trampling seagrasses is not well understood. A four month study of replicating trampling at different intensities for a seagrass species in Puerto Rico showed that trampling may reduce seagrass biomass above and below ground, especially for seagrasses growing in soft substrates (Eckrich and Holmquist 2000). The highest intensity of trampling was 50 times per month, a little less than 2x a day. A shorter term study of three weeks in Indonesia also found physical damage to seagrasses in the form of detached leaves and uprooted grasses (Nurdin et al. 2019). This study also suggested that other factors such as the size of the person who is trampling may influence the amount of the damage, finding that the seagrass recovered faster to control densities in plots that were trampled in children than adults (Nurdin et al. 2019). Preventing trampling in more heavily used areas such as those that receive tourists may help protect our seagrasses.

Tosatto (2013) reported that community leaders identified commercial jet-ski operations in East Agana Bay and removal of intertidal green seaweed had major negative impacts on marine environments. The impact of boats on seagrasses have focused on propeller scars and anchor impacts, which can physically tear seagrasses apart or from soils. However, the impact of jet skis or wakes in seagrass is less understood. A study of boat generated waves showed that the waves resuspended small amounts of sediment which redeposited in a few minutes (Koch 2002). The suspended sediment may increase turbidity and reduce availability of light for photosynthesis (Browne et al. 2017). Koch (2002) also found the waves also caused porewater (water in between sediment particles) pumping, which increased the concentration of ammonia in the water column. Another found that seagrass epifauna were displaced by boat wakes, with five times lower abundance of amphipods and polychaetes in areas that were disturbed compared to undisturbed control areas (Bishop 2008). The study also found that although these invertebrates are mobile, they did not completely recolonize the impacted area within 1 hour, so repeated areas that experience waves could have long term depressed invertebrate populations, which may cause ecological implications (Bishop 2008). The effect of jet skis on seagrasses is an area of needed research. Jet skis using jet propulsion, pump water into the jet-ski and then back out. Potential research questions may address whether jet skis may suck up seagrass seeds and disperse or damage them, the impact of any resuspended sediments or nutrients, and any impacts on epiphytes or epifauna.

b. Sediment resuspension and burial

Although one of the benefits of seagrasses is their ability to trap particles and prevent sedimentation of coral reefs, seagrasses can also be susceptible to being smothered or buried by sediment resuspension or inputs. Changing sediment dynamics, either burial or erosion of sediment, may be caused by strong storms events, changes in land use practices, or from coastal development projects that involve dredging or the creation of permanent structures (Cabaço et al. 2008). Different measures such as siltation curtains, turbidity thresholds, modeling of sediment plumes tidal dredging, and other techniques can help reduce the impacts of dredging in coastal development projects (Erftemeijer and Lewis III 2006). Sediment in the water can be harmful to seagrasses by increasing the turbidity and reducing the photosynthetic capabilities of seagrass (Cabaço et al. 2008). If seagrasses are buried by sediment it also reduces the amount of leaf area that can photosynthesize (Cabaço et al. 2008). Additionally, if the sediment is organic or anoxic, it can expose leaves or meristems to anoxic conditions of sulfide toxicity (Cabaço et al. 2008). Dredging that moves sediment or changes hydrology and causes erosion can also be harmful by exposing underground tissues to drilling organisms and waves (Cabaço et al. 2008).

The amount of light reaching seagrass is affected by water color, concentration of suspended solids, phytoplankton, sediment deposition, and epiphyte cover on the leaf (Erftemeijer and Lewis III 2006). Larger slower growing seagrasses with large carbohydrate reserves are more likely to be able to survive longer periods with high turbidity, however smaller opportunistic species are more likely to bounce back and return to their original state after a disturbance (Erftemeijer and Lewis III 2006, Cabaço et al. 2008). In southern Florida, seagrasses need 10% of light, much higher than many plants such as phytoplankton that only need 1% (Kruczynski and Fletcher 2012). Although seagrasses in Guam are in very shallow water, there is high turbidity in seagrasses areas of southern Guam that could reduce photosynthesis. The amount of photosynthesis, and by extension likely the amount of light, can be reflected in different δ13C (ratio of carbon-13 to carbon-12 isotopes) (Kruczynski and Fletcher 2012). Seagrasses preferentially uptake the lighter carbon-12 isotope, however when the source of carbon is exhausted of carbon-12 isotopes due to high photosynthetic rates, carbon 13 is used (Kruczynski and Fletcher 2012). Comparing the δ13C of seagrasses and the source can help determine the recent photosynthesis/light levels (Kruczynski and Fletcher 2012)

It can be difficult to separate out the impacts of sedimentation of leaves and high turbidity (Erftemeijer and Lewis III 2006). In general seagrasses with high epiphyte loads are more impacted by sedimentation since the epiphytes can gather even more sediment (Erftemeijer and Lewis III 2006). Benham et al. (2016) found that in the Great Barrier Reef region, both shading and burial affected growth rate of Zostera muelleri and Halophila ovalis, however burial by greater than 10mm reduced growth rate by a greater amount than shading. Seagrasses have varying responses to burial, the most common species in Guam, *E. acoroides,* has been found to very resilient to burial. (Bach et al. 1998, Cabaço et al. 2008) and has been found to survive in areas with the most siltation where other species could not survive (Terrados et al. 1998), likely due to its large size (Cabaço et al. 2008). However *H. uninervis* is a smaller seagrass, with a moderate level of susceptibility to burial (Bach et al. 1998, Terrados et al. 1998). Burial by large amounts of sediment (8cm and 16cm) was found to cause an initial reduction in shoot density, followed by a recovery and changes in morphology (greater branching frequency and internode length) (Cabaço et al. 2008). Another research question may be to consider if sedimentation or burial of *H. uninervis,* a smaller pioneer seagrass, reduces *H. uninervis* growth and affects expansion or recovery of seagrass areas.

c. Sulfide toxicity:

Microbes break down organic matter through respiration. Microbes in waterlogged and submersed anoxic soils must utilize other terminal electron acceptors for respiration aside from oxygen, including sulfate which leads to the production of sulfur compounds, H_2S, HS^- and S^{2-}, all of which are toxic to plants (Lamers et al. 2013). These reduced sulfur compounds are potent phytotoxins because they can affect the ability of the cytochrome c oxidase enzyme in the mitochondria to produce energy and inhibit photosynthesis by affecting the photosystem II (Lamers et al. 2013, Dooley et al. 2015). Seagrasses are relatively hardy compared to other plants and are capable of surviving at thresholds of 2000-6000 µmol/L, although sublethal impacts to growth have been observed in some species at 200-500 µmol/L (Lamers et al. 2013).

The amount of sulfide threatening seagrasses depends on processes that occur within the seagrass and in its environment. When seagrasses photosynthesize oxygen is generated and brought down to the underground tissues and surrounding sediments via their lacunae system, a process in wetland plants also known as radial oxygen loss (Lamers et al. 2013). The addition of oxygen to the sediment can help reduce the amount of sulfide in the surrounding sediment. However, if for any reason there is less light or photosynthesis, less oxygen is released by seagrass roots and sulfide can diffuse into the roots and into photosynthetic tissues (also known as sulfide intrusion) (Lamers et al. 2013). In general seagrasses are at more risk of sulfide intrusion during the night when anoxic conditions are more likely to occur (Lamers et al. 2013). Experimental shading to show reduced light conditions (mimicking other low light conditions like high turbidity) and experimental removal of photosynthetic tissues were demonstrated to show increases in sulfide concentrations (Lyimo et al 2017). Smaller seagrass species are at particular risk since sulfur can more easily travel from the roots to inside leaves (Lamers et al. 2013). Once Inside the plant the sulfur can be metabolized by different enzymes into less toxic organosulfur compounds such as the amino acid cysteine (Lamers et al. 2013).

Other conditions external to the seagrass will affect their vulnerability to sulfide toxicity. Metals like iron can sequester sulfides, and form other non-toxic compounds such as FeS and FeS_2 (pyrite) (Lamers et al. 2013). Experimental additions of iron to *Posidonia oceanica* has been shown to counteract the impacts of sulfide (Lamers et al. 2013). Discharge of iron rich groundwater into wetlands can also help protect plants against sulfide toxicity (Lamers et al. 2002). However when the iron is bound and precipitates out as FeS or FeS_2, into the sediment, it becomes unavailable to be absorbed as a nutrient by seagrasses and used for important processes such as chlorophyll synthesis (Chambers et al. 2001). Pyrite in particular is likely to stay in that form and is considered a permanent burial of sulfides (Schippers and Jørgensen 2002). Additionally sulfides can be released into the atmosphere. H_2S is a gas and can be released into the atmosphere or can be transformed into other compounds such as dimethylsufide that can be released into the atmosphere (Lamers et al. 2013).

Other organisms in the seagrass beds can also impact sulfide concentrations. Different bacteria in the rhizosphere can also oxidize sulfur or alter the toxicity of sulfur compounds (Devereux 2005, Lamers et al. 2013). Oxidation of sulfate by microbes in the sediment will also generate acid which can slow down sulfate reduction and provide another means of protection (although too much acid also can cause NH4+ toxicity). The presence of infauna and bioturbation of sediments can also introduce more oxygen in sediments. *Lucinid* bivalves are present in temperate and tropical seagrass beds and contain beneficial sulfide oxidizing symbionts that have been experimentally shown to greatly reduce sulfide concentrations and help promote seagrass growth (Lamers et al. 2013, Chin et al. 2020). The chemistry of sediments is complicated and can have nuanced effects on seagrass. Sanmartí et al. (2018) found that *Cymodocea nodosa* reduced root branching in sediments with high amounts of organic matter, resulting in fewer *Lucinid* clams, which reduced the amount of protection provided against sulfide intrusion. Additionally, despite the toxicity of sulfide, sulfate reduction by bacteria can actually be helpful to break down organic matter and make other nutrients more available (Lamers et al. 2013). A study of seagrasses in Thailand showed sulfate reduction had a minimal role in providing nutrients, except in one case where it provided 81% of the phosphate (PO_4^{3-}) (Holmer et al. 2001).

Sulfide toxicity has been more heavily studied in temperate ecosystems but research shows similar results for tropical seagrasses. Holmer et al. (2001) studied mixed species seagrass beds in Thailand and found evidence of sulfide intrusion, and among the four species, the greatest sulfide levels were found in the belowground tissues of *E. acoroides.* Higher sulfide reduction rates correlated positively with below ground biomass, suggesting that the microbial activity was being stimulated by the root rhizosphere. (Holmer et al. 2001) also found that low iron levels in seagrass and high concentrations of pyrite in sediments, suggestion potential iron limitation due to sequestration of sulfides by iron.

Sulfide toxicity may combine with other stressors to result in more negative effects. A study of Florida Bay's tropical seagrass beds found that *T. testudinum* was tolerant to high levels of sulfide exposure for almost a month, and unaffected by high temperature and high salinity treatments as a separate treatment, however the combined stressors caused mortality (Koch and Erskine 2001). High salinity may cause greater oxygen consumption by the seagrass, making them less resilient to sulfide intrusion (Johnson et al. 2018). These three factors have been implicated in large seagrass die-offs in the past (Kruczynski and Fletcher 2012). As temperatures rise due to climate change, not only may seagrasses be stressed by warm temperatures, sulfate reduction rates may increase and increase risk of sulfide toxicity (Koch et al. 2007).More research would need to be conducted to determine if sulfide toxicity is affecting Guam's seagrasses by testing seagrasses for compounds indicative of sulfur intrusion and measuring sediment concentrations. However measuring sulfide can be difficult and requires careful sampling and the use of specialized electrodes or gas chromatography (Lamers et al. 2013).

d. Nutrient Inputs and Pollution

Excessive run-off of nutrients is another potential threat to seagrasses, which may cause direct physical stress due to ammonium toxicity, or indirect stress due to reduced light availability from the increased growth of plankton, macroalgae, and epiphytes (Burkholder et al. 2007). In order to prevent toxic accumulation of ammonia, seagrasses shunt carbon to increase amino acid synthesis, which could potentially prevent that carbon from being used for other important uses (Burkholder et al. 2007). Nitrogen pollution has been implicated in declines of the seagrass *Z. marina* partially because seagrasses are vulnerable to attack by the slime mold *Labyrinthula spp.*(Sullivan et al. 2013) Since carbon is used for amino acid synthesis to prevent ammonium toxicity, it may redirect carbon that would be used for the creation of other important compounds that would deter infection such as phenolics and anti microbials (Burkholder et al. 2007, Sullivan et al. 2013).Whether increased growth of epiphytes can interfere with nutrient uptake or act as competitors is something that needs further study (Romero et al. 2006). Addition of nutrients can also influence the concentration of toxic sulfide compounds. Eutrophication can spur the growth of mats of filamentous algae, which can reduce the amount of oxygen input into sediment, and cause greater sulfide toxicity (Holmer and Nielsen 2007).

Phase shifts from seagrass dominated systems to macroalgae (especially for shallow environments) and phytoplanton are of concern (Burkholder et al. 2007, Collado-Vides et al. 2007). There is evidence of a seagrass to macroalgae transition in Saipan that has been attributed to greater human development (Houk and Camacho 2010). Over a period of years between 2005 to 2008 In areas where the watershed and population size were low, Houk and Camacho (2010) found that macroalgae and *H. uninervis* coverage had an inverse seasonal relationship, with *H. uninervis* cover roughly peaking around June and decreasing in the fall and winter. However, for areas with high human population, Houk & Chamcho (2010) found the cycle did not return to seagrass. Pollution was part of a larger number of factors that controlled seagrass cover, with variation being hierarchy controlled by winter storm disturbances, land-based pollution, and seasonal environmental cycles in that order (Houk and Camacho 2010). Another study of Saipan lagoon over a longer period of 10 years from 2006 to 2015 Camacho and Houk (2020) found similar results, with macroalgae growth being explained by a mix of seasonal patterns, watershed sizes, and huamn development.

Although eutrophication is of concern, seagrasses rely input of nutrients supplied by run-off or consumers like fish or birds (Powell et al. 1991, Allgeier et al. 2013). Nitrogen or phosphorus limitation in tropical seagrasses are common (Burkholder et al. 2007, Kruczynski and Fletcher 2012). LaRoche et al. (2019) found relatively low ratios of N:P in seagrasses at various sites in Guam suggesting N limitation. Pinkerton et al. (2015) studied seagrass coverage and δ15N values from 10 sites around central and southern Guam, found that seagrass were primarily using sewage derived N. There seemed to be neutral impacts, δ15N did not correlated with seagrass cover or growth (Pinkerton et al. 2015). Unlike their findings for *H. uninervis* in Saipan described above, Houk and van Woesik (2008) found that *E. acoroides* actually had a weak positively correlated relationship with human development.

Directly measuring water for nutrient content is ineffective since nutrients are taken up by plants or adsorb to sediment, and do not remain in the water for long (Burkholder et al. 2007, Govers et al. 2014). A study of seagrass in Florida showed that seagrass biomass correlated with watershed nitrogen inputs, not with water column nutrient concentrations. Instead, seagrasses themselves are considered bioindicators that can reveal longer term (days to weeks) trends of water quality (Kruczynski and Fletcher 2012). Lower ratios of carbon to nitrogen (C:N) and carbon to phosphorus (C:P) indicate greater availability of nitrogen and phosphorus. Ratios may be compared between pristine and polluted areas. Although it varies by species, the average the C:N:P for seagrasses is 550:30:1, and deviations can reveal information about the supply of nutrients. Generally, a N:P ratio of less than 30:1 in seagrasses indicates nitrogen limitation, and a ratio greater than 30:1 means the seagrass is phosphorous limited Alkaline phosphatases (APAs) can also be an indicator of nutrient levels (Burkholder et al. 2007). In the seagrass *Posidonia oceanica* APAs were found to decrease in response to the addition of phosphates and nitrates (Martínez-Crego et al. 2006). However, Martínez-Crego et al. (2006) also suggested that APAs be used with other bioindicators since the effect on APAs was not evident in the winter season, and may also vary with depth and sediment characteristics. In some cases length might change in response to nutrient input, however this could be due to other factors such as light availability (Burkholder et al. 2007).

e. Overfishing and changes to the seagrass community

Seagrasses and the community living within seagrasses both affect each other. Epiphyte overgrowth is often attributed to nutrient pollution, however overfishing of epiphyte consumers is also an issue (Heck Jr and Orth 2007). A herbivore exclusion experiment found that seagrass epiphytes supported the diet of small invertebrates such as juvenile shrimp and amphipods (Ebrahim et al. 2014). When these small grazers were excluded, epiphyte biomass increased 233% (Ebrahim et al. 2014). The effect of small grazers reducing epiphyte biomass and increasing seagrass biomass has been observed in other temperate and subtropical systems (Scott et al. 2018). Analysis of five fisheries closures in Kenya (ranging from 5 to 42 years since closure) was correlated with greater benthic coverage of seagrass (McClanahan 2014). Grazers on other plants in the seagrass ecosystem may also impact seagrasses. In Sweden, Baden et al. (2012) found that overfishing likely caused an overgrowth of filamentous algae which can compete with seagrasses for nutrients and space, and cause hypoxia and sulfide poisoning.

Overharvesting of sea cucumbers could also have impacts on seagrass. Wolkenhauer et al. (2010) experimentally excluded sea cucumbers (*holothurian scabra)* and found greater losses of seagrass biomass, and higher amounts of organic matter and benthic microalgae compared to control plots with natural densities of sea cucumbers. Sea cucumbers and may help reduce the impacts of nutrient pollution however they may also increase bacteria and bacterial consumption of oxygen in sediments (MacTavish et al. 2012). However another study by Houk et al. (2013) in Yap found a negative correlation between *Holothuria atra* and seagrass condition (condition was defined by the ratio of seagrass cover to macroalgae cover, and evenness of macroalgae taxa). However, their study location in Yap had net input of nutrients from offshore to inshore and sparse watershed development, which is different from Guam's coastal lagoons. The role sea cucumbers play in recycling nutrients needs further study.

f. Other Land Based Sources of Pollution:

In addition to nutrient and sediment pollution, other chemical agents can wash into seagrass beds, including antifouling compounds, herbicides, pesticides, heavy metals, and other petrochemicals (Ralph et al. 2007). The impact of these chemicals will depend on residence times and amount of flushing in the area. A more in depth discussion of these contaminants can be found in Ralph et al. (2007). More research in Guam and collaboration with GEPA would be needed to determine if any of these types of chemical pollutants are impacting seagrass beds.

g. Climate change and ocean acidification:

Waycott et al. (2011) estimated seagrasses in Guam are expected to decline due to climate change , with estimates of 5-20% by 2035, 5-35% by 2100 with more conservative emission projections, and 10-50% for higher emission projections. The exact modeling was unclear, however Waycott et al. (2011) generated estimates using factors such as light, temperature, rainfall, sea level rise, and storm impacts. The impacts of climate change on seagrasses are complex and not well understood. Warmer seas may cause stress during extreme heat events, increase the growth rate of seagrasses, or the growth rate of competitive algae (Björk et al. 2008). Similarly, increased CO_2 in water may increase seagrass photosynthetic rates or photosynthetic rates of epiphytes and other competitors (Björk et al. 2008). Sea level rise may cause shallow water species to receive less light. *E. acoroides* also is limited to shallow waters due to pollination occurring at the surface, which may also mean that seagrass may die off in some areas, and migrate close to shore in others if sedimentary conditions are correct. Changes in rainfall may also affect salinity or cause more inputs of land based sources of pollution (Björk et al. 2008, Waycott et al. 2011). Ocean acidification is relatively less of a threat to seagrasses which actually naturally increase pH locally (Björk et al. 2008). Rasheed and Unsworth (2011) studied past responses by seagrass to natural climate variations in an effort to predict future climate change impacts. Rasheed and Unsworth (2011) found that *H. uninervis* and *H. ovalis* in Australia and found that elevated temperatures and reduced flow from rivers were correlated with periods of lower biomass. Studying how Guam's seagrasses have responded to past climate variation could provide insight into the future. Moving forwards managers are recommended to reduce human impacts and improve water quality, identify and prioritize areas that are of low risk to climate change impacts, and maintain connectivity to other habitats (Björk et al. 2008).

VI. Conservation recommendations and knowledge gaps:

*For future reference, a new review paper, “Seagrass ecosystems of the Pacific island countries and territories: ecology, ecosystem services and threats" is currently in editing, to be published in a special edition of Marine Pollution Bulletin (pers comm. Dr. Roy Tsuda).

- *E. acoroides,* the most abundant seagrass, is a very slow growing seagrass that can take an estimated 10 years to recover. It grows and recovers through sexual reproduction so connectivity between different areas is important to allow male pollen to meet female flowers. Positive feedback loops may also make areas hard to recover if they have shifted to algae or sand dominated areas. Therefore emphasis should be placed on protecting existing areas
    - There is a lack of knowledge on *E. acoroides* flowering patterns and reproductive output
- Much more research on human impacts and climate variation is needed to better understand the causes for decline. Reaching out to work with other seagrass experts and research labs could help evaluate seagrass condition.
    - Are there correlations between seagrass extent and past variations in climate? How much variation can be attributed to “natural variation” and climate change as opposed to local stressors that can be more readily addressed by local management? How can this inform how *E. acoroides* will respond to future climate change?
    - Are seagrasses being stressed by sulfide intrusion?
        - Particularly in areas where photosynthesis might be limited (by high turbidity or high epiphyte coverage) or where there is organic matter input and anoxic conditions.
    - Are seagrasses being stressed by low light due to turbidty or epiphyte cover?
    - Are seagrasses threatened by lack of genetic diversity and connectivity which helps support better survival and growth?
        - How do Guam’s currents affect potential dispersal of pollen and flowers?
- Need to better understand seagrass resiliency
    - Where is *H.uninervis,* is it acting as a fast growing pioneer species here?
    - Are there *H. uninervis* seedbanks?
    - What are reproduction and dispersal patterns like?
        - Community monitoring help assist in looking for seagrass flowers.
- Involving the local community can help minimize threats and increase knowledge
    - Outreach on the importance of seagrasses and the potential harmful impacts of trampling may also help
    - Community monitoring could help keep an eye out for seagrass flowers
    - Stable isotope studies using fin clips gathered from the fishing community could determine how different species might use seagrass areas
- Guam has a relatively low amount of seagrass diversity compared to other areas in the indo-pacific. Have other seagrasses existed here historically? If *E. acoroides* beds are a sensitive species to climate change (similar to how many acroporid corals are sensitive), should we be thinking about more extreme measures such as introducing other seagrass species?

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MANGROVE BIOLOGY AND ECOLOGY

Contents:

Table 2. Historical Records of Mangrove Species

Vegetation type:

ocean facing- grows on the most seaward edge immersed in sea water very often

riverine mangroves- grow along rivers and in more freshwater environments

coastal strand- grows near the coast, tolerant to coastal conditions (salt and salt spray, wind, sun, etc.) but grows above the high tide line

Species	**Vegetation Type as described by Adrienne Loerzel (pers comm. 2020)**	**Notable Identifying Features**	**(FAO 2005)**	**(Mueller-Dombois and Fosberg 1998)**	**(Ellison 1995)**	**(Scott 1993)**	**Fosberg (1975) as cited by (Lugo 1990)**	**(Fosberg 1960)**	**wilder (1976) and stone (1970) as cited by (Amesbury 2007)**
Acrostichum aureum	n/a	Mangrove associate- fern	x			x			
Avicennia alba	ocean facing	Pencil roots	x		x				x
Avicennia marina	ocean facing	Pencil roots	x		x	x	x		
Avicennia marina var alba	ocean facing	Pencil roots		x					
Barringtonia racemosa	coastal strand	Distinct white/pink flowers						x	
Bruguiera gymnorhiza	ocean facing	Knee roots	x	x	x	x	x	x	x
Dalbergia candenatensis	n/a	Mangrove associate- vine					x		
Derris trifoliate	n/a	mangrove associate- vine					x		
Excoecaria agallocha	*can also be found upland- may not be	Laterally spreading roots	x		x				
Heritiera littoralis	riverine forest	Buttress Roots	x	x	x	x		x	
Hernandia sonora	coastal strand	Broadly ovate leaves and white flowers						x	
Hibiscus tiliaceus	coastal strand	Yellow and orange flowers				x		x	
Lumnitzera littorea	ocean facing	Red flowers	x	x	x	x	x	x	x
Nypa fruitcans	riverine forest	Palm	x	x	x	x	x		x
Rhizophora apiculata	thin prop roots	Prop roots	x		x	x			x
Rhizophora mucronata	ocean facing	Prop roots	x	x	x	x	x	x	x
Rhizophora mucronata var. stylosa	ocean facing	Prop roots					x		
Rhizophora stylosa	ocean facing	Prop roots	x		x				x
xylocarpus mekongensis	n/a	Prop roots							
Xylocarpus moluccensis	ocean facing, riverine, and upland	Plank roots	x	x	x	x	x	x	x
		Total species reported:	12	7	10	10	9	8	8

I. Mangrove species found in Guam:

a. Past records:

Guam has several mangrove species, although the records vary due to what surveyors consider a mangrove, or a subspecies. Some species are only mildly tolerant of saltwater and are rarely flooded by saltwater during only the highest of tides. Fosberg (1960) mentioned *Barringtonia racemosa* in a discussion of mangroves and its ability to survive in tidal channels, but also stated that it is not exclusively found in mangrove swamp areas, which may not qualify it as a mangrove (see more about criteria for "true mangroves" in the introduction section).

Nypa fruticans was introduced into Guam to help prevent erosion and for its usefulness as thatching material (Adrienne Loerzel pers comm. 2020). There have been a few reports of *N. fruticans* acting as an invasive species in the Niger Delta, reporting that *N. fruticans* outcompetes mangroves and does not provide the same erosion control and fisheries support as mangroves, however these reports lacked quantitative data (Isebor et al. 2003, Numbere 2019).

b. Zonation:

Mangroves follow trends in zonation according to flooding frequency and exposure to salt water. The mangroves in Guam experience a daily tidal variation of about 75-90 cm (Guam Department of Aquatic and Wildlife Resources 2006). One of the earliest accounts, Fosberg (1960), described the zonation of Micronesian mangroves with the following genus based generalizations:

- *Rhizophora*: are found farthest into the marine environment on muddy and silty bottoms
- *Bruguiera, Lumnitzera, Xylocarpus*: found in mangrove areas but not as close to the marine environment in soft and jelly like organic mud
- *Excoecaria:* relatively open areas in mangrove vegetation and rock stand vegetation
- *Nypa:* found in estuarine environments and inner edges of mangrove forests farther from shore in muddy soft soils
- *Acrostichum:* found in open places around the landward edges of mangrove swamps, may be an early colonizer

Waycott et al. (2011) also describes a similar zonation pattern, with *Rhizophora, Bruguiera, Lumnitzera,* and *Avicennia* described as "mid zone" mangroves and "*Xylocarpus, Excoecaria, Acrostichum, Heritiera*, and *Nypa*" as in the landward zone. In a study of mangroves in southern India *Rhizophora, Avicennia, Sonneratia,* and *Kandelia* were found closer to shore, and *Bruguiera* and *Excoecaria* species were found closer to landward edge of mangrove forests (Sreelekshmi et al. 2018). However Sreelekshmi et al. (2018) also observed variation between different areas, and observed *Avicennia* species and *Rhizopohora* species in slightly different patterns of zonation in different locations.

Another way to describe the mangrove habitats of Guam is to organize them into the sub habitats that they would belong to. As shown in the table 2, a discussion with Adrienne Loerzel (2020) about her observations in wetlands and forests in Guam led to the categorization of mangroves into three groups: ocean facing mangroves, riverine, and coastal strand forest. Some vegetation within the riverine or coastal strand forest such as *Acrostichum aureum*, *Heritiera littoralis, Nypa fruticans, and Barringtonia racemosa* can also be described as "mangrove associates" (pers comm. Jessica Gross 2020).

