SEAGRASS MONITORING IN SAN ANTONIO BAY, TEXAS WITH IMPLICATIONS FOR MANAGEMENT

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Abstract.–As resource managers have become more aware of the ecosystem services provided by seagrasses (providing food, cycling nutrients, stabilizing sediments, etc.), the need to evaluate and monitor the condition of seagrass beds over time has become a conservation priority. In 2012, the Texas Parks and Wildlife Department (TPWD) launched a pilot seagrass monitoring program designed to monitor changes in seagrass condition across coastal Texas. Given limited state resources, an ongoing monitoring plan needs to be feasible using existing staff and equipment in an efficient manner. As part of the pilot study, seagrass percent coverage and canopy height were measured at fifty stations in San Antonio Bay (the Guadalupe River estuary), Texas. Seagrass beds were monitored in early fall over three years (2012, 2014, and 2015) to capture peak above-ground biomass. Percent coverage of *Halodule wrightii*, the dominant seagrass species in San Antonio Bay, decreased significantly over time, as did canopy height. Two other seagrass species, *Halophila engelmannii* and *Ruppia maritima*, were documented at lower frequencies in the bay during the study. Higher occurrence of *Ruppia maritima* in the third and final year of the study may have been linked to reduced bay salinities.

Keywords: seagrass, monitoring, Texas, management, estuary

Seagrass beds serve as important habitat for estuarine fish and wildlife worldwide. Seagrasses provide food for fish, waterfowl and sea turtles, contribute organic material to estuarine and marine food webs, cycle nutrients, stabilize sediments, and act as global carbon sinks (Hemminga and Duarte 2000; Orth et al. 2006). They are economically important in maintaining fisheries by serving as nursery habitat for juvenile fish and invertebrates. Only relatively recently have seagrasses been singled out as a special conservation concern. In Texas, seagrass has been identified as a critical habitat under the Coastal Coordination Act (31 Texas Administrative Code §501.3). Globally, growing coastal populations and increasing coastal development threaten seagrass habitat (Waycott et al. 2009). Worldwide seagrass decline is most often linked with water quality decline (Orth et al. 2006). As resource managers have become more aware of the ecosystem services provided

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by seagrasses, the need to evaluate the condition of seagrass beds and monitor seagrass health over time has come to the forefront.

Monitoring efforts generally include a landscape-scale component, involving mapping the extent of seagrasses through remote sensing such as aerial photography, and a smaller-scale component employing biological measures of plant metrics along transects or at points in the seagrass bed. Some programs emphasize one approach or the other, but most programs attempt to integrate the two components. For example, the long-running seagrass monitoring program in Chesapeake Bay began in 1984 with annual aerial surveys (Koch and Orth 2003). Aerial photography is analyzed to determine the extent of submerged aquatic vegetation. Ground surveys are used to verify presence and species of aquatic vegetation identified from the aerial images. Seagrass extent is one metric of overall bay health. Regular monitoring has allowed resource managers to measure progress of water quality improvement efforts and set seagrass restoration goals (Orth et al. 2010). Other seagrass monitoring programs use a transect-based sampling design that includes estimation of species coverage with quadrats (Short et al. 2006). Seagrass monitoring in southern Florida goes further, collecting more detailed measures of plant health, such as shoot density and leaf length, analyzing water and/or sediment quality, and collecting physical measurements such as light penetration and water depth (Fourqurean et al. 2002). This multi-agency coordination effort has resulted in a long-term record of seagrass condition in Florida Bay, the Key Largo National Marine Sanctuary, and the Florida Keys. Two seagrass monitoring programs, Seagrass-Watch (McKenzie et al. 2003) and SeagrassNet (Short et al. 2006), have been developed to coordinate multi-national efforts to monitor seagrass beds in approximately 47 countries, often using local volunteers trained by professionals to “adopt” and monitor nearby seagrass beds.

Establishing a statewide seagrass monitoring program is the foundation of seagrass management in Texas. Resource managers must have current, accurate information regarding the condition of seagrass beds along the Texas coast, and it is vital for regulatory decisions to be science-based. To accomplish this, statewide seagrass monitoring must focus limited resources on collecting vital information that allows

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managers to detect trends in seagrass loss. An ongoing monitoring plan must be something that resource managers can accomplish with limited staff and resources, such as boats, that are purchased and operated for multiple objectives, not just seagrass monitoring.