Patterns of succession have not been studied extensively in Guam, and there is not an immediately obvious pattern, as *Avicennia*, *Rhizophora,* and *Bruiguiera* have been observed at the most seaward edge of the fringing mangroves along the southern coast. Other studies in the Indo-Pacific may provide insight. In China, *Avicennia marina* has been observed be the first colonizer, often forming single strand communities until sediments accumulate and other species such as *B. gymnorrhiza* and *R. stylosa* begin to establish (Chen et al. 2016). In Cambodia, a similar pattern was observed, with *A. alba* acting as a pioneer (along with *Sonneratia alba*, a species not found in Guam), and *R. mucronata* establishing in mid succession (Li et al. 2012). Balke et al. (2013) also describes *A. alba* to be a pioneer species, which was faster growing and had higher seedling survivorship compared to *S. alba.* In contrast, Fagherazzi et al. (2017) described successional patterns driving delta progradation in the Mekong Delta, and found that *Sonneratia spp.* were pioneers that then allowed other species such as *A. marina* and *N. fruticans* to establish. The physiology of *A. marina* also suggests it is an early colonizer (Naidoo and Naidoo 2017). *A. marina* exhibits rapid growth of fine roots which supports high nutrient uptake for rapid growth and better exploration of the soil. Tamin et al. (2011) also noted that *A. marina* is shade intolerant (unlike other mid succession species that would grow under an established canopy) and capable of growing in sandy and muddy areas. Tamin et al. (2011) also used the reasoning of *A. marina* being a pioneer species as reasoning behind planting with a seawall for additional shoreline protection.

c. Reproductive Biology:

For brevity, this section with focus on the most seaward mangroves observed in Guam. Extremely detailed descriptions of the morphology of flowers and propagules for *Rhizophora, Avicennia,* and *Bruiguiera,* and other species can be found in Aluri (2013) who recorded observations of mangroves in Andrha Pradesh, India. Aluri (2013) noted that *Rhizophora* is pollinated by wind and insects, and *Avicennia* and *Bruiguiera* by insects. Mangrove reproduction in general is limited by many factors including fecundity of the parent plants, timing of flowering and propagule production, pollination, dispersal factors (eg. currents, length of propagule buoyancy period), retention (eg. getting caught in other nearby mangrove roots) and predation on immature and mature propagules (Van der Stocken et al. 2019). Crabs in particular can affect mangrove density and species distribution and act as a major early bottleneck in recruitment (Lindquist et al. 2009).

A meta-analysis showed that 70% of propagule release occurs during the wet season (Van der Stocken et al. 2017). The length of their buoyant period will depend on the species, and different studies have reported different buoyancy periods (which is also affected by salinity) and instances of refloating (Van der Stocken et al. 2019). The variation in floating periods even among the same species may enable propagules to better colonize different areas and spread out risk (Van der Stocken et al. 2019). Below are some more details for Guam's most seaward mangroves as reported by (Aluri 2013) observations unless otherwise noted:

- *Rhizophora*: Flowering for *R. apiculata* occurs throughout the year, with greater flowering during August-September, and *R. mucronata* from June to November. Propagule production took approximately 60-65 days for *R. mucronata* and 30-35 days for *R. apiculata*. Their larger propagules tend to get trapped by roots more easily than many other genera (Van der Stocken et al. 2019).
- *Avicennia*: For *A. alba* and *A. marina,* flowering began in June after the monsoon season and continued into the end of August. Maturation of propagules takes about 5-6 weeks for *A. alba,* and about a month for *A. marina.* For *A. marina,* described as a pioneer species, there is a high tolerance to salinity, no dormancy period, and resistance to wave action (Van der Stocken et al. 2019)

- *Brugueria*: flowers throughout the year, and more intensely during April-June. The flowers have an explosive pollination mechanism, which were observed to be activated by bees (Aluri 2013) and birds (Mortensen et al. 2008). Maturation of propagules took roughly 30-35 days.

II. The Mangrove community:

a. Overview of the importance of mangrove community ecology:

Although many terrestrial and aquatic organisms use mangroves as a habitat and food source, compared to seagrasses and coral reefs, there has been less research on top-down biotic effects compared to bottom up effects of nutrients, and little characterization of particular "functional groups" within the community. Of the existing studies of biotic effects, emphasis has been placed on understanding leaf and propagule predation. (Farnsworth and Ellison 1997) found that across 42 sites around the world, an average of 28.3% propagules were predated upon mostly by grapsid crabs, coleopterans (beetles), and lepidopterans (butterflies and moths). The predation also nearly doubled the abscission rate of premature propagules (Farnsworth and Ellison 1997). Cannicci et al. (2008) reviewed the impacts of the biotic community on mangroves as described below unless otherwise noted:

- Crabs: play a large role in consuming mangrove leaves (and therefore retaining mangrove production within the mangrove habitat), enriching mangrove materials into more nutrient rich and palatable faecal pellets, aerating the soil, and potentially reducing competition among propagules through propagule predation
- Ants: more studies need to be done, but so far existing studies support the idea that ants help protect mangroves from other herbivores such as scale insects, lepidopterans, beetles, and crabs.
- Gastropods: play a role in consuming mangrove leaves, propagules, and rearranging the sediment as they move, which can impact the microphytobenthos. In the Indo-pacific, *Terebralia palustris* are the primary consumers of mangrove leaves, and also consumes *A. marina* propagules.
- Sponges: although they don't appear to be common in Guam (pers observation), sponges can protect mangroves from burrowing isopods, and support growth through nutrient transfer
- Other attached sessile invertebrates (eg. oysters, barnacles) : affect water quality and can also weigh down roots and break them if heavy enough
- Fish and other vertebrates: sea turtles have been observed in other areas of the world have been observed to eat mangrove propagules, however there is very little research on the effect of vertebrates on the mangroves or mangrove environment

Additional groups not mentioned by (Cannicci et al. 2008):

- Birds: can serve as links between mangrove habitats while traveling between feeding and breeding areas, and have functional roles in transporting nutrients, facilitating pollination, and imposing top down control of insects (Buelow and Sheaves 2015)
- Microbes: mangroves also have a rich diversity of bacteria and fungi that help recycle nutrients, including phosphorus, nitrogen, and sulfur, as reviewed briefly by (Sahoo and Dhal 2009).

b. Guam's mangrove community:

Mangroves serve as a unique transition zone habitat between the terrestrial, freshwater, and marine environment, allowing them to be a habitat for birds, insects, reptiles, fish, and numerous invertebrates (Nagelkerken et al. 2008). Scott (1993) compiled information on wildlife that can be found in Sasa Bay, Achang Bay, and the Atantano wetland mangroves:

- Invertebrates: gastropods (*Littorina scabra* and *Cerihium sp.*), bivalves (*Gararium tumidum* and *Crassostrea cucullata),* crabs (*Uca chlorophtalmus, Uca Volans, Cardisoma carnifex,* and *Scylla serrata*).
- Adult fish including ponyfish (Leiognathidae,), rabbitfish (Siganidae), mojarra (Gerreidae), and milk fish (Chanos Chanos) and mudskippers (Periopthalmus koelreuteri)
- Juvenile fish using mangroves as a nursery: jacks (Carangidae), barracudas (Sphyraenidae), snappers (Lutjanidae), and grouper (Serranidae) used the mangroves as a nursery.
- Reptiles: Hawks Bill sea turtles (*Eretmochelys imbricata)* occasionally coming to mangrove areas to eat sponges off the mangrove roots, native skink (*Emoia caeruleocauda)*
- Brackish/riverine fauna that may be found in the Sasa Rivers: shrimp (*Caridina* sp., *Atyoida pilipes* and *Macrobrachium lar*), tilapia (*Oreochromis mossambicus* and *Tilapia zilli*), gobies (*Awaous guamensis* and *Sicyopterus macrostetholepis*), and the flagtail (*Kuhlia rupestris*).
- Birds: Yellow Bitterns (*Ixobrychus sinensis)* were reported in the Achang Bay Mangroves

Scott (1993) also reported some additional brackish water species such as various shrimp, gobies, and snails may be found in areas that are characterized by lower salinity/more freshwater such the Talofofo River Valley, in addition to higher salinity species such as barracuda, rabbitfish, and snappers. Mangrove crabs (*Scylla serrata*) were reported to live near *N. fruticans* stands.

A more complete inventory of birds in Guam was created by Wiles (2003), which reported at least one sighting of the following species in mangrove habitats in Guam: Yellow Bittern (*Ixobrychus sinensis*), Pacific Reef-Egret (*Egretta sacra*), Black-crowned Night-Heron (*Nycticorax nycticorax),* Pacific Golden-Plover (*Pluvialis fulva*), Mongolian Plover (*Charadrius mongolus*), Black-winged Stilt (*Himantopus himantopus*), Wood Sandpiper (*Tringa glareola*), Wandering Tattler (*Heteroscelus incanus*), Gray-tailed Tattler (*Heteroscelus brevipes*), Common Sandpiper (*Actitis hypoleucos*), Whimbrel (*Numenius phaeopus*), Far Eastern Curlew (*Numenius madagascariensis*), Eurasian Curlew (Numenius arquata), Bar-tailed Godwit (*Limosa lapponica),* Ruddy Turnstone (*Arenaria interpres*), Sanderling (*Calidris alba*), Sharp-tailed Sandpiper (*Calidris acuminate*), Swinhoe's Snipe (*Gallinago megala*), Island Collared-Dove (*Streptopelia bitorquata*). The following also were reported in mangrove habitats at least occasionally but are now extinct: Mariana Fruit-Dove (*Ptilinopus roseicapilla*), Micronesian Honeyeater (*Myzomela rubratra*), Guam Flycatcher (*Myiagra freycineti*), Rufous Fantail (*Rhipidura rufifrons*). More information can be found in (Wiles 2003) regarding whether the species are considered residents or visitors, and frequently they were observed. Bird populations were greatly impacted by the invasive Brown Tree snake, so this list is likely not an accurate representation of bird diversity in mangroves.

There is also evidence that Apra Harbor may be an important pupping ground for scalloped hammerhead sharks, which are listed as critically endangered by the International Union for Conservation of Nature (IUCN). There are numerous anecdotal observations of adult and juvenile scalloped hammerheads in Apra Harbor from scientists at the University of Guam and NMFS, although there have been less observations recently, suggesting that the area may have previously been pupping grounds (NOAA 2015). Other observations also found scalloped hammerheads specifically in the mangrove environment (Loerzel pers. comm 2020.) However it has not been proven that mangroves specifically help enhance the nursery capabilities of the Apra Harbor area for hammerhead sharks. Other elasmobranchs that can be found in the mangroves include stingrays and spotted eagle rays (Jessica Gross pers. comm. 2020). A recent study using environmental DNA (eDNA) to detect scalloped hammerhead sharks in Apra Harbor & Adjacent Nearshore Waters by UOG researcher, Tom Schilis was recently completed and may provide more information in the near future.

III Mangrove Extent and Decline in Guam:

It is estimated that mangroves globally have lost 35% of area between the mid to late 1900s (Valiela et al. 2001). The loss has been driven primarily by conversion of mangrove areas for agriculture and aquaculture (Valiela et al. 2001, Thomas et al. 2017). However, in Guam, developmental threats are more likely to be driven by military expansion or removal of small areas by private landowners. There were extensive impacts on mangrove areas and wetlands for military development in Apra harbor between 1945 and 1950, however the extent of changes have not been historically well recorded (Marshall et al. 2020) and may be hard to quantify since this period was before satellite imagery was available. Mangroves may have existed in other areas of Guam during prehistoric times and changed with changes in sea level. Amesbury (2007) found evidence in the form of arc clams (which grew in mangrove areas), mangrove wood, and mangrove pollen that suggested mangroves previously existed at Tumon Bay before a relative decline in sea level that occurred within the last 4000 years. Pollen evidence suggests that after the decline of mangroves in Tumon, there were increases in mangrove habitats in Southern Guam, with pollen found at Asan, Manenggon, Tipalao Marsh in the Orote Penninsula, and around the Laguas River (Athens 1995, Ward 1995, Amesbury 1999). Other more recent estimates of mangrove coverage include:

Table 3. Records of Mangrove Extent in Guam

Study	**Author and year**	**Estimate**
2018 Integrated Report	(GEPA 2018)	8.1 miles of mangrove shoreline, 7% of total shoreline *shoreline length measurement, not total area
Guam Comprehensive Wildlife Conservation Strategy (GCWCS).	(GDAWR 2006)	2.25 ha
A Directory of Wetlands in Oceania	Scott (1993)	70 ha *further breakdown of observations of mangroves below in table 4
Status report on Pacific Island Mangroves; World Atlas of Mangroves	(Ellison 1999b) as cited in (FAO 2005) (Spalding et al. 1997)	94 ha ***unable to confirm this number in original publication by Ellison (1999b) , seems like citation year does not match title, and (Ellison 1999b) cites 70 ha from Scott (1993). The 94 ha number seems to also appear in Spalding et al. (1997) and generated by estimates from maps created by UOG and USDA

A Directory of Wetlands in Oceania by Scott (1993) recorded details about multiple fresh and estuarine wetland areas in Guam, five of which mentioned mangroves: Sasa Bay, Atantano Wetland, Agfayan River Valley, and Achang Bay, and Talofofo River Valley. Details about these areas are summarized below in table 4.

Table 4. Mangrove Observations from "A Directory of Wetlands in Oceania" Scott (1993)				
Location	**Size of area**	**Species present**	**Other notes about mangroves**	**Other notes about the area**
Achang Bay	~10 ha, 2.3km long, 20-60m wide	*Rhizophora mucronata* and *Bruguiera gymmnorrhiza* as the most common species. *Avicennia marina* is also common, while *Rhizophora apiculata, Heriteira littoralis, Xylocarpus moluccensis* are rare.	Trees about 4-8m tall	only area where *B. gymnorrhiza* is common, some small areas of mangroves were removed
Sasa Bay	30-174m wide strip along edge of bay	*Rhizophora mucronata, Rhizophora apiculata, Bruguiera gymnorrhiza, Avicennia marina and Lumnitzera littorea* are the dominant species A few *Heritiera littoralis* and *Hernandia son*ora grow along the back edges of the mangroves, as does a small grove of *Nypa fruticans* near the Laguas River	Scrubby immature growth, although patches of large trees exist. Mangroves occupy only about 30% of the wetland	Mud sediments are generally 10-60cm deep. This area was altered significantly due to filling, which likely altered water flow
Atantano Wetland- split into 2 halves	Western half contains mangroves, estimated 1.2 km and 500m wide	*Avicennia marina* and *Rhizophora apiculata* are dominant, with *Bruguiera gymnorrhiza* and *R. mucronata* also present. Other common coastal strand and mangrove associate species west of the road include *Hibiscus tiliaceus*, *Dalbergia candenatensis*, *Barringtonia racemosa* and *Acrostichum aureum.* Nypa fruticans is also in the area.	Trees are approximately 3-12m tall, largest area of *A. marina* which grows in a pure grove south of the river.	described as the "most developed mangrove forest in the Marianas Islands" Scott (1993) noted multiple human influences (clearing for crops, crab hunting, industrial sites nearby, and oil spills)
Agfayan River Valley	A narrow strip of habitat following up river about 1.2 km inland. The wetland is about 300 m	*Rhizophora apiculata* and *Bruguiera gymnorrhiza*. *Xylocarpus moluccensis*, *Heritiera littoralis*, *Nypa fruticans*, *Hibiscus tiliaceus, Derris trifolia* vine	Trees are approximately 5-10m tall	Soils consist of a deep and poorly drained mucky clay, tidal inundation allows mangroves to grow inland. Scott (1993) noted at the time the

	wide at its greatest point.			wetland was privately owned
Talofofo River Valley	About 6 km long and varies in width from 100-500m	*Barringtonia racemosa, Hibiscus tiliaceus, Nypa fruticans, Acrostichum aureum*	Has large stands of *B. racemosa.*	More of a freshwater area, has other freshwater plants present. *N. fruticans* limited to about 900m upstream from the river mouth. Scott (1993) noted at that time that all land largely privately owned

More recently, Raymundo et al. (2018) made observations of mangroves in the Manell-Geus Habitat Focus Area and Achang Marine Preserve by taking measurements while kayaking along the periphery of the forest with a transect and GPS, making the following observations:

- reported three species- *A. marina, B. gymnorzhia, R. apiculata.*
- The most common tree was *R. apiculata* (1249 trees), followed by *A marina* (406 trees), and *B. gymnorrhiza* (323 trees).
- The majority of trees were small (10 cm or 15 cm trunk diameter categories).

(Fosberg 1960) reported extensive *Nypa fruticans* strands, and *Barringtonia racemosa* growing around tidal channels. Fosberg (1960) also reported the occurrence of some other mangroves: *B. racemosa* in the Talofofo river estuary, living as pure strands in mostly freshwater areas only exposed to sea water during the highest tides. A public map with compiled historical observations from UOG technical reports and other studies can be found at: https://www.google.com/maps/d/u/0/viewer?mid=1qjj7mpXJmjOboceKbsr4e32zbyjFYbEX&ll=13.348544564160914%2C144.7210199&z=11

IV. Natural stressors:

a. Typhoons and storms:

Strong typhoons can have immediate and delayed impacts on mangroves. A case study of mangrove decline in Yap reported by (Cannon 2014) determined that the primary cause of decline in multiple areas was typhoon damage. In the short term, (Kauffman and Cole 2010) found that after Typhoon Sudal there was a 6%-32% mortality rate among trees, with many trees suffering canopy damage or snapped. Less damage occurred to *Rhizophora* and *Bruguiera* which were more flexible and did not break as easily in the wind. In addition to any immediate damage from knocking over trees, typhoons can cause sub lethal damage and expose the tree to pathogens. These infections can weaken the tree making it more susceptible to being broken or pushed over by subsequent storms (Cannon 2014). Analysis of satellite imagery revealed a 10% reduction in mangrove area since 2006 to 2012, which was primarily attributed to Typhoon Sudal (Cannon 2014). Typhoons may also move around sediment and objects, change coastlines, and change patterns of water flow which could impact mangroves.

As detailed in a NOAA Abandoned Vessel case study, the *Seagull,* a 70' fiberglass ketch that had been moored at the Marianas Yacht Club broke free during Supertyphoon Pongsona in 2002 and was grounded on "dead coral pavement" adjacent to mangroves. There was only slight damage to the keel, and the owners funded salvage operations that involved creating a channel to access the *Seagull* and subsequent filling. This particular case was resolved however boat groundings could also be another potential threat to mangroves, particularly if there is difficulty in funding salvage operations.

b. Fungal disease:

Cannon (2014) found that fungi belonging to the genera *Ganoderma* and *Phellinus* commonly infect mangroves in Micronesia. However, in Guam samples of fungi were only investigated in other non-mangrove plants. These fungal genera are also a large issue for upland forests where they are also very common (Adrienne Loerzel pers comm.) Infection causes rotting of the heartwood and is commonly described as "butt-rott". The fungi may decay the lignin in the tree (Blanchette 1991) but does not kill the sapwood, cambium and phloem, allowing the tree to survive but with reduced structural integrity (Cannon 2014). As the fungi grows it forms detectible fruiting bodies known as "conks" or "shelf fungi" and different mangrove species may be more or less susceptible and have a different percentages of individual trees with conks, as seen in Yap (Cannon 2014). Many mangrove species are very susceptible to *Phellinus* infection from minor bark injuries, so any people harvesting mangrove materials should be educated on methods to minimize risk of fungal infection (Cannon 2014). Gilbert et al. (2008) was able to identify fungi to the species level and found *Phellinus fastuosus, Aurifica luteoumbrina, Coriolopsis sanguinaria* were found to be strongly specific to mangroves in a study of trees in Kosrae and Pohnpei, and colonized mangrove species that can be found in Guam (*R. apiculata* and *B. gymnorhiza*). Continued monitoring of mangroves can screen for any fungal infections of concern.

V. Anthropogenic stressors:

a. Invasive Brown Tree Snake impacts on pollination:

A study by Mortensen et al. (2008) compared *B. gymnorrhiza* reproduction in Guam and Saipan and found that Saipan had greater pollination of flowers and production of propagules, largely due to birds. The Micronesian honeyeater was the most common pollinator of *B. gymnorrhiza* in Saipan, a bird species which is extinct in Guam due to the introduction of the invasive brown tree snake. Mortensen et al. (2008) recommended restoring conditions for natural pollination or assisting reproduction via planting. Mortensen et al. (2008) also noted that other bird pollinated trees may be at risk, including another mangrove found in Guam, *Lumnitzera litorea.*

b. Sea level rise, sediment accretion and erosion:

Sea level rise is considered the major climate change related threat to mangroves in the Pacific Islands (Ward et al. 2016). Sea level rise can causes mangroves to drown and die if they are not able to migrate landwards or accrete enough sediment to keep pace with sea level rise (Lovelock et al. 2015, Woodroffe 2018, Saintilan et al. 2020). Landward migration requires that there is enough land of moderate elevation on the landward side without human development (too steep would prevent necessary flooding), the ability of propagules to reach these new areas, and the ability of these seedlings compete with existing vegetation (Healy et al. 2002). However many coastal areas are developed and limit mangrove retreat. Coastal squeeze is defined as intertidal habitat loss which arises due to the high water mark being fixed by a defense and the low water mark migrating landwards in response to sea level rise (Pontee 2011). Natural resource managers are recommended to include buffer zones for coastal wetlands to expand using strategies to set land aside, modify the land and structures, and assist restoration (Leo et al. 2019). In southern Guam, fringing mangroves that are bordered by the road may be at risk due to coastal squeeze and sea level rise. As communities plan for climate change adaption, mangroves should also be included in planning efforts to facilitate migration and continued coastal protection.

The other method of coping with sea level change is accretion of sediment. Changes in hydrology impact the settlement of particles which can cause erosive or accumulative sediment regimes. Accretion requires availability of sediment (including material the organic material the mangrove itself can provide), however too much sediment can also smother mangrove roots (Ellison 1999a). Human activities can reduce the amount of sediment reaching mangroves, making them susceptible to erosion or sea level rise. For example, a large area of mangroves near the Godavari Delta, India were lost likely due to the construction of dams that which prevent vertical accretion of sediment in the delta (Malini and Rao 2004). Some natural feedback loops may help promote accretion. As more frequent flooding occurs, mangroves are provided with more sediment and nutrients to produce organic material that can become sediment (Healy et al. 2002). Also in some conditions such as those in coastal plains, mangroves may also play "catch up" rather than "keep up" by initially retreating until sea level stabilizes and then slowly recolonizing and accumulate sediments (Woodroffe 2018).

Paleoecology studies can study how mangroves have changed in the past in response to changes in sea level. Mangroves are expected to be unable to cope with sea level rise greater than 6.1 mm a year, and currently sea level is rising by roughly 3.4 mm per year (Saintilan et al. 2020). In the Indo-pacific, many sites are expected to accumulate sediment too slowly to keep up, especially with human changes such as the creation of dams, and sites with a low tidal range and sediment supply may be submerged as soon as 2070 (Lovelock et al. 2015). More recent measurements can also be useful for estimating whether mangroves are keeping pace with sea level rise. Krauss et al. (2010) investigated sedimentation and elevation changes of mangrove forests in Kosrae and Pohnpei and found a range of elevation change (-3.2 to 4.1 mm per year) depending on the location. Krauss et al. (2010) found that fringe mangrove forests were most susceptible to sea-level rise. Another study by Krauss et al. (2003) in Kosrae and Pohnpei found that prop roots facilitated sediment accretion more than pneumatophores of *S. alba,* suggesting different mangrove roots structures may affect ability to adapt to sea level rise. Taking elevation measurements and modeling changes in sea level rise can help determine how at risk Guam's mangroves are to sea level rise.

Accretion tends to be greater in locations with minimal turbulence. Even in shorter time periods, erosion has caused problems for mangroves. Wave undercutting occurs when waves erode the lower portion of a cliff or bank, causing the formation of an overhang that eventually collapses of its own weight (Marsh and Kaufman 2012). Signs of erosive regimes include bank undercutting include a cliff like appearance, exposure of roots, and lack was an advancing edge (Healy et al. 2002). Undercutting described a contributor to mangrove loss at locations in Yap, Palau, and Kosrae (Cannon 2014), and natural erosion affects mangrove areas worldwide (Thomas et al. 2017).

c. Climate change:

In addition to sea level rise, other components of climate change may also affect mangrove growth and health directly or indirectly through changes in the environment, including changes in temperature, rainfall and salinity, changes in soil that change nutrient availability and growth, changes in growth rates of pathogenic and beneficial microorganisms, and changes in photosynthetic and respiration rates (Gilman et al. 2008, Ward et al. 2016, Jennerjahn et al. 2017, Simard et al. 2019). Not all changes may be harmful to mangroves. Increased precipitation can decrease pore water salinity and levels of sulfate, which could promote greater growth (Gilman et al. 2008). Climate change effects on rain, average temperatures, and storm patterns can have significant impacts. Simard et al. (2019) found that 74% of variation in mangrove canopy height measured in 2000 could be explained by past precipitation, temperature, and cyclone activity (precipitation and temperature accounted for 71% of that variation). However, Krauss et al. (2007) studying mangroves throughout Micronesia found that species may respond differently to higher precipitation rates, and mangroves in Micronesia which are in soils that are consistently wet have had little correlation with seasonal weather patterns and may be less likely to be affected by changes in precipitation than other regions. Waycott et al. (2011) estimates that mangroves in Guam are estimated to decline due to climate change 10% by 2035, 60% by 2100 with conservative emission projections and 70% by 2100 with higher emissions rates, although a specific cause for this decline or details of the modeling was not described. Climate change may also impact the ecosystem services provided by mangroves. Rising temperatures may increase anaerobic consumption in organic sediments and offset the carbon sequestration by MG, impact on mangroves themselves uncertain (Waycott et al. 2011). Climate change may also have impacts on the microbial life and biotic community within mangroves.

d. Clearing, Removal, and Filling for development:

In Guam mangroves have been cleared for various projects, including the following developments noted by Scott (1993) and citations within:

- Construction of highway 1 blocking natural water flow in Sasa Bay
- The creation of Navy facilities including the construction of Dry Dock Peninsula & Polaris Point in Apra Harbor between 1945-1950 filled in approximately 500 ha of wetlands and caused destruction of mangroves in Sasa Bay and potentially around the Atantano River.
- Construction of a dam that channels water from Laguas River away from Sasa bay and into a reed marsh
- Construction of naval facilities in the mid to late 1940s in the Atantano Wetlands and a few homes and businesses
- A small area of mangrove forest was cleared for creating the marina in the 1970s
- Two small clearings of mangrove made by adjacent landowners at the Western end of Achang Bay.

More recently, in 2005 an incident occurred where mangroves were removed within Achang Marine Preserve, allowing GDWAR to intervene (pers comm. Brent Tibbatts). Legal Protection for mangroves in Guam is primarily through local preserves (see Legal Protections section).

e. Oil spills and Pollution:

Oil spills can cause acute impacts such as immediate death, loss of leaves, deformation, stunting of mangroves, and death of associated wildlife (Getter et al. 1981, Hoff 2002). It can also cause chronic or long term changes in the future of mangrove forests in the area by causing seedling deformation or mortality, and higher rates of mutations (Getter et al. 1981, Duke 2016). Other sub-lethal impacts observed include changes in the number or size of lenticels, changes in pneumatophore growth rates, pneumatophore deformities, reduced growth, defoliation and yellowing of leaves, elevated soil temperatures, and erosion or changes in hydrology of areas where sudden mangrove death occurred (Getter et al. 1981, Hoff 2002, Duke 2016). The persistence and impacts of oil will also be affected greatly by location and physical features such as exposure to waves and currents (Getter et al. 1981). Recovery of oil damaged mangroves is estimated to take at least three decades for the trees themselves

not necessarily the biotic community (Duke 2016). Different species may also have different levels of risk. Naidoo and Naidoo (2017) suggested that *A. marina* as a pioneer species with many fine roots might be more susceptible to oil pollution.
Below are known oil spills and leaks in Guam's mangrove areas:

- In June 1980 an estimated 38,000 liters of diesel fuel spilled at the mouth of the Laguas drainage due to a leakage from a pipeline buried along Highway 1 which affected approximately a 1.8 ha area of mangroves, killing approximately 4000 mangroves. (Pacific Basin Environmental Consultants (PBEC), 1981 as cited by (Scott 1993)
    - There was also an article published in the newspaper "Islander" in 1984
    - See past mangrove restoration projects section for more information on the restoration response to this spill
- Detailed in a report by (PBEC 1983), in October 17, 1981 an accidental spill of bunker fuel occurred at the Guam Oil and Refining company (GORCO) near the GORCO-Navy Tie-in Facility at the northeast end of Sasa Bay. GORCO records estimated the spill was small (50-100 gallons). The spill site was inspected by GEPA and PBEC for preliminary damage and GORCO signed a contract with PBEC on August 30 1982 for restoration of the damaged area.
    - GORCO likely helped prevent further loss of the mangroves by immediately spraying off *Rhizophora* prop roots.
    - Observations of dead and dying (yellowing) juvenile and adult *R. mucronata stylosa* and *R. apiculata* were observed along with mortalities of mudskippers and crustaceans.
- In 1983, a major oil spill of 3.8 million liters that had been leaking from a pipeline for an unknown amount of time was discovered in Atantano Wetland. The oil spill seeped outward washing up into Apra Harbor. Clean up efforts lasted two and half years and removed 2.8 million liters of oil. No direct die-off of mangroves were observed, however other sub-lethal effects on mangroves or associated life were not determined (Scott 1993).
- Scott (1993)suspected heavy metal contamination by the Shell Oil Refinery and naval stations near Sasa Bay and Atantano Wetland.
- Scott (1993)also reported two active oil pipelines and four old pipelines buried near Sasa Bay suggesting the need for future monitoring for leakages.

Aside from witnessing immediate death, it can be challenging to understand and observe the sub-lethal impacts of oil or other pollution is on the mangroves and associated fauna, which would require more information on the toxicological and chemical characteristics of the particular type of oil released. Lighter oils tend to be more toxic than heavier ones (Hoff 2002). Oil may be retained in the fine organic matter rich sediments and persist in the mangrove environment for decades (Duke 2016). Immediate clean up efforts should be careful to not press oil into sediments (Hoff 2002). Since small leaks may be less detectable or past impacts may be present, some bacterial biomarkers may be useful for detecting future oil pollution. Dos Santos et al. (2011) attempted to identify bacterial groups that could serve as biomarkers by experimentally comparing bacterial diversity in mangrove sediments that were exposed or unexposed to oil pollution. Dos Santos et al. (2011) found that in response to oil pollution, bacteria in the order Chromatiales and the genus *Haliea* decreased, and bacteria in the genera *Marinobacterium, Marinobacter,* and *Cycloclasticus* increased. Further research would be needed before the method could be considered reliable.

f. Nutrient Pollution:

One helpful ecosystem service that mangroves provide to coral reefs is their ability to absorb nutrient pollution (see ecosystem services section). Mangroves can still however be overwhelmed and impacted by nutrient pollution. As nutrients become more available, many plants, including mangroves, invest less in root growth and more in above ground shoot growth (Lovelock et al. 2009, Naidoo 2009). The lack of root development can cause the mangrove to be susceptible to salinity stress and be less efficient at taking up the particular nutrient in excess (Feller et al. 1999, Lovelock et al. 2009).

Lovelock et al. (2009) experimentally added nutrients to mangroves in fringing mangroves and scrub forest mangroves. In treatments without added nutrients, there was no death in fringe forests, and some death in scrub forests which are located more inland and are more likely to have hypersaline soils. This death in the scrub forests was accentuated by the addition of nitrogen (not affected by phosphorous), and was significantly correlated with salinity, likely because addition of nutrients caused less root development. Naidoo (2009) found that one year old *A. marina* seedlings that were enriched with nitrogen (and not phosphorous) increased aspects of productivity (number of leaves, plant height, etc.), however the nitrogen in shoots increased by a greater percent than the roots. Feller et al. (1999) found that *Rhizophora mangle* in Belize that were fertilized with phosphorus had a decrease in phosphorous reabsorption efficacy, and a significant increase in nitrogen resorption efficiency.

Other impacts aside from less root development may also occur. Mandura (1997) observed that A. *marina* mangroves exposed to nutrient pollution via sewage were stunted and had limited and abnormal pneumatophores, although there was no mechanism or causation proved, and this could be to the many other compounds found in sewage. Fauzi et al. (2014) found that eutrophication might cause lower soil pH, resulting in binding of cations and lower levels of cations in leaves. More information on nutrient requirements, nutrient cycling and biogeochemistry can be found in Singh et al. (2005).

g. Harvesting/Use:

Before World War II, portions of Sasa Bay, Atantano Wetland and Talofofo River Valley were used for farming rice and vegetables (Thompson 1947 as cited by Scott 1993). Scott (1993) also noted several hectares of this wetland were used for vegetable and a minor amount of crab hunting. There is some harvesting of mangroves for wood products in Pohnpei and Palau (Cannon 2013) and in many other parts of the world (Vo et al. 2012). In Guam, historically wood from mangroves were used for creating *dagao*, a four and half foot thrust hoe that was used to dig holes for seeds or young plants (Cunningham 1992).

VI. Conservation Recommendations and Knowledge Gaps:

- Mangroves have declined in areas that are now well developed and cannot be restored (eg. military developments), working with private landowners can help protect the small areas of remaining mangroves
- Restoration can enhance the existing areas of mangroves and should seek to include the diversity of mangrove species and genetic diversity to increase resilience to storms, disease, and other stressors
- Mangrove conservation should plan for sea level rise:
    - Model sea level rise (SECAP tool) to understand potential impacts to mangrove areas
    - Measure levels of accretion, check for wave undercutting and erosion
    - Consider options for adaption to sea level rise- landward retreat
        - Measure sediment accretion- are mangroves keeping up?
        - Include mangroves in conjunction with plans for sea level rise and coastal erosion and threats, address coastal squeeze issues

    - Plan restoration projects with sea level rise in mind (Eg. Plant species that are tolerant to frequent flooding or in areas with greater sediment accretion potential)
- Monitor local reproduction & reproductive health
    - Monitor phenology (timing of flowering, propagule maturation) to inform future restoration efforts
    - Since *B. gymnnorhiza* struggles to be pollinated due to lack of birds, humans could facilitate pollination or ensure that the few propagules produced have a greater chance of survival.
        - *L. lumnitzera* which is also pollinated by birds should be monitored for reproductive success
- Monitor for signs of stress and pathologies and consult with indo-pacific mangrove experts.
    - Fungal infections
    - Other signs of stress (defoliation, yellowing leaves, lenticel deformations)
        - Are mangroves still suffering from oil pollution effects? Is oil pollution an ongoing problem?
        - Are mangroves suffering from salinity stress? Changes in past hydrology affecting access to water flow?
        - Are mangroves suffering from nutrient pollution?
    - Monitoring the mangrove community (eg. crabs, snails, etc.) can also offer insight into how impacted the mangrove ecosystem is
- Ensure boats and other structures near mangroves are secured before storms to prevent groundings and marine debris from damaging mangroves

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LEGAL PROTECTIONS:

Contents

I. Introduction: How are mangroves and seagrasses protected through a mix of federal and local protections?

As a US territory, Guam has a complex mix of federal and local protections for their natural resources. The following introduction explaining the basics of mangrove and seagrass protections in Guam was provided via communication with Jessica Toft, Guam Assistant Attorney General, Solicitor Division.

What is the difference between federal vs local jurisdiction and when do they apply?

Mangroves and Seagrasses in Guam are under concurrent *jurisdiction* for federal and local laws, *jurisdiction* meaning the authority to enforce. Federal agencies have jurisdiction/authority to enforce federal laws. Local agencies have jurisdiction/authority to enforce local laws. Local agencies can sometimes be delegated some federal enforcement authority, but not vice versa. A crime or violation can also trigger concurrent jurisdiction, which means that both the federal agency and the local agency have the authority to enforce their laws in the same place for the same act.

Generally, in order to constitute a violation of federal laws, there has to be some federal "nexus" or connection, such as interstate traffic, interstate commerce, or interstate travel, or other. Therefore, in most cases, taking of seagrasses and mangroves under Guam's local laws would most likely stay a local violation, and the local enforcement agency would have jurisdiction to enforce. However, if a federal connection is established, such as triggering interstate commerce if someone were to transport the mangroves or seagrasses out of Guam, or sell them for a large sum, federal jurisdiction would be triggered.

Mangroves and Seagrass Protections are primarily protected locally by existing in a preserve, under statute 5 GCA § 63116.2.

In the next sections, many related federal and local protections are outlined, however the primary way seagrasses and mangroves are currently protected is through the local statute 5 GCA § 63116.2.

Local Statute 5 GCA § 63101 Government Operations Division 6 – Agriculture Chapter 63 - Fish, Game, Forestry & Conservation defines seagrass and mangroves:

- mangroves as "plants growing in soils with a high salt content and/or possess a well-developed system of conducting tissue to transport water, mineral salts, and sugars that occur in estuarine-tidal flat areas to include, but not limited to, species in the family Rhizophoraceae; ..."
- Seagrass as "any species of marine angiosperms (flowering plants) to include, but not limited to, species in the families Hydrocharitaceae and Potamogetonaceae; ... "

Local statue 5 GCA § 63116.2 determines "Activities within Marine Preserves.

- All forms of fishing, and the taking or altering of aquatic life, living or dead coral and any resources to include, but not limited to, mangroves, seagrass, sand, and rocks within a preserve, is unlawful except as specifically permitted by the Director of Agriculture through regulations."

What are local statutes versus regulations?

Statutes are public laws passed by vote of the Legislature of Guam, as opposed to regulations which are rules passed by an executive agency. Satute 5 GCA § 63101 and statue 5 GCA § 63116.2 vest authority in the Department of Agriculture to enforce violations against takings of seagrass and mangroves within the Marine Preserves in Guam.

How are local laws enforced? What are criminal versus civil violations?

Any violation of these local statutes is a *criminal violation*. A *criminal violation* is punishable by arrest, jail time, and fines. In contrast a *civil violation* is remedied mostly by fines, and potentially injunctions, and cease and desist orders.

For development outside of a marine preserve, there is generally no local criminal violation of 5 GCA § 63116.2; so it does not constitute "take" under local law. It has to occur within the preserve in order to constitute a criminal violation under Guam laws. As of August 2020, there have been no arrests of developers for this particular local crime. There are no "civil" violations set forth in law for the taking of mangroves and seagrasses. Civilly, there aren't any Guam laws that specifically make taking of mangroves and seagrasses a civil violation; except maybe for tangential laws like Guam's Water Pollution Control Act.

What is federal consistency and how does it apply for impacts on mangroves and seagrasses that occurs outside of preserves?

There can be some special ways of challenging the progress of the development in Guam outside of preserves using federal civil laws, including the *federal consistency* process under 15 CFR Part 930 which is handled by the Guam Coastal Management Program (GCMP). Federal consistency requires that federal agency actions must be consistent with the enforceable policies of a state or territory's coastal management program. The process aims to prevent conflicts between states/territories and federal agencies by fostering early consultation and coordination. According to the NOAA's website (https://oceanservice.noaa.gov/facts/fedconsis.html):

> "Federal consistency is a provision in the Coastal Zone Management Act that requires the federal government to comply with a state's Coastal Management Program when taking actions that are likely to affect coastal resources. In order to ensure federal consistency, a state agency reviews any programs being implemented by the federal government. Along with the state review, the National Ocean Service interprets the CZMA, oversees applications of federal consistency, provides management and legal assistance to coastal states and federal agencies, and mediates CZMA-related disputes"

Whenever an activity, such as development, that is covered under 15 CFR 930 is undertaken by either a private company, person, or a federal agency, that entity is required to submit an application to the GCMP in order for the GCMP to make sure that the activity is not affecting coastal resources (such as mangroves and seagrasses) or is affecting the resource as little as possible. If the GCMP objects to the activity, it can sometimes prevent the activity, prevent the issuance of a federal permit to the applicant, or request the entity to modify its proposed activity so that it doesn't damage the coastal resource as much. Examples of activities that would go through the federal consistency process include construction of sea walls/jetties/wharfs/piers, and discharges of dredge spoils.

II. Federal Protections Related to Mangroves and Seagrasses:

Mangroves are included in and protected by the U.S. definition of wetlands:

Mangroves are primarily protected through their inclusion in the US Army Corp of Engineers and US EPA definition of wetlands as "*areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions*." (pg. 9 US Army Corps of Engineers wetlands delineation manual). The definition includes 4 categories of wetlands (marshes, swamps, bogs, and fens); with mangroves belonging to the swamp category.

Federal regulatory authority of wetlands is primarily under the US Army Corp of Engineers (USACE) and EPA generally through Section 404 of the Clean Water Act (CWA). However, Section 10 of the Rivers and Harbors Act of 1899, and Section 103 of the Marine Protection, Research, and Sanctuaries Act of 1972 also apply. Federal Executive Order 119900, Protection of Wetlands, also seeks to "avoid to the extent possible the long and short term adverse impacts associated with the destruction or modification of wetlands and to avoid direct or indirect support of new construction in wetlands wherever there is a practicable alternative," which also applies to military projects. Other protections of wetlands also include legislation to prevent agricultural conversion of wetlands such as 1985 Food Security Act, although this may be more relevant to Guam's inland freshwater wetlands rather than mangroves. Seagrasses are not included in this definition of wetlands, however they are protected by similar federal regulations as outlined in the next section.

a. Federal Protections- Coastal Development and Waterways:

Clean water Act (CWA), 1972

Section 404 of the Clean Water Act (CWA) which requires permitting for any discharge of fill or dredged materials into US waters. This includes development projects that may affect mangrove wetlands as well as seagrasses, such as filling for development, infrastructure development, mining, and dams. Permits must show that steps have been taken to avoid impacts to wetlands, minimize impacts, and provide compensation for any remaining unavoidable impacts. The USACE runs the day to day program and the EPA works in conjunction make permit decisions, create policy and criteria. Seagrass restoration projects may require individual, general, or other permits depending on the effect on navigable waters and whether the restoration project helps stabilize coastlines.

More information at https://www.epa.gov/cwa-404

An example of this legislation being implemented was in a recent settlement between the EPA and Vital Energy Inc for violations of the CWA due to improperly stored fuel that was leaking and could potential cause an oil spill into Piti Channel and Apra Harbor. More information can be found at https://archive.epa.gov/epa/newsreleases/us-epa-requires-vital-energy-inc-protect-guams-waterways-oil-spills.html.

The River and Harbors Appropriations Act (RHAA), 1899

Section 10 of the Rivers and Harbors Appropriates Act (RHAA) requires permits for construction of potential obstructions to navigable waters such as boat ramps, bridges, breakwaters, bulkheads, dams, piers, and other activities involving excavation or filling that may affect navigability of waters. RHAA is also administered by the USACE. Seagrass restoration projects that involve placing seagrass in navigable waters may require a permit.

More information at:
https://www.spl.usace.army.mil/Missions/Regulatory/Jurisdictional-Determination/Section-10-of-the-Rivers-Harbors-Act/

National Environmental Policy Act (NEPA), 1970:

The National Environmental Policy Act (NEPA) requires all federal agencies to assess the environmental effects of their proposed actions prior to making decisions, such as constructing public facilities and making federal land use decisions. Under NEPA federal agencies need to prepare statements with assessments of the environmental impact of projects and potential alternatives as well as provide opportunities for public review and comment. Environmental impact statements are reviewed by the EPA.

More information at https://www.epa.gov/nepa/what-national-environmental-policy-act

b. Federal Protections- Wildlife and Habitat Conservation

Endangered Species Act, 1973:

The ESA is administered by USFWS and NMFS with the goal of protecting and recovering imperiled species and the habitats they rely upon. Organizations or individuals can petition for certain species to be listed as either "endangered" (at risk of extinction throughout all or a significant portion of its range) or threatened (at risk of being endangered in the forseeable future). Species are evaluated for listing based on the following criteria: 1) damage to, or destruction of a species' habitat; 2) overutilization of the species for commercial, recreational, scientific, or educational purposes; 3) disease or predation; 4) inadequacy of existing protection; and 5) other natural or manmade factors that affect the continued existence of the species. Protection is provided using several measures including:

- Prohibition of take (defined as harassing, killing, trapping, capturing, collecting, or attempting to engage in any such conduct) and trade of listed species without a permit
- Designation of critical habitat with protection in regards to federal activities
- Cooperation of other federal agencies, requiring consultation before authorizing, funding, or carrying out actions that may affect listed species
- Providing federal funding for states to create and maintain state led programs for listed species
- Section 10 of the ESA allows landowners to obtain a permit for developing land inhabited by listed species if they create an approved habitat conservation plan.
- Other resources for landowners to manage land with habitat of listed species

The Mariana Common Moorhen (*Gallinula chloropus guami*) has only a few hundred individuals remaining and utilizes Guam's wetlands. However they rely more on freshwater habitat rather than mangrove habitat.

More information can be found at: https://www.fws.gov/endangered/laws-policies/

Magnuson-Stevens Fishery Conservation & Management Act MSA (1976), revised by the Sustainable Fisheries Act (1999), and revised again as the Magnuson-Stevens fishery Conservation and Management Act (2006)

The Magnuson-Stevens Fishery Conservation & Management Act is the primary law regulating fisheries management in the US. The act created eight regional fishery management councils, of which Guam is part of the Western Pacific regional fishery management council. The Sustainable Fisheries Act (SFA) passed in 1996 revised MSA fishery management plans to develop measurable criteria for determining when a stock is overfished. MSA assesses fish stocks to prevent overfishing and also requires regional fishery management councils to identify essential fish habitat for federally managed fish species for protection. Essential fish habitat" which includes "*those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity.*" Examples of managed species in Guam include the broadbill swordfish (Xiphias gladius), sailfish (Istiophorus platypterus), tuna, and shark species.

Once essential fish habitat has been identified, other federal agencies must determine whether their actions, such as development projects or naval activities, might negatively impact these habitats. This also includes wetland habitats that are fish habitat, and clearance through MSA is required before a permit can be given through section 404 of the CWA.

More information at:
https://www.habitat.noaa.gov/application/efhinventory/index.html
http://www.wpcouncil.org/

Fish and Wildlife Coordination Act (FWCA), 1934:

FWCA requires that federal agencies consult with the USFWS, and in some cases the NOAA NMFS, in addition to State wildlife agencies for activities that affect, control, or modify any stream or bodies of water regarding any impacts on fish and wildlife resources. The FWCA requires that fish and wildlife resources are given consideration and requires measurement and mitigation of impacts these resources or wildlife habitat. The consultation is incorporated into the process of permitting through Section 404 of the Clean Water Act, NEPA, or other federal permits and review requirements.

More information at: https://darrp.noaa.gov/fish-and-wildlife-coordination-act%C2%A0

c. FEDERAL Protections- Prevention and Mitigation of Impacts

Resource Conservation and Recovery Act (RCRA)

RCRA is administered through the EPA and regulates both hazardous and non-hazardous waste. The EPA sets minimum national standards for how disposal facilities should be designed and operated, and states issue permits in compliance with EPA standards and state regulations. Regulations may apply to government agencies, small businesses, gas stations, and any operations that produce hazardous waste.

More information at:
https://www.epa.gov/rcra
https://www.epa.gov/rcra/hazardous-waste-state-authorization-tracking-system-stats-report-guam-september-30-2019

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), 1980

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), also commonly known as Superfund, is administered via the EPA and manages hazardous substances that endanger public health and the environment. CERCLA established requirements for hazardous waste sites, created liability for persons responsible for releases of hazardous waste, and established a trust fund using a tax on chemical and petroleum industries to enable remediation for sites where no responsible party could be identified. Guam has a superfund site at the Anderson Air Force Base and the Ordot Landfill in Agana to help prevent waste entering aquifers/rivers.

For more information:
https://www.epa.gov/superfund/superfund-cercla-overview
https://www.epa.gov/superfund/search-superfund-sites-where-you-live

Oil Pollution Act (OPA), 1990

OPA works through the EPA and Office of Emergency Management to respond to and prevent catastrophic oil spills. The OPA requires oil storage facilities and vessels to submit plans on oil storage and large oil spill response plans to the Federal government. The EPA also has regulations for storage facilities and for Coast Guard oil tankers. The OPA also requires plans on a regional scale to respond to oil spills, and has a trust fund financed by oil taxes to clean up sills when responsible parties are incapable or unwilling. Guam has had suffered oil spills that have impacted mangroves and coastal habitats; see the Mangrove Biology and Ecology section for more information about past oil spills that have impacted Guam's mangroves.

For more information: https://www.epa.gov/laws-regulations/summary-oil-pollution-act

III. Local Protections Related to Mangroves and Seagrasses:

Mangroves and seagrasses are protected on Guam primarily through marine preserves, however there are some other related protections which are outlined below.

a. Local Protections- Wetlands (including mangroves)

- E.O. 78-21 Protection of Wetlands:
  - Allows the Territorial Land Use Commission, consistent with the Guam's Land Use Plan and Coastal Management Plan to designate wetland areas and promulgate rules and regulations to protect wetlands.
  - Mangroves are specifically included in the definition of wetlands
  - http://governor.guam.gov/governor-content/uploads/2017/08/E.O.-78-21-Protection-of-Wetlands.pdf
- E.O. 78-23 Land-Use Districts
  - Established conservation districts that protected natural and wilderness areas including wetlands.
  - Conservation districts did not allow the establishment of any zones and required permits for development.
  - http://governor.guam.gov/governor-content/uploads/2017/08/E.O.-78-23-Promulgation-of-the-Rules-and-Regulations-under-.pdf
- E.O. 90-10 Requirements for Environmental Impact Assessments for All Territorial Land Use Commission Actions
  - Required environmental impact assessments to be submitted to the Guam EPA
  - Wetlands are included as environmentally sensitive areas, and development in environmentally sensitive areas cannot waive the requirement for EIS despite meeting other requirements
  - http://governor.guam.gov/governor-content/uploads/2017/07/E.O.-90-10-Requiremtns-for-Environmental-Impact-Assessments.pdf
- E.O. 90-13 Protection of Wetlands
  - Updated wetlands protections, repealing 78-21
  - Designated the official interim wetland map for Guam to be the National Wetlands Inventory map published by the United States Fish and Wildlife Service for guiding development projects.
    - See more at https://www.fws.gov/wetlands/data/Mapper.html)
  - Tasked GEPA, DOAG, Bureau of Planning, and other land use agencies, to conduct a study of wetlands and drafts of protective legislations
  - http://governor.guam.gov/governor-content/uploads/2017/07/E.O.-90-13-Protection-of-Wetlands.pdf

b. Local Protections- Coastal Development:

Public law (PL) 12-108, 1974 – Guam Territorial Seashore Protection Act of 1974:

- Created a Seashore Reserve that included all land and water extending seaward to the 60 ft depth contour, and extending landward to the mean high tide line plus either (a) 10m on the horizontal plane or (b) to the nearest inland edge of a public right of way. Also included in the reserve are all islands in the government's jurisdiction except Cabras Island
- The act also established the Guam Territorial Seashore Protection Commission to create the Guam Seashore Reserve Plan with goals to maintain "Ecological planning principles and assumptions to be used in determining the suitability and extent of allowable development."
- The 2020-2021 Coastal Management Program Fellow will be working on further developing the Territorial Seashore Plan

c. Local Protections- Coral Reef and Climate Changed Related Protections

EO 12-05, 2012 – Adoption of the GCRI to establish a policy development mechanism for the protection of Guam's coral reefs

- Includes ecosystem connectivity and emphasizes "the global effort to conserve, restore, and effectively manage coral reef ecosystems, including, where appropriate, mangroves and seagrass beds…"
- Superseded EO 97-10 "Adoption of the Guam Coral Reef Initiative" and updated the duties of the GCRI Coordinating Committee (GCRICC) and GCRI policy advisory committee (GCRIPAC)
- GCRICC started identifying local action strategies in 2002, and revised 5 priority areas in 2013: LBSP, fisheries management, recreational use and misuses, climate change and reef resilience, and impacts of the Department of Defense (DOD) expansion.

EO 19-16 Relative to Implementing a New Coral Reef Resilience Strategy to Protect and Preserve Guam's Coral Reefs from all Threats Including Climate Change:

- The result of previous executive orders (19-09) that established a working group to review the new coral reef resilience strategy, resulting in five aimed outcomes summarized as: (1) fisheries management, (2) decreasing LBSP, (3) increasing responses to reef threats and reef restoration, (4) establishing sustainable recreational uses and tourism, (5) championing human community resilience and climate change adaptation.

EO 19-19 Relative to creating the Climate Change Resiliency Commission

- Created the Climate change Resiliency commission, revoking the previous EO 15-18
- The mission statement of the commission is to develop a strategy to build resiliency against with outcomes including ocean and land resources, development planning, food security, carbon footprint, and others.
- Mangroves are specifically mentioned as a ocean and land resource
- https://www.guam.gov/wpdev-content/uploads/2019/08/EO-2019-19-Relative-to-creating-the-Climate-Change-Resiliency-Commission.pdf

d. Local Protections- Coastal Hazards:

EO 19-18 Hazard Mitigation Plan (2019)

- Described coastal hazards including climate change, coastal erosion, and sea level rise, mitigation actions.
- May be an area to include mangroves and seagrasses in stabilizing shorelines
- https://www.guam.gov/wpdev-content/uploads/2019/07/19.0726-Transmittal-to-Speaker-Executive-Order-2019-18-re-Hazard-Mitigation-Plan-2019.pdf

PL 33-159 Establishment of the Southern River Erosion Council (2019)

- Acknowledges erosion issues on the Talofofo, Ugum, Namo, Manenggon Rivers, and other rivers in southern Guam that need to be addressed through work on the Bolanos conservation area.
- Recognized that erosion threatens public lands, private lands, and heritage sites, impacts agriculture and tourism related jobs, decreases water quality, affects the navigation of rivers, and damages nearshore benthic ecosystems.
- Created the Southern River Erosion Council, composed of representatives from various local and federal government agencies, UOG, mayors of southern villages, and private land owners.
- Mandated creation of a master plan to identify and mitigate erosion problems.

More info: http://www.guamlegislature.com/Public_Laws_33rd/P.L.%20No.%2033-159.pdf

e. Local Protections- Marine Preserves and Fishing:

PL 24-21, 1997 – Establishment of fishing regulations and marine preserves (MPs):

- Established five marine preserves at the following locations: Tumon Bay, Piti Bomb Holes, Sasa bay, Achang Reef Flat, and Pati Point. Marine preserves include the land horizontally 10 meters from the mean high tide mark or. If there are mangrove in the area the boundary extends to the extreme inland edge of the mangrove if the mangroves are farther inland than 10 meters from the mean high tide mark. The ocean boundary of the Marine Preserves shall be up to 13 the six hundred (600) foot depth contour.
    - Piti Bomb holes MP and the Achang Reef Flat MP have seagrass beds
    - Sasa Bay MP includes mangroves
- PL 24-21 also defines many terms related MPs and fishing.
- PL 24-21 created guidelines for acceptable fishing and harvest of invertebrates, including those found in seagrasses and mangroves
- PL 27-87, passed in 2004, "Creation of an eco-permitting system for marine preserves" authorized DOAG and DAWR to regulate non-fishing activities in MPs however no regulations have been made or enforced as of mid 2018.