Texas does not currently have an official state seagrass monitoring program. However, in 1999 the three state agencies with primary responsibility for conserving coastal natural resources, the Texas General Land Office (GLO), the Texas Commission on Environmental Quality (TCEQ), and the Texas Parks and Wildlife Department (TPWD), adopted the Seagrass Conservation Plan for Texas (TPWD 1999). Currently, TPWD facilitates quarterly meetings of a Seagrass Monitoring Work Group comprised of experts from academia, government and non-governmental organizations. The group's primary focus is to facilitate implementation of a statewide seagrass monitoring plan. Members of the group developed recommendations for a monitoring approach incorporating landscape analysis and field-based indicators of environmental quality and seagrass condition in a three-tier system (Dunton and Pulich 2011). Tier 1 is the landscape analysis component, calling for aerial imagery of the entire Texas coast to be obtained on a regular basis in order to document the areal extent of seagrass beds. Tier 2 is a rapid boat-based assessment of a few key seagrass condition parameters at numerous fixed sites. Tier 3 is intensive site monitoring using a transect-based design. Tier 3 is intended to explore causes of seagrass decline in areas of special concern or areas of decline (Dunton and Pulich 2011).

In 2012, the TCEQ funded TPWD to develop and demonstrate a coastwide seagrass monitoring project in Texas estuaries. Monitoring followed a tiered approach recommended by Dunton et al. (2011) for Texas, but was also informed by recent work in the northeastern USA (Neckles et al. 2012). One component of the project was to implement Tier 2 monitoring at a bay scale. Fifty fixed monitoring stations were established and first monitored in 2012 in San Antonio Bay. Following completion of that project, we wanted to repeat the survey using the same procedures to determine if seagrass change could be detected using the monitoring parameters. An additional objective of the study was to identify the level of effort involved in collecting annual survey data.

MATERIALS & METHODS

Cost and level of effort.–Purchases and other costs were documented in the TPWD financial accounting system for the first year of seagrass monitoring (2012), as required by the funding contract. Level of effort (TPWD staff time) was documented in the TPWD employee time sheet management system. Cost estimates were derived from these data at the end of the contract (Radloff et al. 2013). Separate cost estimates were made for "setup" and "operating" costs. Setup included project planning, staff coordination, staff training, writing a Quality Assurance Project Plan, grant management, and creating a database for data management. Operating included scheduling staff, preparing boats and other equipment, field work, and data entry. In subsequent years (2014 and 2015), monitoring was led by TPWD staff with assistance from staff from other agencies, including the Texas Commission on Environmental Quality and the Nueces River Authority. In those two years, costs and staff time were not formally documented, but were estimated.

Site selection.–San Antonio Bay is the estuary of the Guadalupe River and is located in the central Texas coast near Port O'Connor. Tidal range is less than 1 meter (Morton and Peterson 2006). Seagrass beds are found primarily in shallow areas fringing the barrier island and spoil islands, including those bordering the dredged ship channel, the Intracoastal Waterway (Fig. 1).

Sample size requirements were determined with a power analysis based on summary statistics (mean, standard deviation, coefficient of variance) of previous seagrass data collected in various Texas bays. Power analysis revealed that a sample size of 50 stations would be adequate to detect a 20% or greater change in canopy height and in percent coverage by species. Potential monitoring stations were first identified by generating a list of coordinates using the TPWD Coastal Fisheries sampling grid system (TPWD 2012a) and historic seagrass coverage available as geographic information system (GIS) polygon shapefiles derived from imagery photointerpretation (Mark Fisher,