PL 28-107, 2005- Updates and additions to definitions related to MPs and fishery regulations listed in GCA Title

- Updates and amends definitions for several species and fishing related terms, including adding a term for mangroves and separating seagrasses from other aquatic plants
- "Mangroves - are defined as plants growing in soils with a high salt content and/or possess a well-developed system of conducting tissue to transport water, mineral salts, and sugars that

occur in estuarine-tidal flat areas to include, but not limited to, species in the family Rhizophoraceae"
- "Seagrass - is defined as any species of marine angiosperms (flowering plants) to include, but not limited to, species in the families Hydrocharitaceae and Potamogetonaceae"

PL 29-127, 2008 – Addition of a new section to Chapter 63 of Title 5 of the Guam Code Annotated relative to indigenous fishing rights

- Recognized that the CHamoru people have been historically denied the right to use traditional fishing methods and grounds, and that traditional fishing may will be threatened by current conservation policies.
- Mandates that the Chamorro people shall have special rights to off-shore fishing and harvesting of resources in order to redress historical discriminatory policies.
- Created an Indigenous Native Resources Task Force resources comprised of CHamoru men, women, and youth from CHamoru grassroots organizations.
- The task force was unable to reach consensus and have not been created yet

More information: http://www.guamlegislature.com/Public_Laws_29th/P.L.%2029-127%20(Bill%20No.%20327%20LS).pdf

PL 33-144, 2016 – Guam Ocean and Fisheries Conservation Act of 2015:

- Created the Guam Ocean and Fisheries Management council, composed of four community at large members, three fishing organizations, a faculty member of UOG, and the director of DOAG.
- Council duties are summarized to include:
  - coordinating and implementing the PL 29-127
  - developing and establishing permit requirements and a fee schedule relative to the conduct of fishing vessel operations and harvesting of fish
  - managing of funds in the Guam Ocean and Fisheries Conservation and Development fund, also created in this legislation
  - providing advice on the impacts of laws and expenditures of funds and guidance to DOAG
  - coordinating and promoting sustainable use and activities in connection with the conservation of Guam's oceans, fisheries, and marine and freshwater resources.
- The council has not been appointed and convened as of mid-2018

PL 34-72, 2018 – Marine Conservation Act of 2018:

- Authorizes the director of DOAG, village mayors, and Municipal Planning Councils to establish community-based fisheries managed areas and create fisheries management plans.
- Community based fisheries managed areas are defined as "a system in which fishermen and their communities exercise primary responsibility for stewardship and fisheries management, to include taking part in the decision-making on all aspects of fisheries management, such as harvesting, access, compliance, research, and marketing."
- Specifically designates the creation of *Humatak Bay*, a community-based *Humatak* fisheries managed area and the development of a community-based *Humatak* fisheries management plan, with technical assistance from DOAG, BSP, and the Mayor and Municipal Planning council (MPC) consistent with other plans relevant to *Humatak*, such as the Southern Development Master Plan.

  - States that the plan should include who will help monitor and assess the success of management goals and requires data sharing with MPC, DOAG, BSP, and UOG
- Also states that any new fisheries management plans authorized by this act will not affect existing marine preserves

More information: http://www.guamlegislature.com/Public_Laws_34th/P.L.%20No.%2034-72.pdf

IV. Federal and Local Legislation related to Land Conservation:

The following section describes the legislation or programs most relevant to potential mangrove conservation as a part of land conservation. More legal methods may exist for reaching conservation goals on land such as placing leases or "lease backs", purchasing development rights, creating easements, covenants, equitable servitudes, encumbrances, or a profit à prendre. More information can be found in this legal analysis of private land conservation potential in Guam: https://scholar.law.colorado.edu/cgi/viewcontent.cgi?article=1164&context=books_reports_studies

Forest Stewardship Plan (FSP)-

The FSP is run by the USDA Forest Service and is a voluntary program for landowners to create forest stewardship plans in order to "promote long-term sustainability of private forests by balancing future public needs for forest products with the need for protecting and enhancing watershed productivity, air and water quality, fish and wildlife habitat, and threatened and endangered species." States and regions customize their programs according to local needs and standards with federal guidance and requirements. Currently a Guam Forest Stewardship Plan is in place and mangroves can be included further into the implementation of the program.

More information at: https://www.fs.usda.gov/managing-land/forest-stewardship/program

National Resources Conservation Service Wetland Reserve Program (NRCS WRP)-

The NRCS Wetland Reserve Program (WRP) is a part of the United States Department of Agriculture (USDA) and is a voluntary program for landowners to enter easement agreements and other contracts for wetlands on their property. The program provides federal funding for enrollment and up to 75% or 100% of costs depending on eligibility for the easements value and for restoration of the wetland. Guam is eligible for the program, however applications are competitively ranked and the program is intended more for restoring and expanding wetlands on former agricultural land and does not aim to protect existing wetlands. Areas that have not have altered their hydrology are not eligible. Permanent and 30-year easements have a five acre minimum size and restoration cost-share agreements have a one-acre minimum size. Although the program may not be best suited for wetlands or mangroves on Guam, it may serve as a model for future conservation programs.

More information at:
https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/home/?cid=STELPRDB1049327

Guam Land Conservation Act (1974):

The Guam Land Conservation (GLCA) authorizes the DOAG to create "Agricultural Preserves" which is designed to protect land for agricultural uses, but also includes preservation for "recreational" use or "open space." Mangrove areas may fall into the "open space" category as a space that provides "essential habitat for wildlife." Contracts that outline restrictions on activities on property are formed between the government and landowners that must last for a minimum of 10 years. Property owners in return are given a property tax break on the land with the restrictions. However, the law may not be suitable for mangrove areas due to the high minimum size of 10 ha (24.7 ac), although parcels may be combined to meet the size requirement.

More information can be found at: http://extwprlegs1.fao.org/docs/pdf/gum68534.pdf

V. Summary and concluding thoughts:

- Marine preserves are currently the primary protection for mangroves and seagrasses and prevent any "take" or removal.
    - Mangroves in Sasa Bay and Achang Bay Reef Flat Marine Preserves are protected, however fringing mangroves along the southern coast are not.
    - Key seagrasses areas in the Piti Bomb Holes Preserve, Achang Reef Flat Preserves are currently protected.
- Mangroves and seagrasses may also be protected from development due to a mix of federal and local protections administered through the GCMP, DOAG, EPA, NOAA, and other organizations.
    - Mangroves in particular due to their inclusion in the definition of "wetlands"
    - Seagrasses in particular due to regulations involving clean water and navigable waterways
- We likely first need to better understand threats to mangroves and seagrasses to understand the best way to address them whether through legal protections or other strategies.
    - Are primary threats pollution, jet skis, overharvesting of marine life? These different threats would require very different approaches.
- There are various program and strategies that have been created for working with private landowners such as creating plans with mutual identified goals and land easements. More research may be needed to figure out what will work best for mangroves.

SEAGRASS RESTORATION

Contents:

I. Introduction: mixed success and nature based approaches

Seagrass restoration is one of the most difficult ecosystems to restore due to the challenges of the aquatic environment close to shore with high wave energy and potentially high turbidity. Historically seagrass restoration has had mixed success. There have been roughly 450 published seagrass restoration projects each decade since the 1970s, with roughly 50% of studies utilizing *Zostera marina*, a more temperate seagrass (van Katwijk et al. 2016). The first European Seagrass Restoration Workshop, which gathered non-governmental organizations, researchers, and managers found that 44% of seagrass planting experiments and projects had 0% survival of their planting units, and median survival was only 15% (Cunha et al. 2012). Short term monitoring (<1 year) may also have obscured levels of success (Cunha et al. 2012, Bell et al. 2014).

Due to the difficultly of seagrass restoration, the workshop participants also recommended that seagrass restoration should not be seen as an option for mitigating the impacts of other development projects (Cunha et al. 2012). Kruczynski and Fletcher (2012) summarized a case study demonstrating that seagrass restoration should not be seen as an easy solution for mitigating coastal development impacts. In the 1980s seagrass restoration projects were planned to be conducted as a mitigation response to construction of the Port of Miami, FL. Restoration was to be conducted in two phases, phase 1 planted a total of 38 acres including some plots for testing, and phase two was to plant additional 213 acres. However one year after planting, the mean survival rate was only 12% for phase 1, and phase 2 was scaled back to a total of 93 ac at two sites, which had survival rates of only 12% and 10% respectively. As a result, an alternate mitigation plan was implemented involving mangrove restoration, artificial reef creation, and shoreline stabilization. However, that is only one case and other seagrass restoration projects in Florida and elsewhere have found higher success (Bell et al. 2014, Paulo et al. 2019, Rezek et al. 2019).

Restoration can be a helpful tool but it is recommended to be used with other protective policies. As seagrasses decline, positive feedback systems that promote seagrasses may be disrupted, which can make recolonization more difficult or exacerbate further decline (Maxwell et al. 2017, Valdez et al. 2020). For instance, as seagrass declines: (i) the ability of seagrass to trap and stabilize sediment decreases, which can reduce stability of sediments needed for colonization and reduces the water clarity needed for photosynthesis, (ii) there is less oxygenation of the sediment by seagrass roots which can increase sediment concentrations of toxic sulfides (although high seagrass growth can cause increases in sulfide as well) (iii) there is less seagrass habitat supporting mesograzers and herbivores, making seagrasses more susceptible to the impacts of eutrophication, and (iv) there is less seagrass available to produce pollen and facilitate sexual reproduction (Maxwell et al. 2017, Valdez et al. 2020). Adequate resources should be placed on protecting existing areas in addition to restoring damaged areas. If restoration is needed, it is also important to address issues that caused the initial decline. A global meta-analysis of seagrass restoration found that unaddressed threats like eutrophication or poor water quality due to construction will affect restoration success (van Katwijk et al. 2016).

Another recommendation from the first European Seagrass Restoration Workshop was to prioritize natural restoration potential (Cunha et al. 2012), something that can also be seen in successful restoration work in Florida (Kruczynski and Fletcher 2012, Kenworthy et al. 2018). There are seven species of seagrass in southeast Florida; the most abundant is *Thalassia testudium,* a slow growing climax species often found in monocultures, and *Halodule wrightii* which is considered a pioneer species (Kruczynski and Fletcher 2012). To address seagrass bed damage due to boat propeller scars, restoration efforts seek to support and accelerate a natural sequence of recovery, also referred to "modified compressed succession" (Kenworthy et al. 2018). Similar to mangrove restoration, hydrological changes first need to be assessed before any planting occurs. Deep prop scars that remove sediment can make seagrass recovery more difficult because seagrass rhizomes have difficulty growing downwards, and the prop scar can act like a small channel that directs faster flowing water. Restoration first addresses this change by filling in prop scars with sand bags. Planting, if it occurs at all, is focused on *H. wrightii,* the pioneer species rather than *T. testudium,* the climax species. Seagrass beds SE Florida tend to be phosphorus limited, and one of the most cost effective methods is to set up bird stakes in the area, which provide natural fertilizer (Kenworthy et al. 2018).

However, once again, environmental changes may influence whether the original seagrass state returns. For instance, nutrient addition regimes may affect whether seagrasses transition to climax communities. The addition of bird stakes changes input of nutrients and if the stakes are not removed there may be long term persistence of *H. wrightii* instead of a transition to the climax community of *T. testudium* (Kruczynski and Fletcher 2012, Furman et al. 2019). Seagrass restoration may not be limited by technology as much by the wise application of ecological principles and proper site selection (Perrow and Davy 2002, UNEP-Nairobi Convention/WIOMSA 2020). Another way to approach seagrass restoration may also include restoring the larger community, such as a restoration project in Vietnam that reared and released seahorses and sea cucumbers in addition to planting seagrasses (Huu Tri 2007).

II. Planting Seagrass Main Methods -

a. Transplanting Adults (vegetative) vs. seeds and seedlings (generative)

Seagrass restoration has historically focused on transplanting adults, also known as vegetative growth, as either rhizome fragments with shoots (55%) or as sods and plugs (24%), with less focus on planting seeds or seedlings, known as generative growth (van Katwijk et al. 2016). Transplanting vegetative stocks can be more labor intensive due to the larger size and sediment, however it can be more reliable than seed based methods (Perrow and Davy 2002), which often have low survival (<10%) and sometimes very low survival (1-2%) (UNEP-Nairobi Convention/WIOMSA 2020). However, there is concern that solely planting adults and not seedlings can lead to the loss of genetic diversity, which could reduce seagrass fitness. Less genetically diverse *Zostera marina* seagrass beds formed by transplanted adults were found to grow slower, produce fewer seeds, and have lower germination rates compared to more genetically diverse naturally recruited populations (Williams 2001). Another study of *Z. marina* using seagrass restoration techniques showed that relatively small increases in genetic diversity could even affect ecosystem services. The seagrass plots with greater genetic diversity had plants that survived longer, greater primary productivity, nutrient retention, and contained more invertebrates due to the greater density of seagrass (Reynolds et al. 2012). Transplanted plots with greater genetic diversity survived longer, grew denser more quickly, had greater primary productivity, greater nutrient retention, and served as a habitat for a greater number of invertebrates (Reynolds et al. 2012). Seeds can be collected by seed containing shoots or mature fruits which are held in seawater tanks until most seeds have been released. Seeds can then be used for direct broadcasting which is the easiest and most cost-effective method (UNEP-Nairobi Convention/WIOMSA 2020). Alternatively, seeds or plant fragments may be reared and grown in tank systems until a suitable size as a seedling and then planted, and this can help prevent damage to donor beds while still providing larger plants (Perrow and Davy 2002). Seed-based restoration can be very cost effective and has potential for large scale restoration in certain situations, and has been used for eelgrass (*Zostera marina)* in Chesapeake Bay where approximately 215 hectares have been restored (UNEP-Nairobi Convention/WIOMSA 2020).

b. Planting adults with sediment vs. without sediment:

Adult seagrasses may be planted with or without sediment, each with pros and cons. Planting without sediment can reduce the burden of carrying heavy amounts of sediment, however it also requires additional time intensive labor in that the seagrass need to be anchored in another way, such as rods, pegs, nails, popsicle sticks, stones, shells, or staples (Perrow and Davy 2002, UNEP-Nairobi Convention/WIOMSA 2020). Seagrass plants can be attached to the staples by inserting the rhizome-root portion under the “bride” of the staple and securing the plant with a twist tie (preferably paper and metal based rather than plastic). Metal staples can be removed and reused, however another common technique is using bent biodegradable bamboo skewers if negative buoyancy is not required (UNEP-Nairobi Convention/WIOMSA 2020). However, there is also evidence that materials such as staples or skewers may actually increase the likelihood of ripping up roots (Cunha et al. 2012). Other anchoring techniques used include weaving the seagrasses into biodegradable bags such as hessian bags and attaching to metal frames held down with other heavy materials (Perrow and Davy 2002, UNEP-Nairobi Convention/WIOMSA 2020). Seagrasses can be attached to metal frame with paper strings, allowing the metal frames to be retrieved after the twist ties have degraded and the seagrasses have stabilized and anchored themselves into the sediment (Erftemeijer 2002).

As described by (UNEP-Nairobi Convention/WIOMSA 2020) and summarized in this paragraph, planting with sediment adds a logistical challenge of carrying large amount of sediment from the donor site to the planting site. This method typically uses a coring device that can be made with plastic PVC pipes and caps and can be relatively easy in softer sediments with thinner leaved seagrass species, however it can be challenging with tougher seagrasses with dense root systems and tall leaves, such as

E. acoroides. For deeply rooted species such as *E. acoroides* a tremendous amount of soil may need to be removed to keep the below-ground plant structures intact, and removing large amounts may damage the donor bed and inhibit recovery. If the locations allow, transporting the cores on floating "barges" is an option to help reduce the labor of transporting them to shore and over land.

III. Seagrass Planting Best Practices:

a. For transplanting adults (vegetative methods, any species):

There are various reviews (van Katwijk et al. 2016) and handbooks or guides to seagrass restoration (Perrow and Davy 2002, UNEP-Nairobi Convention/WIOMSA 2020) that have outlined some best practices:

- Seagrass planting success may also be affected by a critical mass (van Katwijk et al. 2016):
    - Planting in clumps of at least 20-50 cm on a side can help prevent disturbance from animals (Perrow and Davy 2002).
    - Research shows that planted seagrass patches of one hectare or larger have higher survivorship over longer time scales than smaller patches, and if possible it is better to think in hectares rather than meters (UNEP-Nairobi Convention/WIOMSA 2020).
- Restored areas should be able to sustain itself with natural recruitment (UNEP-Nairobi Convention/WIOMSA 2020).
- Recommended distance between planting:
    - Eelgrass restoration projects in the US suggests optimal spacing ranges between .5 m and 2 m. (UNEP-Nairobi Convention/WIOMSA 2020)
    - The closer they are planted, the faster they will close up the gap. However planting closely also has a higher cost due to the number of planting units are used (UNEP-Nairobi Convention/WIOMSA 2020).
- Bioturbation may lead to lower initial survival (van Katwijk et al. 2016).
- Site selection is critical and the causes of a lack of seagrass in the area should be considered before planting (Perrow and Davy 2002, van Katwijk et al. 2016, UNEP-Nairobi Convention/WIOMSA 2020):
    - Planting should not be done in places where seagrasses have not historically existed
    - Planting should not be done in areas where the root cause of seagrass loss has not been addressed
    - Planting that takes places in between patches of seagrasses are not necessarily a strong test of the efficacy of the technique, the area may naturally fill in without assistance
    - Transplant sites should be:
        - at depths, salinity, temperature, water clarity, and plant size similar to nearby seagrass beds and donor beds
        - restored ideally in response to anthropogenic disturbance,
        - not areas that are not subject to chronic storm damage
        - stable sediments where seagrasses will not experience erosion or burial
        - similar to other successful sites
        - have sufficient area to conduct the project
        - minimize exposure to air especially at low tide
    - Sightings of seagrass starting to colonize the area is a sign that the site may be a successful restoration site, however sites that are already currently undergoing rapid and extensive natural colonization should not be chosen for restoration.

- Time of year: seagrass should be planted at a time to ensure the longest period before seasonal stressors (Perrow and Davy 2002). Periods of heavy rainfall or large waves due to storms should be avoided (UNEP-Nairobi Convention/WIOMSA 2020).
- Changes to the benthos and hydrology should be addressed before planting. (Perrow and Davy 2002, van Katwijk et al. 2016, Kenworthy et al. 2018)
    - Fill in areas where there were boat groundings to stabilize the sediment and reform a bank structure (Perrow and Davy 2002), even seemingly small changes such as propeller scars can form small channels that will further enhance erosion and prevent growth (Kenworthy et al. 2018).
- Minimize impacts to donor beds (Perrow and Davy 2002, van Katwijk et al. 2016, UNEP-Nairobi Convention/WIOMSA 2020):
    - spread out the collection sources temporally and geographically, this also increases genetic diversity.
    - Harvest fast growing pioneer species instead of deeply rooted slow growing species
    - Harvest from larger beds, especially if you are removing adults
    - Harvest from beds in areas without high wave energy
- Restoration efforts should be spread out in space and time to spread out risk (van Katwijk et al. 2016, UNEP-Nairobi Convention/WIOMSA 2020)
- Planting units should include a meristematic region to ensure growth (Perrow and Davy 2002).
    - For seagrass species that have a mono-meristematic leaf-replacing growth form, such as *E. acoroides* (Short and Duarte 2001) each terminal shoot on a runner is a viable planting unit (Perrow and Davy 2002).
    - Other growth forms require at least 3 or 4 shoots in the planting unit and the rhizome apical meristem (Perrow and Davy 2002). This includes *H. uninervis,* which has a di-meristematic leaf-replacing growth form, and likely *H. minor,* since other *Halophila* species have a mono-meristematic non-leaf replacing growth form (Short and Duarte 2001).

b. For growing and planting seedlings (generative methods, *E. acoroides* specific):

Given that adult *E. acoroides* plants are difficult to extract using seedlings is of particular interest. When using seeds/seedlings, there are some additional considerations for gathering fruits and rearing the plants. Since these techniques are still relatively understudied, below are some of the compiled methods used in previous studies.

Gathering fruits/seeds:

- Pollinated female flowers retract underwater and the fruit develops underwater, the mature fruit is up to 6cm, covered in soft spines, and attached to a spiral peduncle (Kuo and Den Hartog 2007, Dipper 2016) (Dipper 2016; Kuo ultrastructure).
- Each mature fruit may contain 6-10 seeds of different sizes (Ambo-Rappe et al. 2019) about 2cm long (Dipper 2016), fruit and seeds float to facilitate dispersal (see seagrass biology section)

Storage of fruits/seeds:

- Mature fruits can be transported for at least 2h in a dry container with no impact on the growth of the seedlings (Ambo-Rappe and Yasir 2015).

- Seeds will remain viable kept in the fruit and stored at room temperature for 2-11 days. However survivorship and growth rate was greatest when stored for only 2 days, and performance in the seedling phase is correlated to survival in the field (Ambo-Rappe and Yasir 2015)
    - Seedlings should probably not be stored in the fridge. Seedlings stored in a 4C fridge turned black and died after 2 days (Ambo-Rappe and Yasir 2015).

Growing seedlings in the lab:

- Seedlings can be grown in seawater tanks, in seed bags filled with marine sand (Tri 2008, Ambo-Rappe et al. 2019).
- Seedlings increase growth at higher temperatures (31 C vs 26C) whereas nutrient addition had little effect, suggesting young seagrasses are highly reliant on internal reserves (Artika et al. 2020).
- Seedlings can be transported to be planted in a cool box containing seawater without sediment (Ambo-Rappe and Yasir 2015).

When to plant:

- *E. acoroides* seedlings have been planted after 100 days (Thangaradjou and Kannan 2008) with some success, and after about 3 months when seedlings achieved a leaf length of about 250 mm and had 1-2 thin roots (Ambo-Rappe et al. 2019).

IV. Applying lessons from the Indo-Pacific to Guam:

a. Planting strategies- pioneer species and mixed plantings:

Since *E. acoroides* is the most common seagrass in Guam, and is considered a climax species, it would likely be the ultimate goal for seagrass restoration. To create *E. acoroides* beds, it may be more successful to use the "compressed succession" method used in Florida where a pioneer species is planted rather than the climax species (Kenworthy et al. 2018). A faster growing pioneer species or opportunist can better suit planting (Perrow and Davy 2002, UNEP-Nairobi Convention/WIOMSA 2020). However, unlike in Florida where seagrasses have a more demonstrated and well-studied succession pattern depending on nutrient inputs (Kruczynski and Fletcher 2012), there is less of a studied pattern in Guam. Rollon et al. (1999) found that *H. uninervis* established more quickly after disturbance than *E. acoroides* in multi species meadows in the Philippines. Perrow and Davy (2002) suggested using a faster growing seagrasses such as *Halodule* or *Halophila spp.* to initiate restoration for slow growing *Enhalus* species. *Halodule* and *Halophila* species are less deeply rooted and easier to dig up for transplant than *E. acoroides.* (Perrow and Davy 2002). Williams et al. (2017) also found that *H. uninervis* grew the fastest in an experiment in Indonesia that transplanted 6 common Indo-Pacific species of seagrass. In contrast, *E. acoroides* transplants can grow extremely slow. Another study in Indonesia found that *E. acoroides* monocultures did not show rhizome expansion like other species during the course of the 490 day experimental monitoring period (Asriani et al. 2018).

It is also possible *E. acoroides, H. uninervis,* and *H. minor* may simply grow in different conditions as well, rather than following a successional pattern. They have been observed to live in separate areas, and mixed, with *H. uninervis* existing interspersed in *E. acoroides* (pers obs. Dr. Kiho Kim). Another consideration, is that *H. uninervis* and *H. minor* seem to exist in fewer places in Guam so there could be a greater potential negative impact to source beds if transplantation failed.

Another potential strategy is to plant multiple species together since there is evidence of a "critical mass" and positive effect of biodiversity. In Indonesia, planted seagrass polycultures (multiple species, including *E. acoroides,* and *H. uninervis*, along with other species) have been shown to have higher survivorship and expand their benthic coverage more quickly than monocultures (Williams et al. 2017, Asriani et al. 2018). Although the mechanisms behind a biodiversity effect is not known, larger slow-growing species might help faster growing smaller species establish by reducing wave energy or exposure to herbivory, and smaller species might help rapidly stabilize sediments for the larger species (Asriani et al. 2018). The stabilized sediments and reduced wave energy may also help retain and grow nutrient pools, facilitating succession (Williams et al. 2017, Asriani et al. 2018). Another challenge of using multiple species, may be different best practices and protocols for the species, and different levels of knowledge about these protocols. The UNEP-Nairobi Convention/WIOMSA (2020) reviewed success with different tropical species, including those found in Guam:

- *E. acoroides:* Successful direct planting of adults, anchoring of adults, and use of lab-reared seedlings.
- *H.* uninervis : Successful direct planting of adults, anchoring of adults, and using cores/plugs, sods. However use of seedlings has been inconclusive.
- H*. minor:* has been attempted using direct planting of adults, anchoring of adults, using cores/plugs, sods, and seeds released in bags, however results have been inconclusive.

Another strategy may be to use both generative and vegetative methods at the same site. A recent study by Ambo-Rappe et al. (2019) tested using both transplants of *E. acoroides* adults and seeds, and found that using adult seagrasses to help protect seedlings improved seedling survival (although seedling survival was still low compared to transplant survival). In this study, adult seagrasses were transplanted into plots and seeds were taken and grown for approximately 3 months before being planted out into areas with adult transplants. After 24 weeks, survival of seeds was near 0% when there was no surrounding vegetation protection, and about 22% with "medium" and "high" density of transplants. Survival of adult transplants after 24 weeks was much higher than seedlings, with >80% surviving. Adult plants likely helped reduce wave energy to better allow seedlings to establish. (Ambo-Rappe et al. 2019) also planted seedlings at a high density which may have helped seedlings establish and stabilize sediments. Using this combination of generative and vegetative methods may be able to help increase genetic diversity in the area while also retaining the benefits of the greater survivorship of adult transplants.

b. Compilation of restoration experiments and projects in the Indo-Pacific:

A compilation of methods and other details from past seagrass restoration experiments and projects mentioned above can be found in a spreadsheet at:

https://drive.google.com/file/d/1VkTP551eoQ4yXNhYYMyYv5ltG6UPWA1K/view?usp=sharing

V. Monitoring Restoration Success:

Before planting:

- Count the number of rhizome apicals (for one out of 100 collected planting units) (Perrow and Davy 2002).

Monitoring frequency:

- (UNEP-Nairobi Convention/WIOMSA 2020) suggests monitoring should run for at least five years, with quarterly monitoring in the first year, bi-annual and eventually annual monitoring the following years
- (Perrow and Davy 2002) suggests monitoring for 4 years, with year 1 having monitoring at 60 days, 180 days, and 365 days, and bi annual monitoring for subsequent years.
    - Also suggests that remedial plantings can be made in year 2 and monitored

Measures of success:

Basic measurements include the weather and water quality parameters such as turbidity, dissolved oxygen, salinity, and temperature, which can help explain results (Thangaradjou and Kannan 2008, Wutthivorawong et al. 2011, Vichkovitten et al. 2016). (Perrow and Davy 2002, UNEP-Nairobi Convention/WIOMSA 2020) outlined measurements to take while monitoring seagrass restoration success as described below unless otherwise noted:

- Survivorship: can be recorded as an actual number and as a percent survival through time
- Leaf, rhizome, and root growth: can provide additional information in addition to survival, growth measurements can determine if seagrasses have acclimated to the new area and are growing. Growth of the rhizome also indicates horizontal elongation which could help patches grow or connect to other patches (Thangaradjou and Kannan 2008, Kiswara et al. 2010, Vichkovitten et al. 2016).
- Shoot Density: helps provide a measurement of asexual reproduction rates, random measurements can be taken and compared to control sites
- Area coverage: can be measured at different scales as appropriate until plants coalesce into an indistinguishable patch
- Video transects/Photo documentation: best from standardized positions, can utilize quadrats
- Ecosystem functions: can be measured as relevant restoration goals, examples include: biodiversity, water quality, sediment stability, fish densities, use as a nursery ground, carbon storage

VI. Past restoration project in Guam:

<u>1977 Seagrass Restoration Trials (No authors mentioned, document seems to indicate subsections of overall project, bullet points just information about that subsection/results):</u>

A. **Noted previous work that transplanted 21 clumps of *E. acoroides* along a gradient of depth from 10-18 feet that all died within 2 months**.
    - Likely, an example of why it is important to understand the life history and ecology before planting, this depth is deeper than most areas where you find *E. acoroides* in Guam
B. **Cleared eight 1 m^2 plots to determine the effect of removal of *E. acoroides,* additionally 4 of those plots had all roots and rhizomes removed from the soil.**

- After 12 months no signs of regeneration, which matches the findings of other studies

C. Surveyed around the island to determine optimal growth conditions for *E.acoroides*

- Found *E. acoroides* is the most abundant on inner reef areas and the deepest it is found is about at 1m during low tide.
- The most dense and "luxurious" areas were the inner tidal areas of Merizo which has a deep layer of mud
- Suggested that the areas that would benefit most from restoration were barren sand flats in inner Piti.
- Found small patches in Piti had as many as 40 fish of up to 5 species including *Apogonids, Acanthurids, Chaetodontids, Labrids, Scarids, Lutjanids*, and *Siganids* in *E. acoroides.*

D. Surveyed florescence:

- Flowering male plants were observed in Sept 1977, and June and July 1978 a few days before the full moon, and noted a lunar cycle. [no additional data or details]
- Female flowers, seeds and seedlings were not observed.

E. Laboratory studies:

*****A plug is a group of plants extracted from a bed with post hole digger. A turion is a single leaf group with a rhizome and attached roots)

a. adult transplants: 4 plugs and 8 turions were planted in a tank with flow through seawater and observed for 7 months.

- 3 out of 4 plugs had rooted themselves successfully after three months, but only 2 of the 8 turions exhibited root development after 12 months
  - most of transplants were dead or dying, roots turned black and died before new white roots appeared.

b. Salinity: 45 day old seeds were planted in sand and kept at salinities of 14 ‰, 24 ‰, and 33 ‰ for 18 days.

- Plants in 24 ‰ had the greatest growth of roots and leaf length, and those in 33 ‰ had lowest root development
- Unclear from the report if the differences were statistically significant

c. Nutrient Demand: 5 L of nutrient seawater was mixed and additional NaCl, H_3PO_4, and NH_4Cl was added to prepared seawater (more details included in original report) and 30 day old seedlings with clipped leaves were measured for regrowth.

i. There was no significant effects or trends observed, although indicator dye in the nutrient release tubes had not diffused out, which may mean nutrients were not delivered.

d. Rooting Stimulators: 80 *E. acoroides* seeds were put into 4 treatments and dipped either into (i) Rootone, (ii) Germin's Pentrex, (iii) vitamin B, (iv) nothing additional (control group) and then planted in peat.

i. There was no differences between Petrex and the control, Rootone caused seed bases to turn black

e. Depth of Planting: 40 seeds planted in a sand filled tank in 3 treatments: (i) exposed at the top of the sand, (ii) 0.5 cm, (iii) 1.5cm below the surface. (lists different depths in methods and results, these were the ones stated in the results)

   - **i.** Very significant effect on the average length of the longest leaf with increasing depth, which was 3.99cm, 5.94cm, and 6.56cm, respectively with depth
   - **ii.** However percentage with root development had an opposite trend, with 98%, 69% and 15%.

F. Field Studies:

- **a.** Seedling field planting:
   - i. Close to 100% success except in scour areas such as the inner reef margin
      1. The few failures were attributed to the burrowing and sand displacement activities of an *Arenicol sp*. Worm, a homarid crustacean, and a gobiid fish
   - ii. Peat pots were considered the better methods rather than baffles, taking less time to prepare and being able to be left in place without harm to waders. Direct planting (assuming this means without structure) was generally unsuccessful, except for those planted in muddy areas with little current
   - iii. No seedlings had signs of rhizome growth after 1 year
      1. No data on blade length or other measures of seedling health
- **b.** Adult transplanting field planting: 20 plugs and 20 turions were transplanted into the field at “Flat D” of inner Piti channel, chosen for its lack of seagrass.

   *Seems to be this location which is mentioned early in the report, however the location was not explicitly mentioned again in the methods or results section
   - **i.** 10 were anchored in place with short sections of rebar, and the rest were left unanchored
   - **ii.** No data was available at the time of this report on this section

G. Conclusions made in the study:

- **a.** Recommended introducing other faster growing Micronesian seagrass species such as *Thalassia hemprichii* and *Syringodium isoetifolium*
- **b.** Transplants were less successful, and areas where transplants were taken from did not grow back within 12 months. The authors recommended transplanting attempts be discontinued. Instead, the study recommends the most successful method for starting seedlings was in peat pots filled with sand
- **c.** Transplants and seedlings have established in the field, but none showed horizontal growth via rhizomes within the year

H. Additional notes:

- a. Author mentions “The benefits of *E. acoroides* beds to juvenile fish as habitat and feeding stations is particularly obvious in the inner reaches of Apra Harbor.
- b. Authors were unable to find *E. acoroides* seeds, all the *Enhalus* seeds used in the field and lab experiments were imported from Yap and Chuuk
   - i. Dr. Kiho Kim mentioned in his work in Guam’s seagrasses he has seen flowers occasionally, but there was no particular season, and his work was not focused on reproduction.

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PAST MANGROVE RESTORATION PROJECTS IN GUAM

Due to the multitude of easily accessible and comprehensive mangrove restoration manuals available for the Pacific region, this literature review will focus on what projects have been conducted in Guam rather than restoration techniques and best practices.

<u>In response to 1980 Sasa Bay Oil Spill:</u>

- Mangroves were planted in response to a large oil spill, there are some pictures, however missing more detailed records on the number planted.

<u>In response to the 1983 oil spill in Sasa Bay (as recorded in PBEC 1983):</u>

- GORCO immediately sprayed off oil from rhizophora roots, which likely reduced the impacts of the oil spill
- Before planting, dead trees were cut and removed to reduce potential damage to young trees by debris moved by tides or wind.
- In the first round of planting *Avicennia* seeds that had just fallen off trees were planted. Previous efforts to transplant seedlings of avicennia marine alba were unsuccessful, and despite planting seeds at different depths and in both firm and soft substrate, all 250 seeds did not show signs of growth. Potential explanations for the lack of growth was that the area was relatively higher and inundated only during the highest tides, exposed too intense direct sunlight (as opposed to shade by the parent tree), or predation (PBEC 1981 and 1982 and cited by PBEC 1983).
- Additional plantings in the following months planted *Rhizophora,* including in areas where *Avicennia* seeds had failed to sprout.
- A total of 283 hypocotyls were planted, and 51 *Avicennia* an *Rhizophora* volunteers (plants that begin growth without the aid of planting) also started growth
- Sediment samples decreased in level of petroleum ether extractable substances, from an initial level of 11.000 g/kg to 0.497 g/kg nine months later. A GEPA memo suggests that healthy mangrove communities likely contain less than 1.0 g/kg.

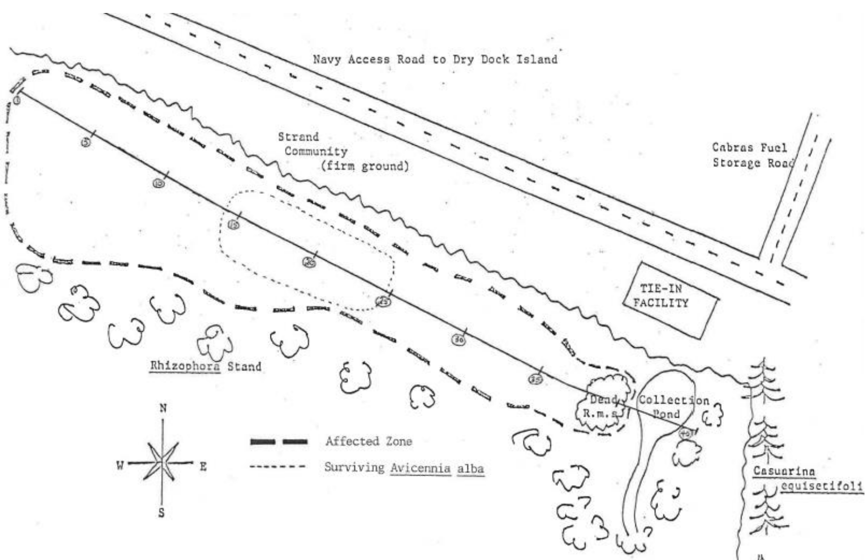

Figure 2. Map of the impacted mangrove community at the Gorco-Navy Tie-in Facility at the northeast end of Sasa Bay. Numbering of rows along the transect line is shown including the area which contains surviving Avicennia alba trees. This figure is adapted from a GEPA Intra-Agency Memorandum dated January 4, 1982 from Dana M. Rowley.

- There were reported difficulties with establishing *Rhizophora* in higher areas that were covered by water, which were attributed to multiple causes such as predation, inability of roots to growth deep enough to stay wet. It was suggested to first grow *Rhizophora* in a nursery and transplant seedlings into deeper holes or to plant at high tides.
    - Based on current best practices, managers are advised to avoid planting in places without suitable hydrology
- No data was provided in this particular report on death or recovery of wildlife populations
- Further recommendations by GEPA suggested planted more *Rhizophora* more evenly though out the damaged area

Table 1. Record of mangrove plantings for the restored area at the GORCO/ Navy Tie-in site, where (H) = hypocotyls and (S) = seeds.

Date	Species Planted	Rows Planted	Total Number Planted	Notes
Sept. 20 1982	Avicennia marina alba (S)	1-29	256	Planted 2 seeds per location
Oct. 14 1982	Rhizophora mucronata stylosa (H)	30-45	70	
Nov. 30 1982	Rhizophora mucronata stylosa (H) and Rhizophora apiculata (H)	1-12, 21-29	108	Replanted area due to high mortality of Avicennia seeds.
Jan. 7 1983	Rhizophora mucronata stylosa (H)	1-29	105	Includes 3 Brugiera gymnorrhiza planted in Row 21. Number includes 31 replacements

Total Avicennia marina alba seeds planted = 256
Total Rhizophora hypocotyls planted = 283
Total Seeds and hypocotyls planted = 539

Total approximate number of Avicennia and Rhizophora volunteers as of 1-7-83 = 51

Potential Restoration 2010, was not completed

In response to pipeline refurbishment in Sasa Bay, Tristar Refurbishment of Fuel Cargo Lines by Duenas & Camacho 2014/2015 (Jessica Gross pers. comm. 2020)

- Planting was conducted at two sites: Sasa Bay by bridge, and at the Marianas Yacht club (MYC)
    - Sasa bay site included three 25m x 25m plots, MYC had three 8m x 8m plots
    - “No net loss” policy for MPAs, required compensatory mitigation ratio of 2:1 and GEPA requirement required planting .02 ha at impact site and .02 ha within the same MPA
    - Planting did not actually take place at impacted site, which did not have enough space, and also may be disturbed in the future for more pipeline repairs
    - Sites were chosen for easy access for planting and monitoring, in areas where mangroves were already present at similar elevation, salinity, and water temperature
    - *A. marina* and *R mucronata* were planted because they were the species impacted by the pipeline

- Species composition varied between plots and was recorded before planting simply to get a better idea of mangrove forest structure due to the lack of literature
    - Sasa Bay had dense stands dominated by adult *A. marina* and *R. mucronata* in plots 1 and 2, plot 3 was disturbed with smaller stunted mixed mangrove and upland species
    - MYC was dominated by *L. littorea* overstory with regenerating *R. mucronata*. Only plot 2 had *A. marina.* Trees were more similar in height.
- At both sites approximately 250 *R. mucronata* and 50 *A. marina* were planted within each .02 ha area
    - Planting was not done in rows, aiming to imitate nature, *R. mucronata* were planted close together with 3 or more closely next to each other so that if a few died off around each other, there would still be one in the center, and so seedlings could support each other with intertwined root systems
    - Several month timeline, seeds were collected while trees were fruiting, and planted during the rainy season which is advised
    - Seeds were collected at the site, *A. marina* seeds were soaked in water before outplanting
    - Seeds were grown in cups and protected from predation by placing in other buckets and/or covered with tekken or other netting until large enough to be planted with being washed away
    - No additional soil was used aside from what was on site. Sasa Bay being more mucky soil and MYC sandier
- Site was revisited up to one year after planting, survival was high at Sasa Bay (estimated 85%), and low at MYC (estimated 5-10%)
    - *A. marina* planting was too time consuming due to high crab predation and high loss through incoming tides.

Naval Base Restoration by Comite Resources (ongoing)

- According to website, mangrove restoration intended to restore ecosystem services impacted by the creation of the naval base.
    - https://comiteres.com/projects/mangrove-restoration/
- Project plant in review by Navy, limited information available to be shared currently (pers comm. Dr. Robert Lane, July 2020, COO Comite Resources)

EDUCATION AND OUTREACH PROGRAMS: PAST ACTIVITIES AND SUGGESTIONS

Need and Interest in educational programs:

A study by Dr. Romina King's in 2010 used household surveys to measure perceptions of the residents in the Manell-Geus Watershed area. The results showed that a lack of knowledge regarding environmental conditions such as the abundance of wildlife and unfamiliarity with the concept of ridge to reef and watersheds. Mangroves and seagrasses are an important part of the ridge to reef conservation strategy and help reduce runoff, stabilize sediment, and improve water quality for coral reefs.

Multiple natural resource managers identified a lack of awareness of the importance of seagrasses and mangroves, and potentially negative associations, as a major impediment to conservation. Currently seagrasses and mangroves are not formally listed as vocabulary terms in elementary through high school curriculum, although they may be incorporated into discussions of "ecology, Micronesia's environment, and effects from human impacts on environmental resources". In light of the need for more formal and informal educational efforts, this section outlined past related educational activities and suggests potential future outreach materials to be created.

<u>Past Awareness Campaigns:</u>

The following information was provided from discussion with Jane-Marie Dia, Guam Department of Agriculture

Piti Pride Campaign:

The Piti Pride campaign focused on increasing support for the Piti Bomb Holes marine preserve and especially targeted fishing groups. The campaign enhanced awareness, increased communication between fishermen about the preserve, and featured a breakdown of effective marketing strategies.

Seagrasses within the Piti Bomb Holes preserve were mentioned as an area to raise awareness of in the future since they are at risk of repeated trampling. The campaign can be used as an example for future outreach campaigns.

<u>Past Informal and formal education:</u>

The following information was provided from discussion with Marybelle Quinata, former GCCRMP coordinator, and Joni Kerr, Professor at Guam Community College.

Guam Community Coral Reef Monitoring Program (GCCRMP):

The GCCRMP created in 2012 engages the community through citizen science monitoring efforts of coral, seagrass, and benthic macroinvertebrates at various sites around Guam. Volunteer training includes a background on coral reef ecology, practicing monitoring protocols on land, and then in water monitoring. After monitoring, results were printed onto postcards and mailed to share with participants. The program works especially well in service learning environments with high school or college students due to the classroom providing more background.

One of the many benefits of the program is to encourage people to look more carefully and develop an appreciation for the seagrasses. More commonly, people may go through seagrass to access reef areas, and may feel uncomfortable, especially with the grasses touching them. However actively looking through the seagrass can help increase comfortability and foster appreciation by highlighting seagrass associated wildlife such as small invertebrates or cryptic fish.

The GCCRMP also is the lead organization running the Science Sundays program, which brings in guest speakers such as UOG scientists, GCCRMP interns, and other experts to talk about their research or other relevant topics to Guam, CNMI, or other parts of Micronesia. Mangroves were also featured in a Science Sunday in the spring of 2018 with speaker Jessica Gross, an environmental specialist with Duenas, Camacho & Associates Inc.

Guam Nature Alliance

The Guam Nature Alliance is a government-affiliated organization, originally stemming from the Guam EPA. Major GNA events include their Ridge to Reef (R2R) adventures with snorkeling and hiking, Earth Day festivals, clean ups, and Earth month social media challenge. Activities are targeted to an audience of families with kids and students.

Some R2R adventures included visits to places where participants could see mangroves. At Merizo, participants could kayak among mangroves, explored to Geus River, snorkeled near the volleyball court, and viewed environmental displays at the community center.

At a Sasa Bay Earth Day event, mangroves were also featured at the Marianas Yacht Club. The day included kayaking, environmental displays, and puppet shows. The event also had a more in depth look at mangrove biology with a guided tour of the mud flat, a mangrove scavenger hunt/guide, and activity booklet facilitating observation. Kayaking has one of the most popular activities.

Life on Guam Book Series:

Life on Guam was “a project to produce relevant class, lab, and field materials in ecology and social studies for Guam junior and senior high schools.” Funding was provided through a grant under the Elementary and Secondary Education Act (ESEA) Titles III and IV from the US Office of Education–Department of Health, Education and Welfare. The series includes multiple guides and activity books on Guam’s various terrestrial, freshwater, and marine ecosystems, as well as schoolyard ecology and gardens. The mangrove ecosystem is represented in its own book “Mangrove Flat” and seagrasses are described on a page within the book “Beach Strand”

The resources are a great source of ecological information and science based activities, however the quality of the printing and style of the books could be updated.

University of Guam Marine Lab

For younger students, the University of Guam 4H program runs high school and middle school camp programs with programming focusing on fisheries.

Guam Community College

The Guam Community College program includes courses in marine biology.

GCC student participation in GCCRMP surveys since 2014 has been successful, and choosing sites such as comparisons between MPs and unprotected areas can show the value of management. Survey findings showing greater amounts of sea cucumbers or differences in water clarity between sites have given students a deeper understanding of environmental issues and management.

Past and Current Educational materials:

- Life on Guam series
- Kika Clearwater activity book (provided in Guardians of the Reef Program)
- GCCRMP ID cards
- Division of Aquatic and Wildlife Resources Fish and wildlife fact sheets
- Guam Nature Alliance Mangrove Scavenger Hunt, Bookmark

Future directions for enhancing outreach:

- Development of an coloring and activity book focusing on holistic coastal management for younger elementary school students
- Surveys to understand knowledge, attitudes, and perceptions to mangroves and seagrasses
    - The 2016 National Coral Reef Monitoring Program Socioeconomic Monitoring Component in Guam draft mentioned asking participants about mangroves, the next set of surveys might also seek to ask questions about seagrasses and magnroves
- Community based monitoring and restoration programs
- Future work with the Guam Nature Alliance Program
- Creative celebrations by artists and students, art competitions (either local or participation in global opportunities)
- More easily accessible media such as videos, interactive adventures/fieldtrips, and social media content
- Teacher requested materials (connecting with teachers to see what products or experiences we could develop would be of best use for them)

Other global educational resources and citizen science programs:

- **Project seagrass/SeagrassSpotter App:**
    - https://www.projectseagrass.org/education/
    - https://seagrassspotter.org/
- **SeagrassWatch:**
    - https://www.seagrasswatch.org/manuals/
    - https://www.seagrasswatch.org/education/
- **Mangrove Action Project:**
    - https://mangroveactionproject.org/mangrove-education/

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Committee on Human Subjects Research (CHRS)
Institutional Review Board

Date: October 20, 2020

TO: Cara Lin, Principal Investigator
Whitney Hoot, Co-PI
Marie Auyong, Co-PI

FROM: Peter R. Barcinas

CHRS Committee Chair

UOG CHRS Chair Signature

Title:	**Understanding Use and Perceptions of Seagrass and Mangrove Ecosystems in Guam**
CHRS#:	20-127
IRB Review Date:	October 09, 2020
Effective Date:	**October 20, 2020**
Effective Expiration Date:	**October 19, 2021**
IRB Review Type:	**Expedited Review**
IRB Review Action:	**Approval**

Dear Cara Lin, Whitney Hoot and Marie Auyong:

The Institutional Review Board (IRB) of the University of Guam has approved your study. Your study meets the **Exempt review** under federal guidelines 45 CFR Part 46.101(b)(2) Category 2 and poses no more than minimal risks to participants.

All participants will have their rights explained in the **Cover Letter**. Consent to take part in the research will be obtained by the completion of an **Informed Consent Form**, and this is appropriate for the study. Participants may withdraw at any time without penalty, and no physical or emotional harm is expected to accrue to the research participants. The research protocols described for this online study must ensure compliance with the principles of voluntary participation, informed consent, anonymity, and confidentiality and privacy of the participants. Data collected from all participants will be adequately protected and appropriate data collection protocols are in place.

Should any modifications or procedures change in your survey, please inform the IRB committee of those changes. The IRB will review the amended procedures prior to implementation. Should the project extend beyond a 1-year period, please submit an extension request.

INFORMED CONSENT:

Project Title: Understanding Use and Perceptions of Seagrass and Mangrove Ecosystems in Guam

This survey is part of a Department of Agriculture effort and results may be published, presented, and used for natural resource management decisions. All information gathered is completely anonymous and confidential and will remain so in any future reports or presentations using data collected from this survey. Only researchers will be able to access the data.

Any answers involving illegal activities, such as harvesting from marine preserves, are completely anonymous and will not be reported to any authorities or result in any penalties.

Paper surveys with data will be stored in a locked office and digitized information will be stored on a password protected computer. Data files may be backed up on a cloud services but will not be shared. All paper and digital files will be destroyed by December 31st 2024

Participation is completely voluntary and you are not obligated to answer any questions. You may stop the survey at any time you wish with no penalties.

This survey is not expected to have any significant emotional or physical risks, however if injury does occur financial compensation will not be provided. If you have any questions you may contact cara.lin@doag.guam.gov or (671) 777-4432. By checking the box below you are acknowledging that you are providing informed voluntary consent for your participation.

☐ I am checking off this box certifying that I provide my voluntary and informed consent in participating in this survey as described above.

Please provide the following demographic information:

Age________

Village ____________________

Occupation _____________________

If interested in attending ocean conservation events, check off the 3 best times you're available.

	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Morning							
Afternoon							
Evening							

CHRS#: **20-127**
Approval Date: October 20, 2020
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Survey Questions:

[Interviewer: Go over quickly what seagrasses and mangroves are with pictures, ask for mangrove answers first then seagrass answers]

Part 1. Ecosystem Services

1a. In your opinion, would removing mangroves have a positive, neutral, or negative impact on the island community? You can also say you are not sure. *[circle one]*

1- Negative
2- Neutral
3- Positive
4- Not sure

1b. In your opinion, would removing seagrasses have a positive, neutral, or negative impact on the island community? You can also say you are not sure. *[circle one]*

1- Negative
2- Neutral
3- Positive
4- Not sure

[Interviewer: Based on answer above, use negative, positive, or both
Use the lists below for both mangrove and seagrass responses
Check the bubbles to indicate mangrove responses, underline for seagrass responses]

2a What effects, positive or negative, might there be if *mangroves* were removed? *[do not prompt, **check off** answers]*
2b What effects, positive or negative, might there be if *seagrasses* were removed?*[do not prompt, **underline** answers]*

Negative:

- Shoreline erosion
- Less seafood
- Loss of other resources
- Less wildlife habitat
- Lower coral reef health (see more specific answers below)
- Worse water quality
- More sedimentation of coral reefs
- More nutrients reaching coral reefs
- More toxins reaching coral reefs
- Loss of nursery area for fish
- More carbon in the atmosphere
- Harming nature or other intrinsic value (eg. natural beauty)
- Loss of cultural value
- Loss of recreational area
- Lower biodiversity
- Other _______________

Positive:

- More or easier beach access
- Fewer mosquitoes
- Better view and aesthetics
- Better water clarity and quality
- Room to create docks, buildings
- More fish
- Other ____________

Reminder: did you ask about mangroves **AND** seagrasses in the previous question?
Survey can now be given to participant

Part 2. Personal experiences with mangroves and seagrasses

<u>Some questions in the following sections may not apply based on the previous answer</u>

*<u>If so, please write or **mark N/A**</u>*

3a. How often do you spend time in, or pass by mangrove areas?

- never
- rarely (once every few years)
- sometimes (1-2 times per year)
- often (a few times per year)
- very frequently (at least once a month)
- frequently within a certain season

3b. How often do you spend time in, or pass by seagrass areas?

- never
- rarely (once every few years)
- sometimes (1-2 times per year)
- often (a few times per year)
- very frequently (at least once a month)
- frequently within a certain season

4a. Why do you spend time in or pass by mangrove areas?

- N/A
- Random, passing by
- Recreation/spending time with family
- Fishing
- Gathering other seafood (eg. crabs)
- Gathering wood or other materials
- Other: ______________

4b. Why do you spend time in or pass by seagrass areas?

- N/A
- Random, passing by
- Recreation/spending time with family
- Fishing
- Gathering other seafood (eg. sea cucumber)
- Other: ______________

5a. If you gather any fish, other seafood, or other materials from mangrove areas, what do you gather?

5b. If you gather any fish, other seafood, or other materials from seagrass areas, what do you gather?

6. We are trying to understand how mangroves or seagrasses have changed in the past decades. Have you noticed any changes in mangroves/seagrasses areas, or the fish or other wildlife in those areas? (increase, decreases, changes in species, water clarity, amount of sediment, number of people using the area, etc.) **Please try to describe a place and time if possible.**

Part 3. Management

7a. More resources (funding, people, time, etc.) should be used to protect mangroves.

1- Disagree
2- Neutral
3- Agree
4- Not sure

8a. Circle the 3 most effective ways to protect mangroves: *[check off 3]*

- Education signage
- Scientific research and monitoring
- Outreach to general public
- Education for students
- Reducing community use
- Legal protections- regulating development
- Legal protections- reducing pollution
- Legal protections- better enforcement of existing regulations
- Restoration- replanting in degraded areas
- Volunteer programs- replanting and monitoring
- N/A
- Other ________________

7b. More resources (funding, people, time, etc.) should be used to protect seagrasses.

1- Disagree
2- Neutral
3- Agree
4- Not sure

8b. Circle the 3 most effective ways to protect seagrasses: *[check off 3]*

- Educational signage
- Scientific research and monitoring
- Outreach to general public
- Education for students
- Reducing community use
- Legal protections- regulating development
- Legal protections- reducing pollution
- Legal protections- better enforcement of existing regulations
- Restoration- replanting in degraded areas
- Volunteer programs- replanting and monitoring
- N/A
- Other ________________

Please return the survey back to the interviewer for a few more questions.

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Approval Date: October 20, 2020
Expiration Date: October 19, 2021

9a. Are there any reasons why more effort or resources should not be used to protect *__mangroves?__* *[not prompts, __check off__]*
9b. Are there any reasons why more effort or resources should not be used to protect seagrasses? *[no prompts, __underline__]*

Other issues are more important:

- Protecting our coral reefs is more important
- Addressing other environmental issues such as deforestation, pollution, etc. is more important
- Other government priorities are more important (healthcare, education, access to food and water, etc.)
- Environmental problems in Guam are on too big of a scale for us to make a significant impact

Ecosystems do not need protecting

- They have not been significantly impacted
- They are not valuable or important
- People already use these areas sustainably

Affects the economy or economic activity negatively:

- Removing them would be better for our economy

Interference with individual rights:

- Too much government regulation, let individuals and communities lead efforts to protect them
- Do not want more preserves, or to add to current preserve restrictions
- Restrictions would harm individuals ability to gather food or resources
- Do not want more interference in personal activities

No reasons:

- There are no reasons not to use more effort or resources to protect mangroves/seagrasses

Other:

- Other ___________________________________

__**Reminder:** did you ask about mangroves **AND** seagrasses in the previous question?__

Understanding Use and Perceptions of Seagrass and Mangrove Ecosystems in Guam

Cara Lin, Guam 2020-2022 National Coral Reef Management Fellow

October 2022

Introduction:

Seagrasses and mangroves provide valuable ecosystem services such as nursery habitat for fish, blue carbon sequestration, erosion prevention, water quality enhancement, and improved coral reef resiliency. Despite their importance, little is known about how mangroves and seagrasses are used or valued by the community in Guam.

A 2010 survey conducted by Dr. Romina King used household surveys to measure perceptions of the residents in the Manell-Geus Watershed area [1]. The results showed a lack of knowledge regarding environmental conditions, and unfamiliarity with the concept of ridge-to-reef conservation and watersheds. Although there was not a focus on mangroves and seagrasses in this survey effort, these ecosystems are also an important part of the ridge to reef conservation strategy and help reduce runoff and stabilize sediment. Overall, informational interviews with multiple current and past natural resource managers who are familiar with Guam indicated that there has been very little focus on seagrasses and mangroves, and efforts to increase public awareness of their benefits would be a critical component of conservation strategies.

Since this 2010 survey, there has been no information regarding public perceptions of seagrass and mangrove habitats. The purpose of this survey was to provide updated and more focused information regarding seagrasses and mangroves. There is very little knowledge and observations of these areas, whether inside or outside marine preserves, so seeking public input can help provide a better historical perspective of any changes. The survey also sought to see if these ecosystems are utilized for seafood or gathering other materials.

Additionally, King's 2010 study sought feedback from participants regarding potential outreach activities. The survey reported 20% of participants joined in on a watershed project in 2009 and 57% were interested in joining one in the future. Respondents also responded that they wanted more activities for youth. Another goal of this new study was to determine what conservation actions Guam's community felt were most effective and were most supportive of.

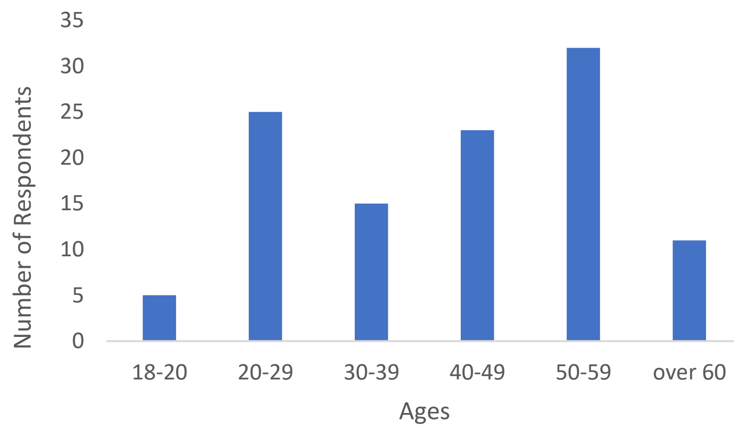
Methods:

This survey was developed in fall 2020 with input from multiple natural resource managers to ensure questions were culturally relevant, informative for conservation issues, and clearly written. The surveys consist of 9 questions (most are two-part questions to address both mangroves and seagrasses) and took approximately 5-10 minutes to complete. The survey was submitted and approved by the University of Guam Internal Review Board (CHRS#: 20-127) to ensure proper precautions were taken for the privacy and safety of the respondents. All responses were anonymous with no identifying information and participants were informed that sharing any information regarding illegal activities would not result in any reports to authories or penalties. Prior to conducting the survey, respondents were shown pictures of mangroves and seagrasses to help reduce confusion with other coastal and marine plants. Surveys were conducted in two locations, twice in a central location (Agana Shopping Center) on 04/25/21 and 05/01/21, and once at a southern location (Merizo Pier) 05/14/22.

Results and Potential Management Recommendations:

Survey demographics:

In total we had 124 individual respondents or submissions. However, it is important to note that often couples, families, or other groups of people would take the survey together, sometimes putting down the same or very similar answers, or discussing with each other. The 124 responses were from 111 groups. The average age was 41.



A few responses were excluded due to accidental improper survey techniques (eg. participants continued answering while self-guided in portions of the survey that were meant to be verbally guided). The majority of respondents were from central and northern villages, with only 10 respondents from the village of Merizo despite surveying at Merizo Pier.

Overall respondents think loss of mangroves and seagrasses would be negative for the island community:

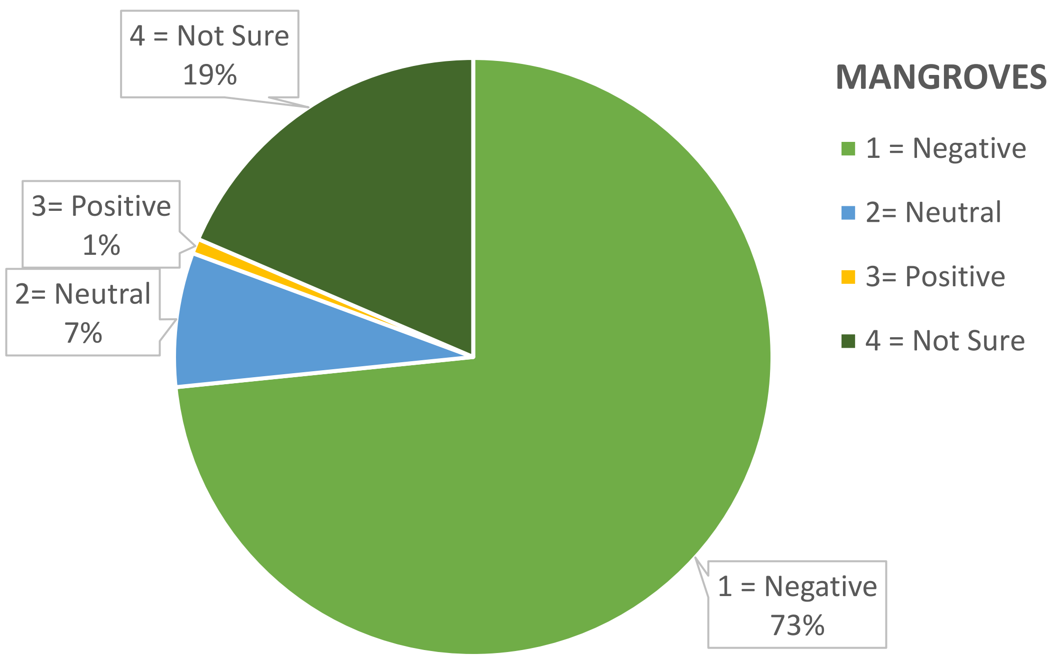
A large majority of respondents, over 70% for both mangroves and seagrasses, thought that removing mangroves and seagrasses would have negative consequences (fig. 1) Only a very small percentage, 1% for mangroves and 3% for seagrasses, thought removing these habitats would result in solely positive outcomes (fig. 1)

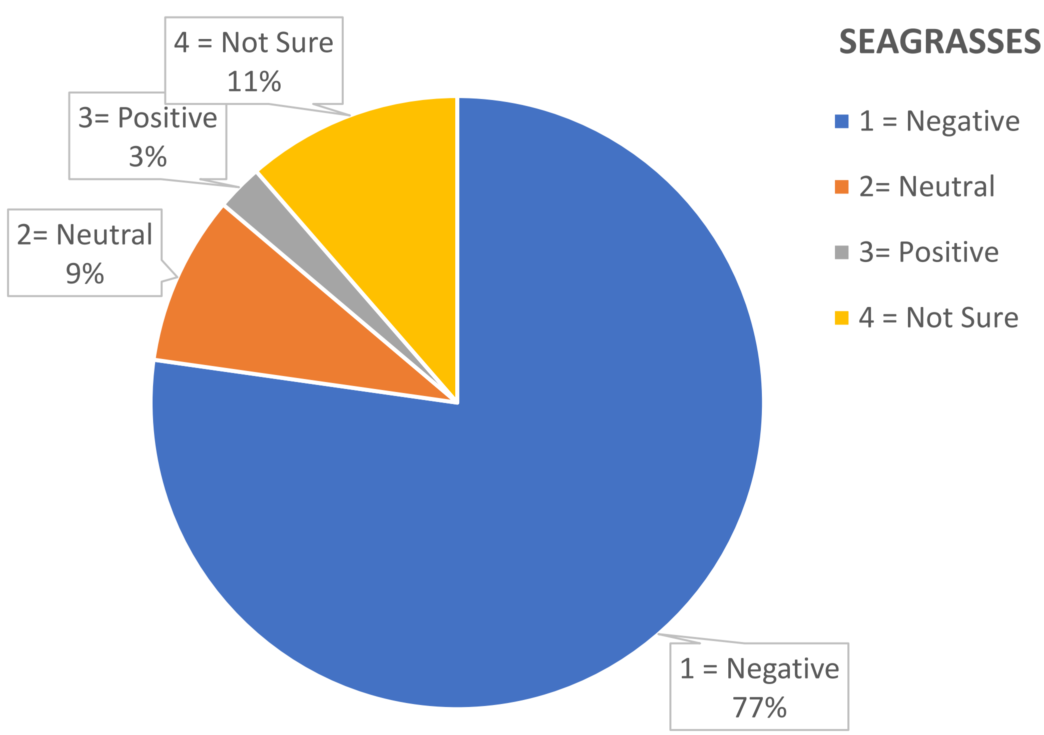
The remaining percentage of respondents answered “neutral” or “not sure”. Participants were informed of the difference between these categories, where “neutral” refers to when there are both positive and negative outcomes, and “not sure” simply refers to feeling hesitant to state an opinion due to a lack of information.

Respondents who responded “neutral” or “not sure” considered factors such as:

- how much would be removed and for what reason, people may need water access
- with less seagrass and mangroves there might be less debris in the water
- seagrasses are uncomfortable or scary to navigate through
- lack of knowledge about any benefits

Figure 1. Percent response to question 1a/b- "In your opinion, would removing mangroves/seagrasses have a positive, neutral, or negative impact on the island community? You can also say you are not sure."





➔ **<u>Potential Management Actions:</u>** Several respondents specifically noted they felt they had a lack of information about the topics, and would appreciate more information. Providing more educational opportunities seem s like something that some community members may find useful.

Mangroves and seagrasses are perceived as valuable for wildlife

Table 1. Question 2a/b *"What effects, positive or negative, might there be if mangroves/seagrasses were removed?"*		
Key words/Response Categories for NEGATIVE impacts of removal: *highlighted categories have over 10 responses		
	for mangroves	for seagrasses:
wildlife	30	32
ecosystem	12	4
harms nature	18	16
erosion	31	7
typhoon	8	1
oxygen	10	9
carbon	1	1
coral	3	2
fish	29	41
nursery	7	3
crab	15	1
water quality	3	5
runoff	2	0
turtles	0	13
cultural	2	0

Most respondents indicated that removing these habitats would have negative consequences. Of these respondents, most mentioned negative impacts on of wildlife and fish for both seagrasses and mangroves (table 1). Many respondents also mentioned an appeal to keeping nature intact for an unspecified but certain value, and a few also mentioned aesthetic or cultural value.

Anonymous quotes:

"just leave it alone, let it be, it's not doing anything, It was here before I was, it must be there for a reason. They play a role, they give back"

Although many respondents associated the habitats with fish, mangroves had more responses regarding crabs (mangrove crabs mostly), and seagrasses were more specifically associated with turtles. There were also a few mentions of nursery habitat and fish eggs.

Mangroves were also associated noticeably with erosion prevention and protection from typhoons.

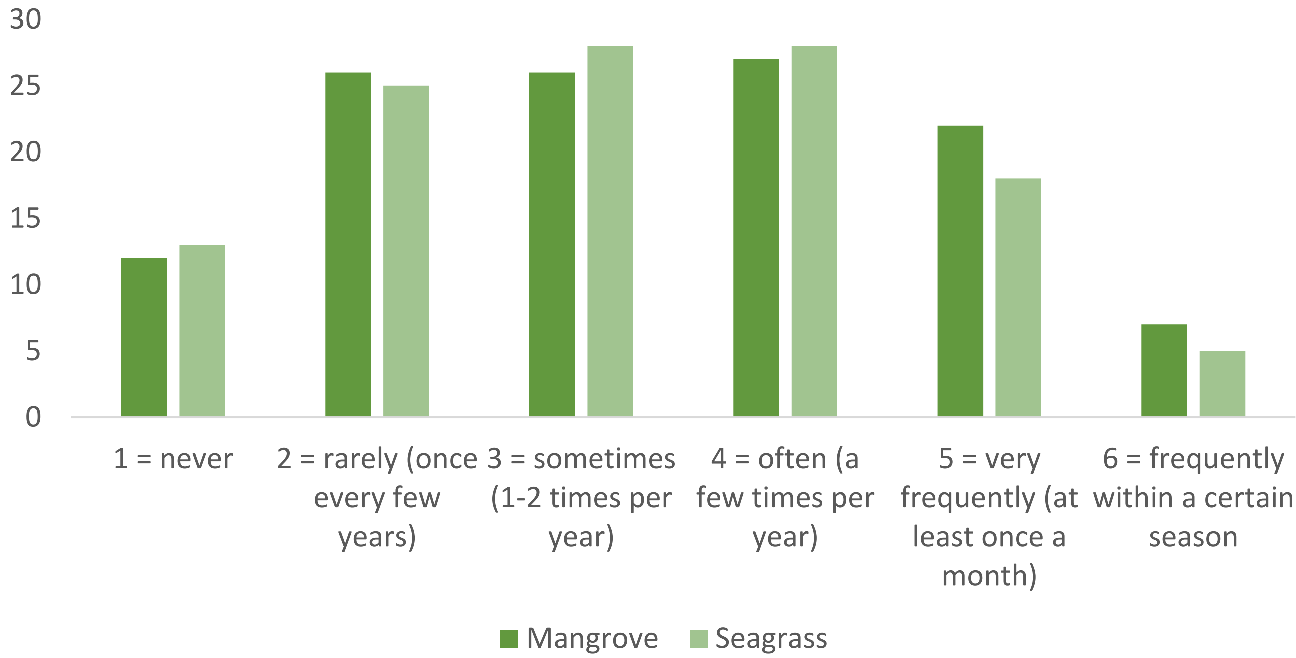
Although there was a few mentions of pollution and stabilizing sediment, the vast majority of respondents did not mention the impact of mangroves and seagrasses on water quality or connections to coral health. Additionally, there were some mentions of oxygen production for both habitats, there was only one respondent who made a connection to carbon storage and climate change.

➔ **Potential Management Actions:** There already seems to already be a stronger sense of value of these ecosystems regarding wildlife and fish habitat. Building on this emphasis on wildlife could help further celebrate these habitats.

Alternatively, increasing outreach about how these ecosystems impact water quality, the importance of water quality, and connecting water quality to wildlife may be area to work on increasing awareness.

Mangroves and seagrasses are areas sometimes used for recreation and gathering seafood

Figure 2. Responses for question 3a/b- *How often do you spend time in, or pass by mangrove/seagrass areas*?

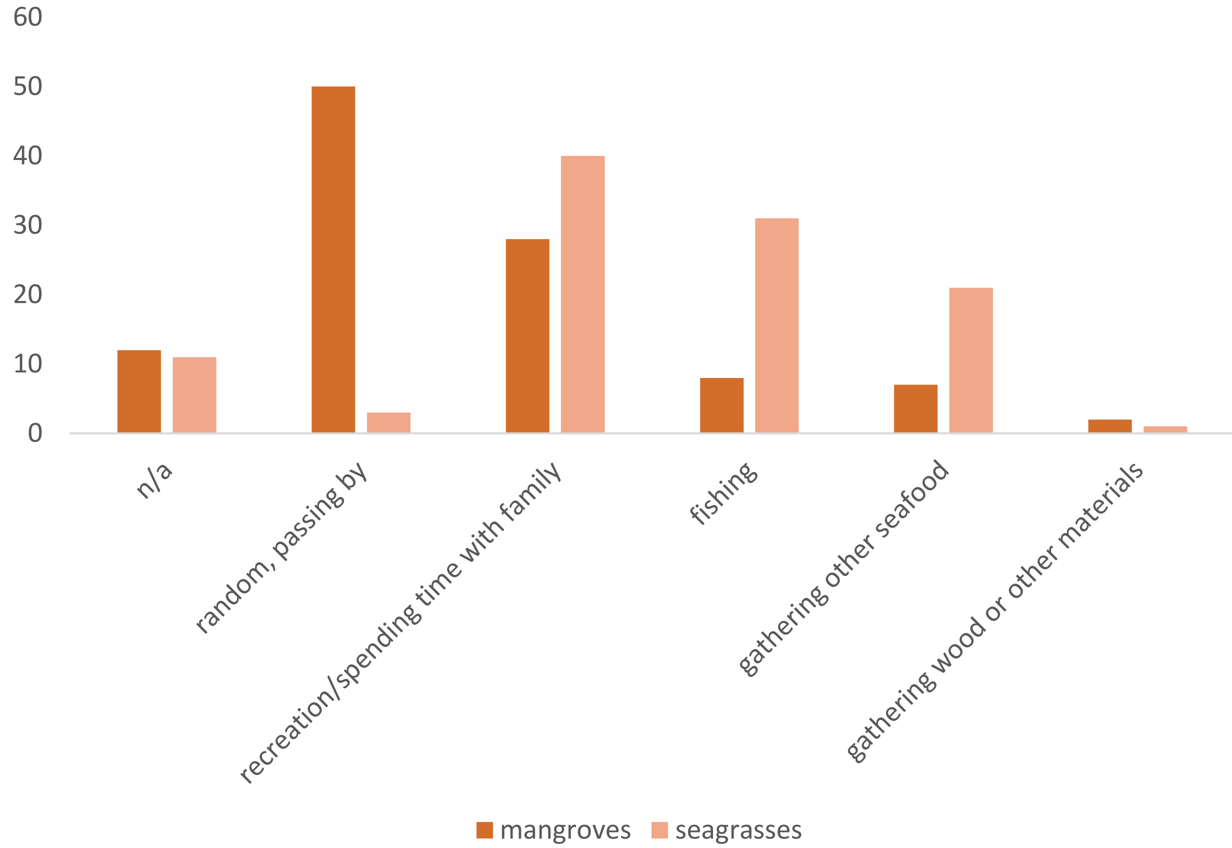


A large amount of respondents, over half, noted that they visited mangroves and seagrasses at least once or twice a year or greater (fig. 2). There did not seem to be more visitation of seagrass despite the larger amount of seagrass areas around the island.

However, the majority of visits for mangroves were “random, passing by” and not for any particular purpose, followed by recreation (fig. 3). Seagrasses were not as often randomly passed by, and instead were more often noted as areas used for recreation, fishing, and seafood. Seagrasses seem to be used more for fishing than mangrove areas.

➔ **Potential Management Actions:** Since seagrasses appear to be used for recreation, emphasizing recreational guidance for seagrasses may be important (eg. avoid trampling them by going at high tide if possible and snorkeling, or at least avoid walking

Figure 3. Responses for question 4a/b- *"Why do you spend time in or pass by mangrove/seagrass areas?"*



Mangrove crabs and fish are harvested from mangrove and seagrass areas

Table 2. Question 5a/b- *"If you gather any fish, other seafood, or other materials from mangrove /seagrass areas, what do you gather?"* **Number of responses that contain the word:**		
	for mangroves	for seagrasses
crab	19	2
cucumber	1	2
shell	5	5
fish	14	20
trash	2	4
other notable answers:		
	normally fishing eels for food consumption	mañåhak, ti'ao
	clams, small fish (~2 inches)	tiao, mañåhak, mafute', etc.
	satmoneti, clam, octopus	clams
	tuna	usually sesyon
*likely swapped answers	laphlapn (unclear written text) and sea cucumber	rocks
	wood for fire	oysters & sea urchins
	branch	for sport, catch and release
	food, decoration	

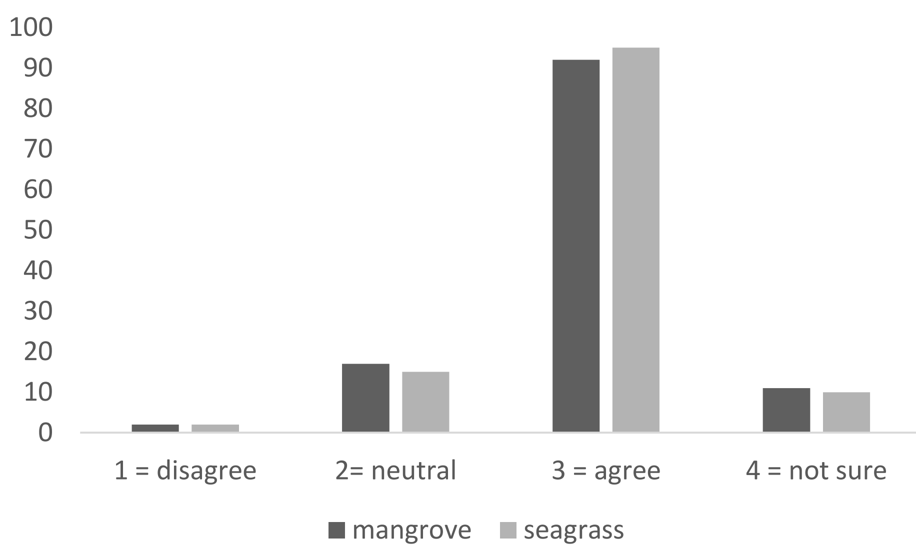
Survey results indicated a small percentage of respondents use these areas for primarily seafood (11% use mangroves to gather fish, 15% use mangroves for crab collection, and 16% use seagrass for gathering fish. Some participants elaborated and mentioned particularly fishing for satmoneti in mangrove areas, and mañåhak, sesyon, ti'ao, and mafute'.

A smaller amount of respondents also mentioned clams from both environments and some other invertebrates.

➔ **Potential Management Actions:** Seagrasses appear to be somewhat valuable areas for fishing and seafood harvesting. Increasing efforts to connect with fishers to monitor and protect these habitats may be another important strategy for conservation. It is unclear from this data whether these habitats can sustain current or greater levels of fishing. Overall, there is a lack of knowledge regarding fish populations in seagrass that could use more research.

Community members believe more resources should be used to protect mangroves and seagrasses

Figure 4. Responses for question 7a/*b* "*Should more resources (funding, people, time, etc.) should be used to protect mangroves/seagrasses?"*

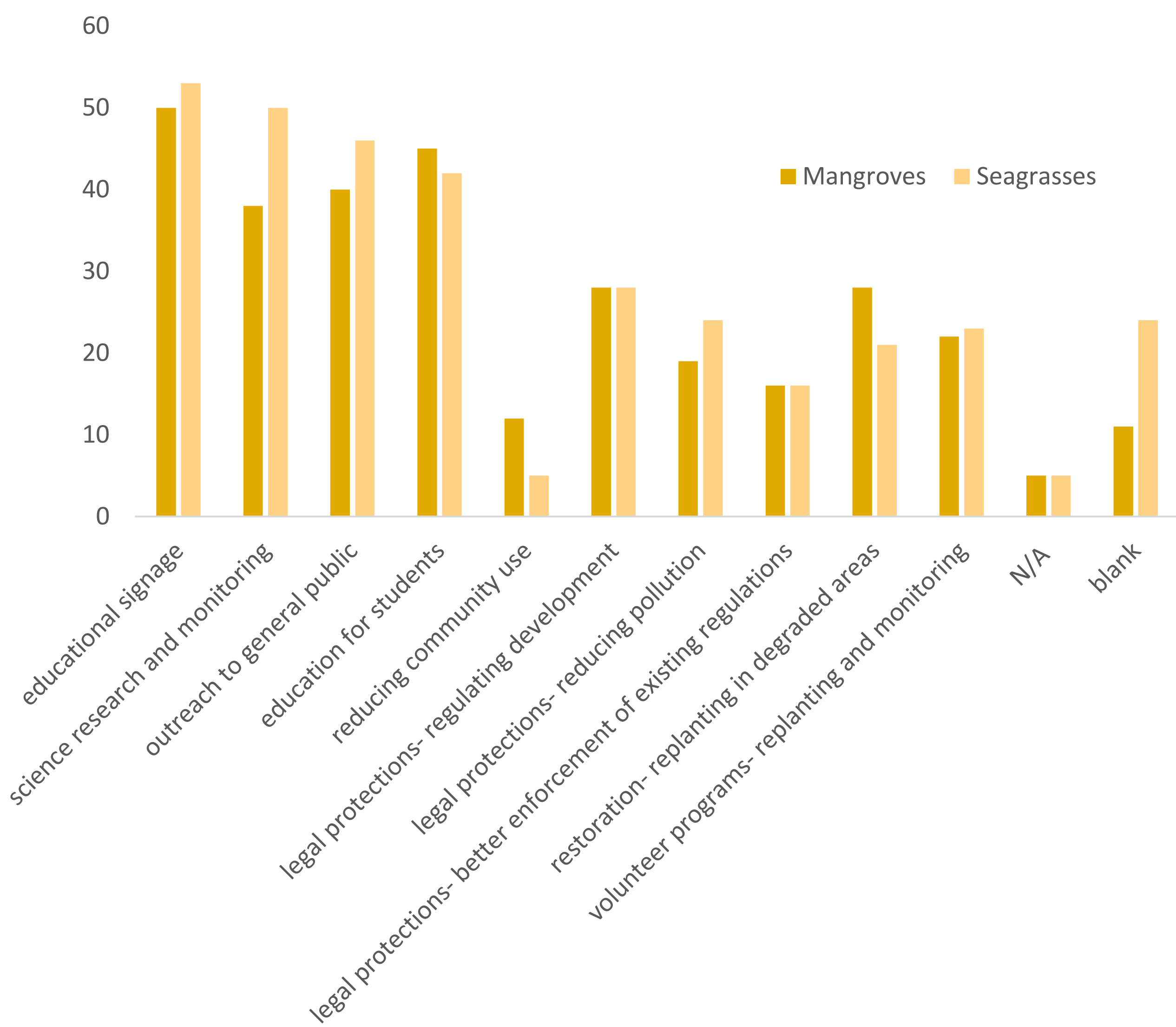


The majority of participants, about 75% for both mangroves and seagrasses, agree more resources should be used to protect these habitats. However, data may be biased, as respondents seemed hesitant to disagree, especially with a surveyor from the Department of Agriculture. Respondents who disagreed cited the following reasons:

- Would need a better understanding of what funding is spent on
- Protecting coral reefs, reducing trash, or addressing other issues is more important
- Simply not feeling particularly strongly about the issue
- Needing more educational information and deliberation

Community members believe education and outreach, as well as scientific research and monitoring, are effective ways to protect mangroves and seagrasses

Figure 5. Responses for question 8a/b *"Circle the 3 most effective ways to protect mangroves/seagrasses:"*



Respondents generally support already existing efforts to protect these habitats, including student education, and outreach intended for the larger community. The most selected action was educational signage. The least popular option was "reducing community use". The various options for different types of legal protections also were less popular, with "better enforcement" being the least popular of the legal protections.

However, order bias could be in effect here since many of the earlier options seem to have more support. Additionally, some respondents did not follow instructions to only select their top three choices and selected more than three options. All the extra selections were included.

A portion of respondents also selected restoration and volunteer programs. There were also many comments of trash being an issue and something they personally take action on by picking up trash when in these habitats.

➔ **Potential Management Actions:** Educational signage seems to be seen as the most effective way of helping to protect these habitats. Installing the beach signage that has already been designed should be a priority. Developing further signs may need more input (eg. Would mangrove/seagrass signage be helpful at Achang boat ramp, Merizo Pier, other seagrass locations?).

Mangrove and seagrass planting is not easily incorporated into volunteer programs since there is limited coastline to plant and liability issues for activities in the water. However, given the interest in volunteering, it may be worth it to further emphasize the connection between the sea and tree planting, and advertise these events on more the DOAG forestry page.

Community members have observed changes in mangrove and seagrass areas over time, including changes in water quality and sedimentation.

Many respondents had additional observations, comments, and thoughts to share (table 3). Despite not mentioning water quality in the earlier question regarding ecosystem services, a few more comments about water quality and sedimentation were noted here. Participants may have mentioned water quality issues as observations rather than benefits connected to seagrasses and mangroves due to high sedimentation overwhelming the capacity of mangroves and seagrasses to capture and stabilize sediments. Some seagrass area have high sediment loads on the blades and live in very silty and muddy sediments. Since there is too much sediment overwhelming the mangroves and seagrasses, the sediment is only viewed as a stressor, and this particular ecosystem service of mangrove and seagrass is not recognizable.

Despite showing respondents pictures of seagrasses and mangroves to help confirm which plants were the survey was addressing, it is easy to confuse seagrasses and mangroves with other algae or coastal plants. Some answers indicate that there was likely confusion or alternative priorities since respondents sometimes mentioned areas that do not have seagrass or mangroves (Eg. Tumon area).

Overall, responses included observations of both decline and growth of seagrasses and mangroves, and their associated wildlife. Some comments especially noted the major loss of seagrass near Cocos Island, and changes in the amount of algae. Additionally, 9 respondents stated they have not observed any changes, and many respondents left this open comment section blank.

➔ **Potential Management Actions:** It is difficult to quantify changes through anecdotal comments, however these responses suggest a wide range of different perceptions about the status of these ecosystems. Respondents that used the habitats for seafood also indicated some declines in their harvest, which may be something to further monitor or investigate.

The comments reveal there is some awareness of erosion, sedimentation, and water quality issues, and it may even be impacting fishing experiences (making areas muddy and difficult to navigate). It may be helpful to gain support for watershed conservation efforts by connecting fishing quality with water quality. The large amount of comments despite the question being optional also indicate that there is a willingness to share, and there may be additional knowledge to learn from the community, especially in the community of fishers.

Table 3. Open ended responses to question 6- *"We are trying to understand how mangroves or seagrasses have changed in the past decades. Have you noticed any changes in mangroves/seagrasses areas, or the fish or other wildlife in those areas? (increase, decreases, changes in species, water clarity, amount of sediment, number of people using the area, etc.) Please try to describe a place and time if possible."*
***Red coloration indicates comments that mention declines or negative impacts, green indicates growth of either habitats. Bolded comments refer to water quality or sedimentation issues.
***Additionally, it is important to note that some of these comments are taken exactly as written from respondents who wrote their own answers without any discussion. Alternatively, some comments were delivered verbally, so the text was paraphrased or shortened as the surveyor took notes while respondents shared their comments.

Mentions seagrass	Mentions mangroves	Mentions both seagrasses and mangroves	Others comments not specific to one environment
changes in fishing, too much netting. Too much spearfishing, even little juveniles are being caught. Pago Bay and Marine Lab	increased number of mangroves	I am proactive in protecting this area of mangrove habitat on Guam. I have visited daily on Big Navy Polaris & Talofofo Bay where I observe either seagrass or the mangroves plus Cocos Lagoon for seagrass. It is a very important area for nesting sea birds, and nesting/breeding/nursery area for juvenile fish & turtles	There may be a decrease of species and **[more sediments?] in the area**
changes in seagrass, looking more like algae than seagrass. Not sure if weather is to blame, also fishing is not as great as before	decrease in mangroves in Piti area along the **road pollution, runoff**	yes, the seagrass are more weaker compared to before and the mangroves are skinnier and some white spots (Philippines and Talofofo area some mangroves with white spots?	**water clarity would play a big factor, the color has become more cloudy**
east Agana bay fish quantity smaller due to overfishing	decrease in the amount of mangrove trees in southern Guam villages	mangrove decreased, water clarity decreased in mangrove/ seagrass area because of pollution, increase # of people using area	water clarity/flow, flooding in lower areas due to sediment build up
seagrass is growing	need to increase more protection for mangroves to save our fish habitat	haven't observed changes, but have observed increase in areas being developed and area undergoing construction which may cause depletion in mangrove and seagrass area	a little not good as before
yes, less sea urchins since I've lived here, rabbitfish now only the east side of the island	southern Guam becoming less and less of mangrove due to water eating	probably more people fishing, using the area, with more urbanization, negative impacts	**yes, amount of sediment is worsening islandwide**

are parrotfish abundant the amount of seagrass has changed at turtle cove.	away the land to the public roads and leaves them nowhere to go	on the mangroves, seagrasses and fish/wildlife in the area	
I **noticed an increase in clarity of beaches in general** due to increase in seaweed and seagrass. All areas	I noticed mangroves have been affected in a negative way by people	less mangroves of my house have shown less fish in the area, (agat) more seagrass near our harbor has led to more fishing (2021, Agana Bay and Naval Base)	clams- have not seen any
go fishing at night, mostly reef fish come to sleep at night in the seagrass, hard to see pollution in seagrass.	decrease- there are some trash resting in the roots of mangroves along Talofofo Bay and also Ypao beach	I think fish would have increased considering they use seagrass as home and food. Trees are cool. Let it be.	rarely seeing crabs
I notice some changes in the grass, sometimes there are dead ones, the color of the seasgrass fades away, or they're all dead	before, about 10-15 years ago, my family would go catch mangrove crabs in Inarajan. Today there are not as much as before.	I notice mangroves and seagrass decrease because of abusive people throwing around plastic trash around beaches and throwing a lot of oils	increase in the number of people using the area
seagrass-last month ago I went to a place to look for cucumbers and there was nothing. Most places they don't have anymore.	I have noticed that due to people mishandling of the natural process, mangroves had been in decline	I've noticed a decrease in mangrove and seagrass due to human activity. **The waters are not as clear, mostly murky waters.** Less fish in the lagoons and must fish in deeper waters.	good and bad thing. Less fish to catch, people litter the place
certain fish in seagrass abundant, spearfish in grass. Losing a lot at Cocos used to a lot at Cocos in 2003, now mostly sand, no more grass in a lot of areas, maybe acitivty, lacha greenichs yellow not grey, grass looked cut think from lacha eating. Grown back big 1 ft 1.5 lbs	hardly see mangroves down south	Mangroves overgrown, close to preserve, past boat ramp, Papa Niyok to Achang. Seagrass old and long since the preserve not much activity from people walking through it, with a lot of algae. More chaetomorpha. Male seagrass flowers in April every year	decrease due to trash

East Agana beach- for the better?	seen some get cut down because blocking the road, pass mangroves to access river	Mangroves submerging in mud, river mouth live there, used to more in just grass, now more mud. **More mud, sedimentation. Pollution coming down from the rivers** when fishing, walking in mud, sinks in mud, feels? Crabs, 1000 ft tiao nets grass, less healthy, lots of heavy rain (last year harvesting tiao, not as good). Yes there are currents but doesn't affect bay unless storm. **Used to be rocks and sand, now deep in mud**	some fishes and water levels have changed
Seagrass only in areas low current	mangroves very important to my place because the fish like ot stay under the mangrove and also cover the island for typhoon.	57 year in Maelsso. Sumai area b/t Inarajan and Malesso' removed typhoon yuri in 91' decimated the area there, left beach, moved roads, since then have grown back, laws may have helped to recover maybe cleaning from typhoon, around then preserve. **Heavy flooding with rains would silt the seagrass, die back**	
a lot less seagrass	mangrove area between naval station and Piti seems to remain constant. Also in Malesso' seems about the same.	I learned the importance of mangroves and seagrass through Guam Community College and USDA	
	In some mangrove areas in merizo (Achang bay) has decreased with the last 10 years	Seagrass only in Inalahan, easy to plant, long thing once it falls down will grow right away. 20 years ago mangroves have grown (in the preserve?)	
	during Guam's rainy season, the mangroves become submerged under deep water	I have noticed people going into mangrove areas near the Naval Base Guam, Piti. I assume there are probably crabs there. I know we have less seagrass than when we went in the water in the 60s. All I know is seagrasses would be a good hiding place for fish and eels.	

	I rarely see mangroves, last time was at Cabras Beach. Usually seen at hidden beaches with trees	the mangroves down south at the preserves seem more dense, almost impossible to trail through. Theres a decrease in seagrass cause I barely see them when I'm diving. Example: Tarague beach in Andersen Base.	

Summary:

- The majority of respondents believed removal of mangroves and seagrasses would have a negative impact on the island community. The reasons for protecting these habitats was to support wildlife, as well as a desire to keep nature intact.
- Mangrove and seagrass areas are used for recreation and by some community members for fishing, crabbing, and occasionally gathering other seafood or materials.
- A majority of respondents believed that more resources should be used to protect mangroves and seagrasses. The actions perceived to be most effective for conservation included installing educational signage, more outreach and education for the public and students, and more scientific research and monitoring.
- Community members have varied perceptions of changes (or a lack of change) over time in seagrass and mangrove areas, as well as declines in water quality and increased sediment loads in the waters.

References:

[1] HOUSEHOLD SURVEY MEASURING ATTITUDES, PERCEPTIONS AND KNOWLEDGE OF THE RESIDENTS OF THE MANELL-GEUS WATERSHED. 2010. Romina P. King. https://www.ncei.noaa.gov/data/oceans/coris/library/NOAA/CRCP/other/grants/NA09NOS4190173/Guam/Guam_TNC_Manell_Geus_CAP.pdf

UNIVERSITY OF GUAM
UNIBETSEDÅT GUAHAN

Committee on Human Subjects Research (CHRS)
Institutional Review Board

Date: October 12, 2020

TO: Cara Lin, Principal Investigator
Whitney Hoot, Co-PI
Marie Auyong, Co-PI

FROM: Peter R. Barcinas

CHRS Committee Chair

UOG CHRS Chair Signature

Title:	**Understanding Landowner Perspectives on Guam's Mangroves**
CHRS#:	20-113
IRB Review Date:	September 30, 2020
Effective Date:	**October 12, 2020**
Effective Expiration Date:	**October 11, 2021**
IRB Review Type:	**Expedited Review**
IRB Review Action:	**Approval**

Dear Cara Lin and Co-PI's:

On 09/30/2020, after review of your application, the Institutional Review Board (IRB) of the University of Guam has approved your study **CHRS#20-113 – Understanding Landowner Perspectives on Guam's Mangroves.** Your application meets the Expedited review requirements under federal guidelines 45 CFR 46.110 Categories 1, 2, 4, and 7.

All participants will have their rights explained in the **Cover Letter**. Consent to take part in the survey will be obtained by the completion of an **Informed Consent Form** and this is appropriate for the study. Participants may withdraw at any time without penalty and the noted risks are explained with the corresponding support procedures to protect participants. Sufficient precautions for this survey have been taken to protect the participants' anonymity; the confidentiality of data collected from all participants will be adequately protected.

Please refer to the assigned CHRS number in all communications related to your application and this approval. Should any modifications or procedures change in your survey, please inform the IRB committee of those changes. The IRB will review the amended procedures prior to implementation. Should the project extend beyond a 1-year period, please submit an extension request.

UOG Station, Mangilao, Guam 96923
Telephone: (671) 735-2994 Fax: (671) 734-2290
A Land Grant Institution Accredited by the Western Association of Schools and Colleges

Dear ______________________________,

The Guam Department of Agriculture is conducting a study on the relationship between landowners and their land, with a focus on the vegetation and mangroves. The goal of the project is to learn from the community and their experiences with mangroves, and to include the perspectives and voices of community members in any future conservation projects and management efforts.

Participation in the survey is completely voluntary and has minimal risk. The survey involves mostly open-ended questions and, with your permission, a brief look at the vegetation on your property. If at any time you are uncomfortable with a question please let us know and we can skip that question. The interview consists of 18 questions and takes approximately 60-90 minutes to complete. To prevent transmission of COVID-19, we will wear masks and practice social distancing throughout the interview.

Your responses will be kept private and confidential. Only the research team will have access to any identifying information and survey responses. Any information shared about any illegal activities will not be reported to authorities or lead to any penalty. Papers with notes will be stored in a locked office and electronic records will be stored on a password protected computer, backed up on a cloud without shared permissions. All paper notes and electronic data will be destroyed by December 31st 2024. The results of the study, including quoted responses, will be included in reports and presentations to educate natural resource managers, and help inform future management actions, but without any identifying information. The final results of the study will also be shared with you and other participants after the study is completed.

You are free to withdraw from this study at any time during or after the survey. Should a physical injury occur during the survey, appropriate first aid will be provided, but no financial compensation will be given.

We encourage participatory research to more prominently and accurately represent the voices of our participants and include local knowledge and ideas. If you are interested in getting more involved in this research project by helping us to interpret results, create reports, or present results to natural resource managers please let us know. This survey is also intended to inform future work with landowners and vegetation. If you are interested in advising natural resource managers with their efforts or would like to get more involved with conservation on private property please let us know.

Our study protocols were reviewed by the University of Guam's Institutional Review Board to ensure that this research is conducted with ethical consideration to privacy and wellbeing concerns. Further information can be obtained from the Office of Research and Sponsored Programs at the University of Guam concerning pertinent questions about the research and an explanation of your rights as a research subject. The Research and Sponsored Programs serves as the official contact office in the event of research related injury to you 671-735-2672. You can also reach the research team at cara.lin@doag.guam.gov or (671) 777-4432 if you have any questions about survey content, withdrawing your answers, or any other inquiries.

Thank you very much for your interest and participation, we appreciate your time and input!

______________________ ______________________

Surveyor Signatures

______________________ ______________________ ______________________

PI Signatures

CHRS#: **20-113**
Approval Date: October 12, 2020
Expiration Date: October 11, 2021

CONSENT FOR PHOTOGRAPHY

Understanding Landowner Perspectives on Guam's Mangroves

Cara Lin (DOAG), Whitney Hoot (BSP), Marie Auyong (NOAA affiliate)
Department of Agriculture

Reviewed by the University of Guam IRB

This study involves the taking photos of your property using a phone. All pictures will be transferred to a password protected computer and deleted from the phone within 3 days. The photo files on the password protected computer will be deleted by December 31st 2024. Identifying information will only be associated with the photos to allow researchers to match photos with notes and only researchers will be able to view photos.

Photos of the vegetation on property may be reproduced in whole or in part for use in presentations or written reports that result from this study. Neither your name nor any other identifying information (such as images of your home or decorations on property) will be used in presentations or in written products resulting from the study.

By signing this form, I am allowing the researcher to take photos on property as part of this research. I also understand that this consent for photos is effective until December 31st 2024 and the photos will be destroyed on or before this date.

____
Participant's Signature

____
Date

CHRS#: **20-113**
Approval Date: October 12, 2020
Expiration Date: October 11, 2021

CONSENT TO AUDIO-RECORDING & TRANSCRIPTION

Understanding Landowner Perspectives on Guam's Mangroves
Cara Lin (DOAG), Whitney Hoot (BSP), Marie Auyong (NOAA affiliate)
Department of Agriculture
Reviewed by the University of Guam IRB

This study involves the audio recording of your interview with the researcher using a digital recorder. Identifying information will only be associated with the audio recording to allow researchers to match recordings with notes. Only the researcher will be able to listen to the recordings. The recordings will be handled by the researcher and stored in a secure, password-protected computer.

Transcripts of your interview may be reproduced in whole or in part for use in presentations or written reports that result from this study. Neither your name nor any other identifying information (such as your voice) will be used in presentations or in written products resulting from the study.

By signing this form, I am allowing the researcher to audio record me as part of this research. I also understand that this consent for recording is effective until December 31st 2024 and the recording will be destroyed on or before this date.

____
Participant's Signature

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Date

CHRS#: **20-113**
Approval Date: October 12, 2020
Expiration Date: October 11, 2021

Debriefing Form

Understanding Landowner Perspectives on Guam's Mangroves

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Department of Agriculture
Reviewed by the University of Guam IRB

This form serves as a reminder that you participated in our study. Your responses are completely voluntary. If you wish, you may withdraw your responses to this survey at any point, at which point all records of your participation will be destroyed. You will not be penalized in any way if you choose to withdraw.

We will also provide you with final reports of the results and invite you to presentations where the information is presented.

Thank you for your participation in this research study. If you have any questions about the study you may contact us at (671) 777-4432 or at cara.lin@doag.guam.gov

Should you need counseling due to the nature of the questions, the University of Guam's Isa Psychological Services Center provides free mental health services to UOG students, staff, faculty, and members of their families, as well as to adults, children, and families from the local community who are not able to access services elsewhere. The services include: Individual psychotherapy for adults, adolescents, and children, family and couples' therapy, group therapy, clinical assessment, crisis intervention, consultation, outreach programs, personal growth retreats. They are open Monday to Friday from 9:00 AM to 5:00 PM and can be contacted at (671) 735-2883. Their email is isa@triton.uog.edu and are located at the Humanities and Social Sciences Building, room 202 at the University of Guam.

Thank you again for your participation.

CHRS#: **20-113**
Approval Date: October 12, 2020
Expiration Date: October 11, 2021

Landowner with Mangroves Survey goals (~60-90 min):

1. Learn about relationships between land and landowners
2. Learn about mangroves and people's relationships with mangroves from personal experiences
3. Gauge people's interest in conservation programs such as the Forest Stewardship Plan, and understand any landowner needs and concerns with their land

Pre-survey To Do (refer to Form-E procedures for more details):

- Introductions, review covid procedures:
    - COVID Procedures:
        - Provide mask if they need one
        - Provide hand sanitizer as we do paperwork/ offer refreshment.
        - Find an outdoor location (bring foldable chairs), review social distancing 6ft and no touching surfaces
        - Offer refreshment again
- Inform/ask if anyone else will be joining us
- IRB document review and explain, and signing (if multiple people are taking the survey, each person needs to fill out the paperwork)
    - Review protections for participant as explained in the informed consent form
    - Confirm recording and pictures are ok
    - If minors are joining the conversation, separate informed consent form for minors

Part 1- Understanding Property, Land Tenure, and Vegetation on Property:

1. Name, age: ***(if multiple people, note who is the property owner)***

2. Location of property, Village:

3. Can you share why your land is important to you, including how you use it? *[Can be checked off during or after interview, indicate use or personal value with a U or P.]*

- **Do you grow food on your land?**
- **Do you have a personal connection to the history of your land?**

- ○ As a place to live
- ○ As a place to pass onto children or relatives
- ○ Historical connection
- ○ Good community to live in (friendly neighborhood, relatives nearby)
- ○ Good location (by the water, close to place of work, outdoor recreation nearby)
- ○ Aesthetic value
- ○ Space for outdoor recreation, place to gather with friends or for events
- ○ Use for gardening/farming
- ○ Use for ranching (confirm the meaning of ranching)
- ○ Access to waterways
- ○ Other _______________________

4. If you feel comfortable, could you tell me about the history of the property? [*open ended, if they seem uncomfortable remind we can skip any questions any time]*

- From whom did you get the property?
  - From a relative, a private seller, was it subdivided?
- Is the property owned or shared jointly with others?
  - How are decisions made on the property?
- What year did you get this property?
- How long has it been privately owned?
- How long has it been used in this way?
  - Do you know about any earlier uses?

5. Can you show us around the mangroves on your property? *[Show pictures of mangroves to make sure we are on the same page, open ended] [the following bullet points are meant to guide our notes, not necessarily things to be asked, can ask with more friendly wording]*

- Different species present (Different kind of mangrove trees?)
- How many trees? Stands? Estimated area? Density of vegetation? Can draw a rough map or take photos if permitted
- Older/taller trees vs younger shorter trees?
- Sediment conditions- sandy, muddy
- Water conditions- very still, wavy, by a river, clarity?
- Do water conditions always look like this? Do water conditions vary by weather/tide?
- Close to house?
- Close to neighbors?
- Any other observations (eg. losing leaves, fungal or other growths, litter, fences, etc.)

6. Over the years, have you noticed any changes in mangroves on your property? When did those changes happen?*[open ended]*

- Impacts after a typhoon or storm?
- Growth or decline in different areas?
- Health of vegetation?
  - Does anything eat the mangroves? (eg. insects or crabs)
  - Have you seen any strange loss of leaves, death of plants/trees?
- Changes in species?
- Seedlings or new growth present?
- Changes in water flow, water clarity, water level etc.?
- How about changes in the mangroves or water characteristics near the mangroves in the general area around your neighborhood or village?

7. Have you noticed any changes with animals around the mangroves/coast on your property or area? For example panglao (crabs), fish, birds, lizards, fanihi (bats), mosquitoes and other "bugs"? Or asuli (eels), or shrimp *(if closer to a freshwater source)* *[open ended]*

- More or less animals seen in different areas
- Changes in species
- Nests or burrows present?

8. How do you feel about the mangroves on your property? *[open ended]*

- Are they good, bad, a mix, neither/neutral?
- (if good or bad) Can you explain why?

9. Do you know if people have removed vegetation, including mangroves, in this area? *[open ended]*

- ***(If they seem comfortable with it can follow up with individual specific question)*** **"Have you ever removed or added plants on your property including mangroves? If so, for what purpose? Did you notice any changes?"**
- How many/much?
- Your idea? Neighbor? Government agency?
- What were the trees like that you removed? Tall, short, healthy, declining?
- Where on the property were plants removed/added?
- Are you planning to remove or add more vegetation in the future?
- For aesthetic purposes, gardening/food, recreational space?

10. What are your plans for your property? What do you envision it looking like 5-15 years from now? *[open ended]*

- Are you planning on keeping it, selling it, or sub dividing it?
    - Can you explain what factors may result in you potentially selling, giving away, subdividing, or keeping your land?
- Using it for gardening, water access, ranching/recreation, not sure, etc?

11. Do you have any concerns about your property? What might they be? Please describe your concerns, the more details you can provide the better, or feel free to show us. *[can be checked off during or after interview]*

- Coastal erosion/streambank erosion
- Sea level rise
- Flooding
- Fire
- Vegetation may fall over and damage property during storms
- Vegetation overgrowth
- Neighbors flooding or other neighbors issues
- Insects/pests/invasive
- maintenance of the property is difficult
- Access to the property
- Access to the water
- Access to other services (eg. emergency services, reliable utilities, etc.)
- Other_____

12. Anything else you would like to share about the property or mangroves so far? *[open ended, can check and mention the time now to be mindful of their time]*

Part 2- Understanding how management can assist:

Natural resource managers want to help landowners protect and grow vegetation on their property. They are looking for ways to help landowners' protect their land and property because the vegetation on their land provides wildlife habitat, prevents erosion, and keeps soil out of the water and off the coral reefs.

13. I'm going to list some options that may help you protect your land, please say yes or no if you think an option would be helpful. *[write Y or N on left side]*

14. We would like to go over your responses, what do you think are the pros and cons of the options I listed? *[open ended, don't have to go over each one especially if time is limited towards the end of the survey but can prompt with each program if given time or if survey participant doesn't readily respond]*

Benefits **Drawbacks/Concerns**

a. A workshop to learn more about Guam's native plants

b. A workshop to learn more about the background and process behind restoration of vegetation

c. A workshop on storm water management methods such as stormwater gardens and rainwater catchments.

d. A flyer that provides a clear outline of what regulations may apply to your land (eg. what kind of construction is allowed, what kinds of trees can or cannot be removed)

e. An informal discussion on the phone or on property with a permit reviewer or forestry professional

f. An online consultation service where pictures or videos may be submitted via email and advice from a professional can be provided through email

g. Working directly with a natural resource manager to identify mutual goals, and create a plan with possible support in providing and planting vegetation.

h. A program offering a formal written agreement for preserving certain vegetation on land in return for compensation and/or a tax credit

15. Any questions, ideas, or comments on how natural resource managers could help you with your land? Or anything else we have spoken about so far?

Part 3. Interest in Participatory Research

16. Participatory action research is a type of research where people who contribute information, such as yourself, are involved in the research process and decision making for any actions or solutions. We have some different options here to see what fits best in terms of your time and interest. Would you be interested in getting more involved in any of the following ways or in other ways? *[yes, or no, feel free to make notes of any feedback on the options. If asked about compensation- unfortunately, at least at this time, these would be volunteering options without compensation.]*

- Joining the research team to help interpret and/or present results for the final report
- Helping to create and join a landowners advisory group or that provides perspective to natural resource managers on developing stewardship programs, conservation actions, research, outreach, etc. from a private landowners perspective
- Provide a written or spoken testimony for any campaigns to increase landowner participation in stewardship programs, such as sharing your experiences in writing, photos, or videos with media
- Other, any ideas? ______________________________________
- Unsure now, but would like to be invited if something comes up

Part 4. Post Survey Actions- these are questions not technically included in the survey, as they have other purposes

(*If interested in getting more involved in participatory research)* Would you like to stay in touch regarding how you can get more involved? What would be the best way to contact you in the future?

(*If not interested in participatory research)* We would like to share the final results of this study and invite you to presentations of the information. What would be the best way to share the results and notify you of presentations? (email, mail, phone call, hand-delivery?)

The Forest Stewardship Program helps you work with a natural resource manager to discuss the goals for your land. After the initial discussions on mutual goals, if you would like to move forward, you can work together to create a plan to help achieve mutual goals and fill out a written agreement. The program offers vegetation and planting of vegetation free of charge and follow up after planting. If interested, we can put your contact info in a separate list and reach back out to you at a later date to discuss more.

- Interested
- Not interested

Do you know any other landowners with mangroves on their property that we may reach out to for this survey? If you would feel more comfortable reaching out to them first, when can we follow up with you to get in touch with them?

If you would like to join the Guam Coral Reef Initiative for updates on volunteer events and other updates on the coastal ecosystems around Guam, you can follow us on facebook or join our email list at guamcoralreefs.com

Understanding Landowner Perspectives on Guam's Mangroves

Cara Lin, Guam 2020-2022 National Coral Reef Management Fellow

Introduction:

Managing Guam's mangroves is necessary to continue enjoying the ecosystem services they provide, including prevention of shoreline erosion, improving water quality, providing wildlife habitat and support for fisheries, and blue carbon storage. Preserving and maintaining existing mangrove coverage is a key priority since restoration efforts often can be logistically difficult, or struggle to recreate the original forest structure.

The majority of Guam's mangroves are legally protected by existing in either Sasa Bay Marine Preserve or Achang Reef Flat Marine Preserve. Sasa Bay Marine Preserve does not include as many private residences and is likely at lower risk of removal by individuals. Some small areas of mangroves to the east and west of Achang Reef Flat marine preserve are not legally protected, including areas of private residences. Although major removal events have not been reported, a few incidences of mangrove clear cutting have been observed both inside and outside the marine preserve. Guam's southern mangrove areas along the coast are small, however, their position as fringing mangroves along the seashore exposed to waves make them more difficult to restore once lost. Since marine preserves can be difficult to enforce and some mangroves are not legally protected, working with private landowners is a crucial part to preserving existing mangroves.

In order to establish an understanding of landowner needs and perspectives to inform how to best reach mutual conservation and landowner goals, a survey was created for southern landowners, especially those with mangroves on property. The goals of this survey were to:

1. Learn about relationships between land and landowners
2. Learn about mangroves and people's relationships with mangroves from personal experiences
3. Gauge people's interest in conservation programs such as the Forest Stewardship Plan, and understand any landowner needs and concerns with their land

Methods:

This survey was developed in fall 2020 with input from multiple natural resource managers in creating early drafts. An online workshop session with some additional natural resource managers reviewed each question to ensure they were culturally relevant and respectful, clearly written, and addressed the knowledge gaps of interest. The surveys consisted of 16 open-ended questions, each question contained additional suggestions for optional probing questions. The survey took approximately 20-90 minutes depending on how long the respondent wished to talk. The survey was submitted and approved by the University of Guam Internal Review Board (CHRS#: 20-113) to ensure proper precautions were taken for the privacy and safety of the respondents, especially in the light of COVID-19. Participants were allowed to complete the survey in person or over a phone/video call. Respondents were informed that their identities would be kept confidential and the sharing of information regarding illegal activities would not result in any reporting to authorities or penalties. The survey was conducted as interview sessions, which were recorded for later analysis. Participants were recruited via snowball sampling and participants were found via community networks.

Key Findings and Potential Management Actions:

A total of six individuals completed the survey over the course of 2020-2022. Below were some key findings and common themes:

- Landowners often weren't sure if there were multiple types of mangroves, and what types of plants were considered mangroves.
    - In some cases, it was also specifically mentioned it wasn't clear what, if any, benefits the mangroves provided
        - ➔ Potential management actions: creating and sharing a short guide was suggested as a way to provide basic mangrove information
- Gaining access to the water through the mangroves can be as simple as walking through and moving flexible roots to the side, without the need for removal of the mangroves.
- Mangroves have grown over the past decades along the pier forming Achang Boat Ramp. Previously this area was a good look out area for children and community members to view the marine preserve.
    - ➔ Potential management actions: The end of the rocky pier is still accessible, but some branches and thick mangrove growth makes it difficult to walk through. More outreach with the community can help determine if this spot would be a valued look out point worth trimming mangroves, or even an area that could use signage regarding the marine preserve. A mangrove management guide can help inform landowners of what actions are legal and how to trim mangroves instead of cutting them down if absolutely necessary.

Describing the pier- "If we could cut that back and maintain it, I know that it was done so by the previous owners, but I'm not keen on breaking laws…."
– respondent 2

- Respondents reported being potentially interested in a tax credit for protecting mangroves or other vegetation on property.
    - In some cases, formal agreements or involvement with Government of Guam was not something the respondents wished to be involved in

- Respondents reported being potentially interested in a tax credit for protecting mangroves or other vegetation on property.
    - In some cases, formal agreements or involvement with Government of Guam was not something the respondents wished to be involved in.
- Landowners had many useful observations and knowledge of the area that could inform restoration strategies
    - One respondent noted that the Guam Department of Agriculture had previously planted *Avicennia marina* on the southern coast, which have grown into adult trees

      "They were planted there, I think by AG years back and then we just like kind of like the way they grew and looked there…."

      –respondent 4
    - A mangrove area outside of Achang Reef Flat Marine Preserve is owned by many people and would be extremely difficult to sell, essentially protecting it from development. However, this means landowner lead stewardship of this mangrove area is even more important.

      "We don't know who owns which bit. I mean hundreds of people own that. No one has a clue who owns which bit so it's essentially, in perpetuity, I think it's a preserve…it can't be touched…."

      -respondent 3
    - Erosion has occurred in areas where landowners did remove mangroves
    - Submerged land ownership may further complicate any stewardship agreements

- Landowners did not mention specific needs or concerns, such as sea level rise, erosion, or threat from storms. Some concern regarding flooding and preventing flooding by keeping water drainage areas clear was mentioned.

Next steps moving forward:

The amount of responses to this survey was limited, partially due to COVID-19 concerns and delays. As community events resume and more community networks are made, conducting more interviews and informal discussions with landowners will help update these findings and further inform our understanding of landowner perspectives and develop best practices for forest stewardship programs.

GUÅHAN MÅNGLE

RESTORATION ACTIVITIES AND FIELD OBSERVATIONS

2020-2022 Coral Reef Management Fellowship

Cara Lin- Guam Coral Fellow

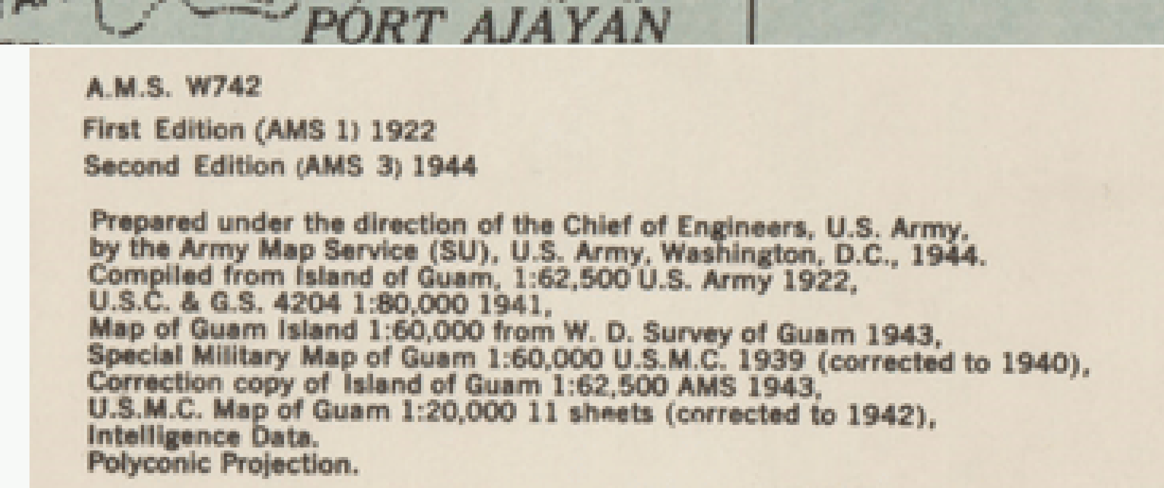
Final Report- Fall 2022

Introduction: Mångle (mangroves) are trees that live along the coast in brackish water (a mix of salty and fresh water). They provide many benefits for wildlife and coastal communities, including support for fisheries, preventing coastal erosion, fighting climate change, and improving water quality.

With these benefits in mind, natural resource managers identified the need to assess the state of Guam's mangroves based on their historical extent and determine if there is a need for mangrove restoration. This assessment was a priority for the 2020-2022 Guam Coral Reef Management Fellow, as part of the National Coral Reef Management Fellowship.

As part of a literature review, this map of Guam from 1944 was examined, and it was found that mangroves likely existed in some areas in southern Guam where they no longer currently exist. In particular mangroves are missing in the eastern half of Achang Reef Flat Marine Preserve and some areas of Inarajan.

Image (above and right): a section of a 1944 map of Guam showing the southern coast. Green symbols along the shore likely indicate mangroves existed throughout Achang Reef Flat Marine Preserve. The details regarding the map are shown to the right.



A.M.S. W742

First Edition (AMS 1) 1922

Second Edition (AMS 3) 1944

Prepared under the direction of the Chief of Engineers, U.S. Army,
by the Army Map Service (SU), U.S. Army, Washington, D.C., 1944.
Compiled from Island of Guam, 1:62,500 U.S. Army 1922,
U.S.C. & G.S. 4204 1:80,000 1941,
Map of Guam Island 1:60,000 from W. D. Survey of Guam 1943,
Special Military Map of Guam 1:60,000 U.S.M.C. 1939 (corrected to 1940),
Correction copy of Island of Guam 1:62,500 AMS 1943,
U.S.M.C. Map of Guam 1:20,000 11 sheets (corrected to 1942),
Intelligence Data.
Polyconic Projection.

The findings support further planting at an existing primary planting site near the Ajayan River. Moving forwards, we will also seek to work with landowners to plant mangroves westwards from the Ajayan river to merge with the existing fringing mangroves.

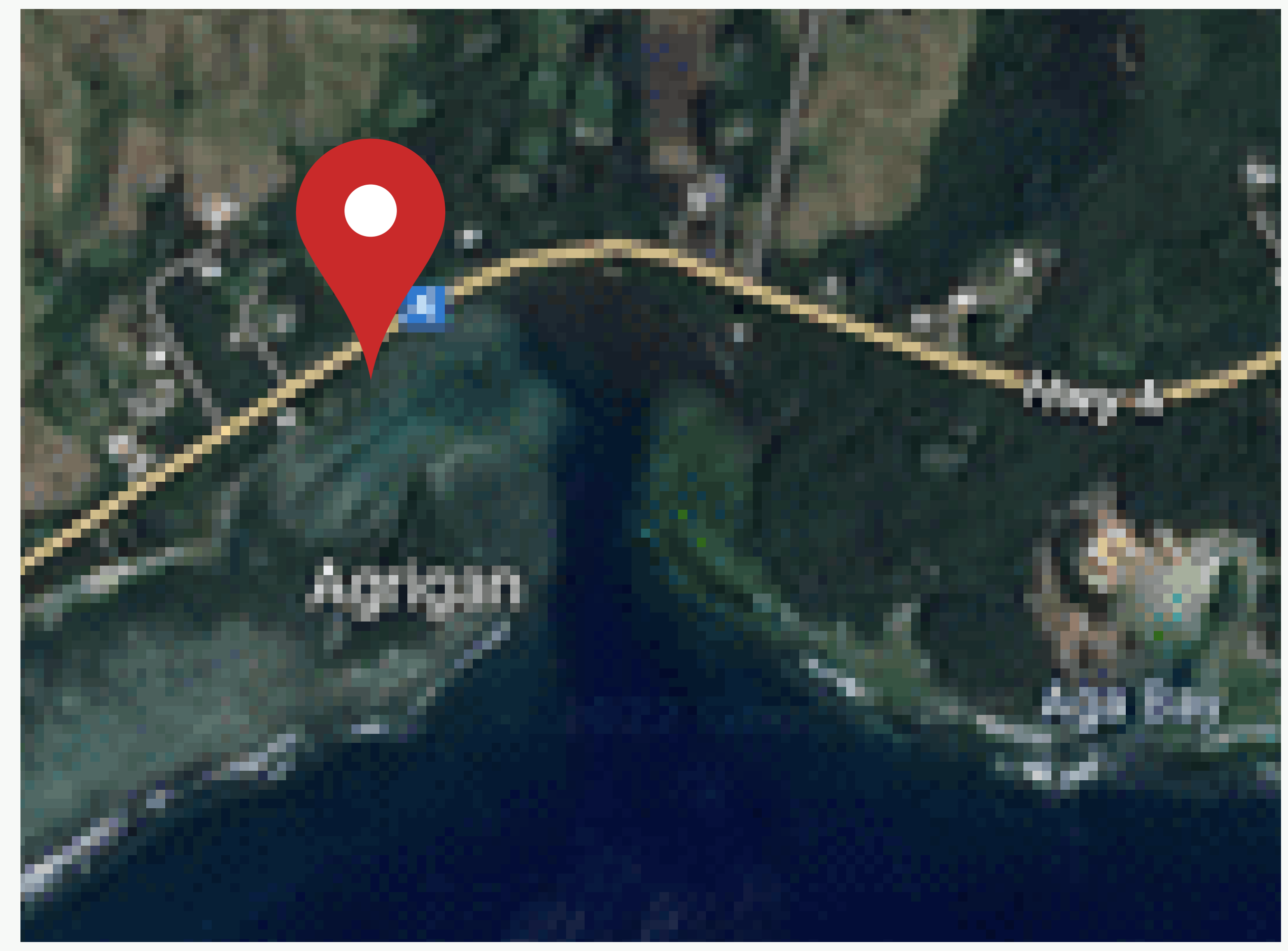


Image (right): location of the primary restoration site close to the Ajayan River.

The existing primary restoration site is owned by the Guam Preservation Trust who agreed to allow our Guam Department of Agriculture (DOAG) mangrove planting activites on the site. In partnership with a landowner, planting activities have also started at another new site with Achang Reef Flat Marine Preserve.

Photos (top): teachers prepare mangrove seedlings for growht in the nursery at 2021 the Southern Water Conservation District Educator Sympsoium. (bottom): Cara Lin with Rhizophora mangroves seedlings about to be outplanted

<u>Planting Activities and Survivorship:</u>

Primary Restoration site: some mangroves were planted at this site prior to the start of the fellowship in 2020. Additional mangrove propagules were collected from Sasa Bay Marine Preserve in central Guam for planting in southern Guam, to help promote genetic mixing. Mangrove seedlings were prepared as part of an activity for teachers at the Southern Water Conservation District Educator Symposium on 07/29/21, and at DOAG's Earth Day II event on 11/13/21 .

These seedlings grew in the DOAG nursery for several months until outplanting on 12/11/21. Outplants were monitored at 5 days post planting, 40 days post planting, 4 months (115 days), and 7 months (204 days) post planting. Survivorship decreased over time, and observations suggest mortality was due to various factors including herbivory, sedimentation/burial, and debris, such as bamboo pieces knocking over seedlings (fig 1).

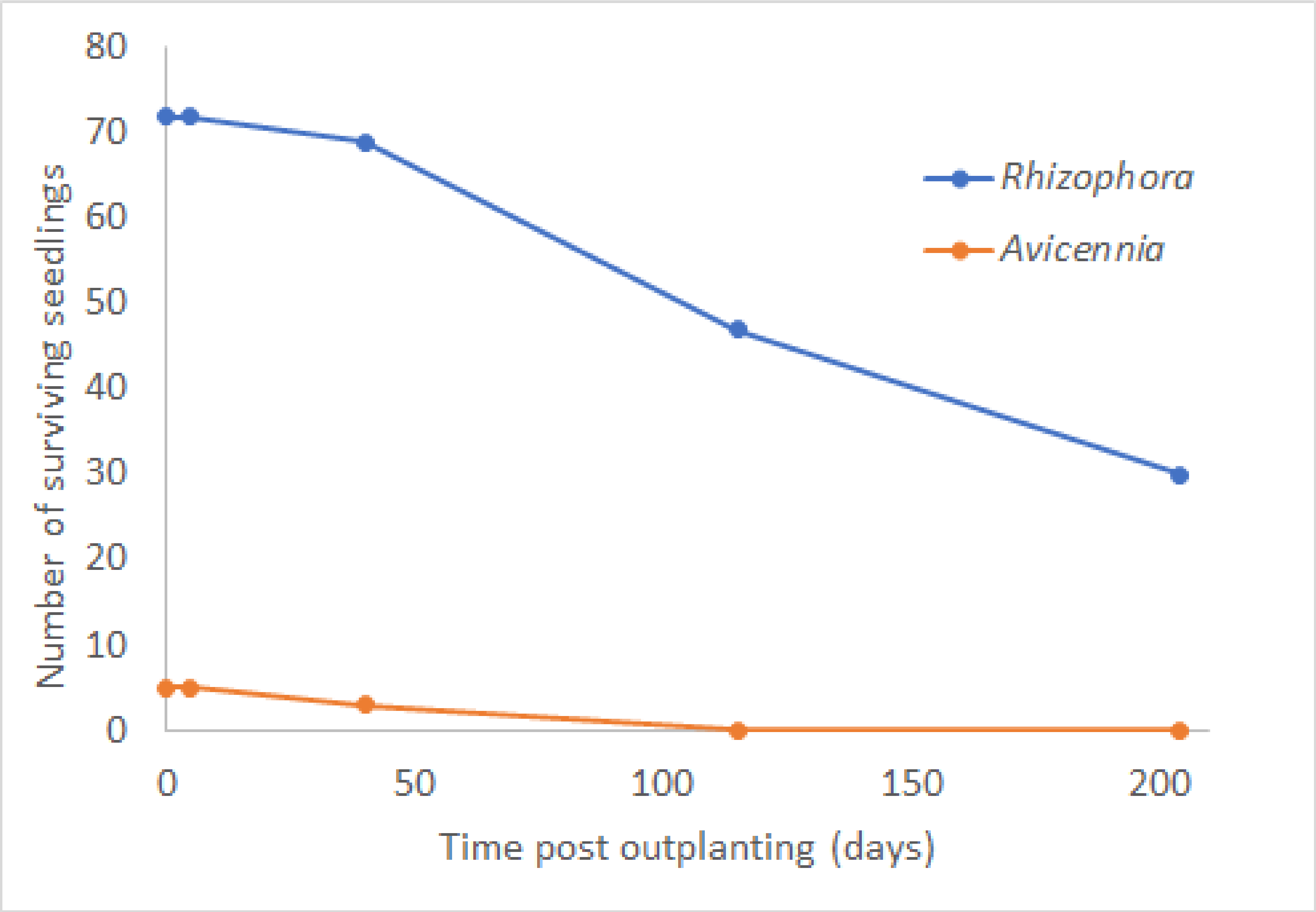


Figure 1: Survivorship of mangrove species. The five Avicennia planted did not survive, likely because they were too small. Rhizophora dropped in percent survival to 65% on day 115 and 42% on day 204. Potential stressors include sedimentation or shorter mangroves, given that leaves were sometimes covered in a layer of mud.

Secondary site: Some mangroves propagules from the previous collection days mentioned above that did not grow as quickly were kept in the nursery and planted at this secondary site. Additionally, local high school students helped gather additional propagules from Sasa Bay Marine Preserve as part of service learining for "Sasa Bay Marine Preserve day" on 02/14/22. These mangroves were grown in the nursery for several months until outplanting at our new site on 06/03/22.These seedlings will be monitored with landowner input beyond the fellowship.

Photos (left top and bottom): students from local high schools explore Sasa Bay Marine Preserve and help collect and prepare propagules for growth. Special thanks to Nina Peck (University of Guam), Marie Auyong (NOAA affiliate), and teachers, Carolyn Haruo, Melanie Blas, and Alexandra Benavente, for supporting the event. Photo credits: Carolyn Haruo

Next steps:

Given some of the lower survivorship seen in the past months of outplanting at the primary site, recommendations for future outplanting include:

- Outplant seedlings before rainy season. Due to schedule constraints, our outplanting took place at the end of rainy season. However, according to mangrove restoration guides, the additional freshwater input may help reduce stress for transplanted young mangroves.
- despite growing for several months, *Avicennia marina* seedlings were outplanted while still only about 15-20 m tall, growing them for longer may produce better results.

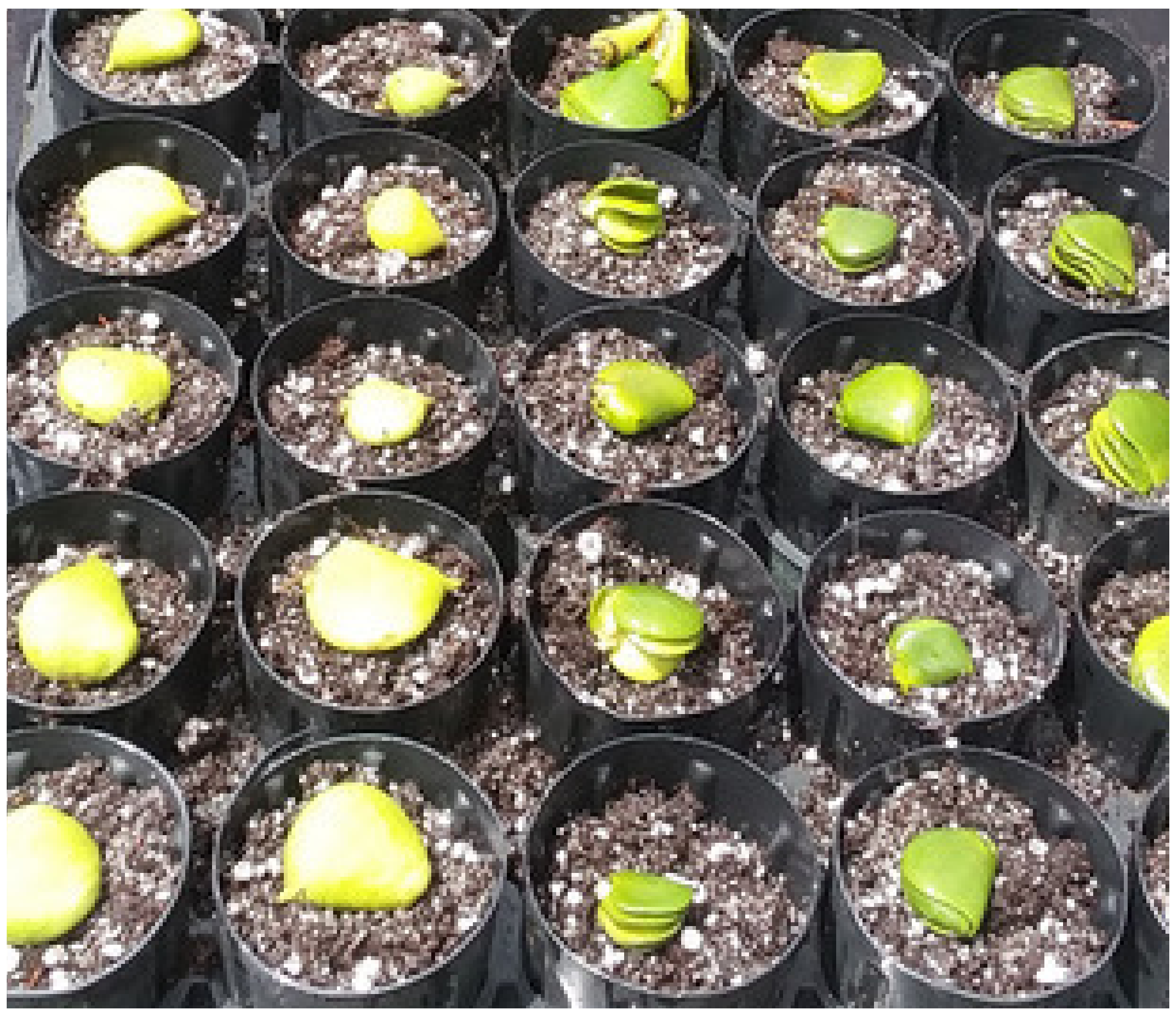


Photo (above): propagules of Avicennia marina are laid out over a mixture of sand and soil to start growth in the DOAG nursery until large enough to be outplated.

Additionally moving forward, we should put more focus and attention on:

- Better growing and preparing *A. marina* in the nursery for outplanting, this species historically has not been able to be successfully incorporated into restoration projects. However, maintaining species diversity in restoration projects is likely crucial for generating ecosystem services.
- Working with landowners to expand our planting sites. Avoiding over planting at the primary restoration site can help ensure that our restoration activities "help nature along" and allow mangroves recruit according to natural patterns.

Mangrove Flowering Period Observations: Over the course of a year, from July 2021 to June 2022, mangroves in Sasa Bay Marine Preserve was monitored for the presence of flowers and propagules to help inform planning for future mangrove restoration (table 1).

Table 1. Reproductive seasonality of different mangrove genera at Sasa Bay Marine Preserve

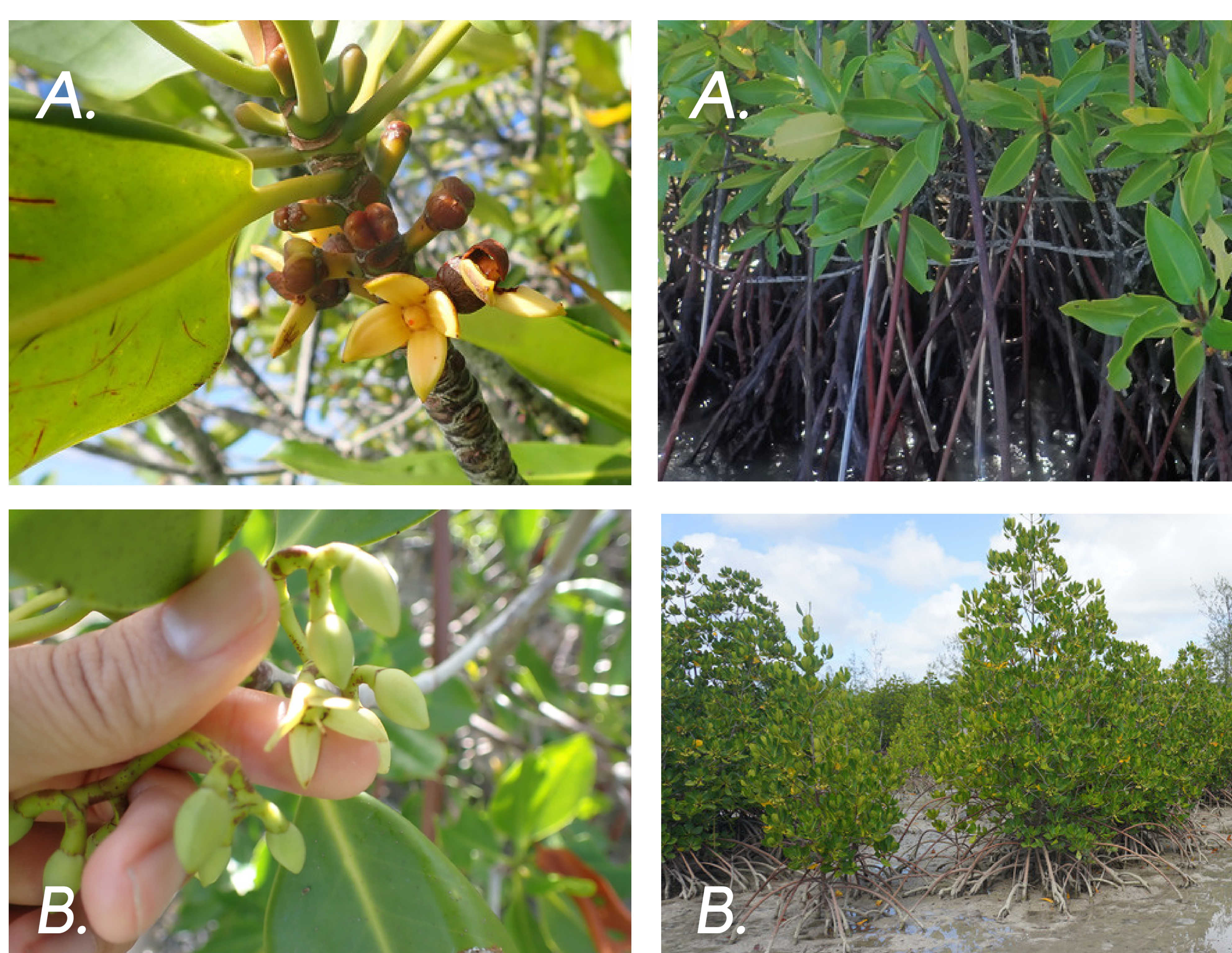
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Rhizophora												
Avicennia					Early flowers	Flowers						
Bruguiera						Many flowers some propagules						
Lumnitzera	Seeds but no flowers				Some seeds, no flowers		Mix, some nothing, some fair amount					

Overall, it was found that most mangrove species seemed to have year long availability of propagules, with some months having less flowers and/or propagules, although this observation was purely through a visual estimate and would need to be confirmed with quantitative data. The reproductive success of *Bruguiera gymnorhiza,* which normally relies on the Micronesian Honeyeater, *Myzomela rubrata saffordi* (Ėgigi), for pollination was of concern since this bird is locally extinct in Guam. Observations found *B. gymonrhiza* propagules present to some degree year round which alleviates some concern. However, whether the number of propagules is comparable to levels prior to the extinction of it's primary pollinator is unknown. The impact of other invasive insects which have been observed in the area, is also unknown.

Rhizophora species:

During the initial literature review, several species of mangroves from the genus *Rhizophora* were reported. With a quick visual exploration in the mudflats near the Marianas Yacht Club, it appears that the majority of mangroves at Sasa Bay Marine Preserve are either *Rhizophora mucronata, Rhizophora stylosa,* or a hybrid of both. Some sources in the literature also suggest that these two species are essentially genentically the same. The difference between the two species is simply the length of the style.

Rhizophora apiculata is also present but to a lesser extent. While still learning and gathering information during the fellowship, it wasn't clear that *R. apiculata* was a different species until later in the year of monitoring, so a complete year of flowering and propagule monitoring could not be completed. However, from March to July, only flowers and not propagules were ever observed. *Rhizophora* restoration may also want to assess if *R. apiculata* has a small population or impacts on primary pollinators, and may need some restoration interventions.



Photos (right): The top row (A) photos show *R. apiculata* which has flowers farther down under the leaves, with brown exterior coloration. The roots often also appear straighter and darker. The bottom row (B) show *R. mucronata (or R. stylosa, or a hybrid), which has lighter colored flowers closer to the end of the branch, and lighter roots that have a more gentle arching shape.*

Other species considerations:

Lumnitzera littorea is only found in Sasa Bay Marine Preserve since the area includes more preferable mud flat habitat, with areas of slightly higher elevation and less inundation. *L. littorea* has a few growing younger plants (evidence of recent reproductive success) and seems to have flowers and/or seeds nearly all year long. However, the success of these seeds and potentail restoration techniques is still unknown. Two attempts to sprout seeds by placing them on soil and sand, as well as in plastic bags with wet towels were unsuccessful. Literature searches indicate that this species likely has a low fertilization rate, which may be lowered further by burrowing insects.

Another mangrove species that has been recorded in Guam previously is *Xylocarpus moluccensis.* However, only one individual, located by the pier forming the Achang boat ramp was observed during the fellowship. Further restoration efforts may also seek to assess the population size and ensure this potentially rare species does not go locally extinct.

Photo (left): Xylocarpus moluccensis, spotted with immature fruit on 07/27/21 near the Achang boat ramp by Farron Taijeron (The Nature Conservancy). Photo credit- Farron Taijeron.

For more information, read the Mangrove Biology and Ecology section of "Guam's Seagrasses and Mangrove s- A literature review to guide future natural resource management and research"

Saina Ma'åse'!: All the mangrove restoration work conducted during this fellowship was supported by many natural resource management professionals. A special thanks to Patrick Keeler (Guam Bureau of Statistics and Plans), Farron Taijeron (The Nature Conservancy), Brent Tibbatts (Guam Department of Agriculture), and Marie Auyong (NOAA affiliate), who helped provide the materials and techniques for growing mangroves, explore mangrove sites, and helped with community based events for seedling preparation.

Additional thanks to the Guam Department of Agriculture, Guam Bureau of Statistics and Plans, Nova Southeastern University, the NOAA Coral Reef Conservation Program, the All Islands Committee, and Department of the Interior for the financial and institutional support for the National Coral reef Management Program.

GUAM CORAL REEF INITIATIVE

NSU Florida NOVA SOUTHEASTERN UNIVERSITY

NOAA CORAL REEF CONSERVATION PROGRAM