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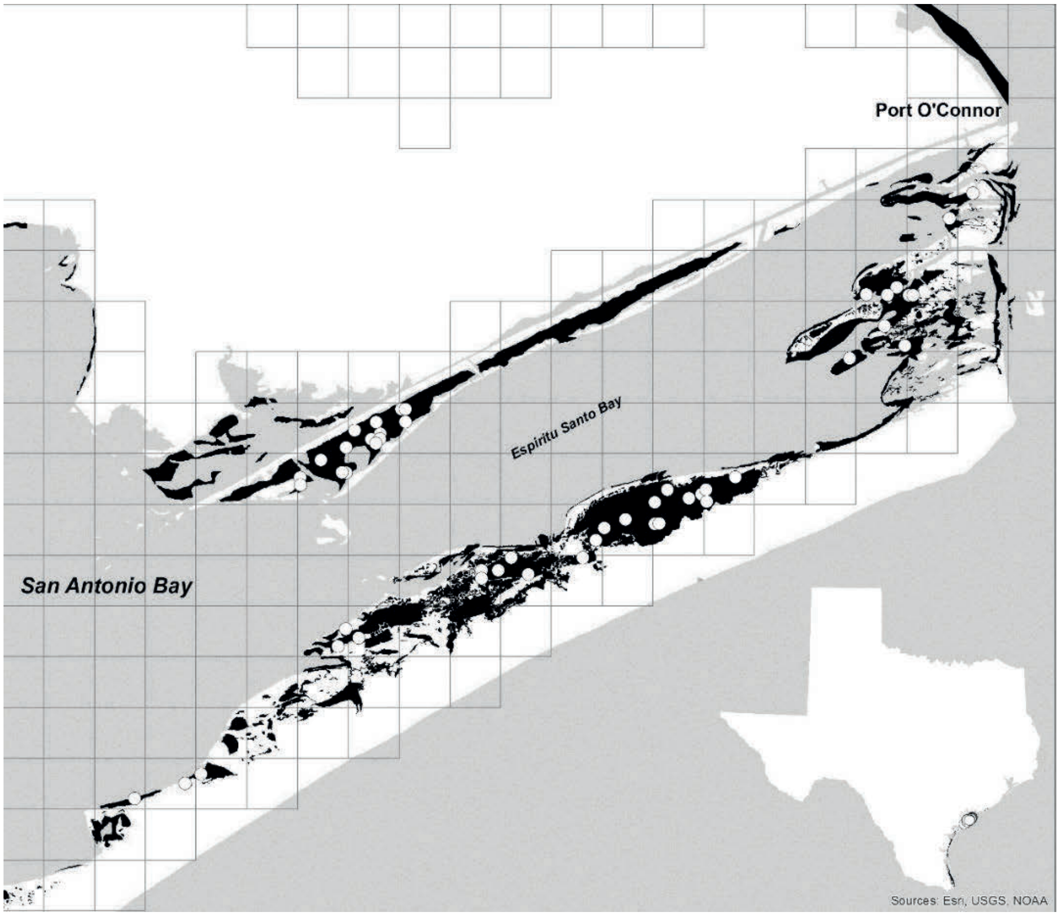

Figure 1. San Antonio Bay showing the TPWD Coastal Fisheries sampling grid (gray squares), seagrass imagery (black), and 50 permanent monitoring stations (open circles).

TPWD, pers. comm.; TPWD 2012b). TPWD grids cover each bay and the Texas Territorial Sea and are one minute latitude by one minute longitude in size. Each sample grid is divided into 144 sample gridlets that are five seconds latitude by five seconds longitude in size (about 154 m by 154 m). Coordinates were obtained for every gridlet for which the center of the gridlet fell within a seagrass polygon. In this way, 149 coordinates were generated for San Antonio Bay. Local staff knowledgeable of San Antonio Bay were consulted to identify coordinates based on the presence of seagrass, accessibility by boat, and lack of navigation hazards. From those coordinates, fifty stations were selected randomly and designated as "primary" sites, and the rest were designated as "alternative" sites. In 2012, potential monitoring stations were visited for the first time under this project. Seagrass monitoring teams navigated to within 10 m of a selected priority site using a handheld GPS and maps with coordinates. If visual observation confirmed that the area within a 10 m radius of the boat had seagrass and was free of navigation and safety hazards, the site was established as a permanent monitoring station. If the site did not meet those criteria, nearby alternative sites were investigated as a replacement to the priority site. This process continued until 50 stations were identified and established as permanent monitoring stations (Fig. 1). Staff participated in a field-based training before the project began in 2012. Primary project staff familiar with seagrass species identification and project methodology were present on each field crew.

Monitoring methods.–Seagrass monitoring in San Antonio Bay was completed annually (in 2012, 2014, and 2015) in September and/or October. Fifty stations were established and first monitored in 2012. These stations were monitored again in 2014. In 2015, weather and other circumstances prevented crews from returning to three of the stations, so only 47 of the stations were monitored.

Basic information, such as date, time, weather conditions, latitude, longitude, total water depth, and names of data collectors was recorded at each site. Percent coverage by species was estimated within an open square polyvinyl chloride (PVC) quadrat 0.50 m by 0.50 m (0.25 m^2). Quadrats were thrown into the water from the boat in a haphazard manner, once each near the bow, stern, starboard and port sides of the boat. Macroalgae, dead seagrass and other material were cleared from the area within the quadrat, with care taken to avoid uprooting seagrass. Percent coverage for each seagrass species present within a quadrat was defined as the proportion of the quadrat area obscured by rooted seagrass when viewed from directly overhead. Thus, the total of all species present plus bare area always equaled 100%. When water clarity prevented visual assessment of seagrass percent coverage, staff used touch to estimate seagrass percent coverage (for about 32% of the observations). Seagrass canopy height was estimated using leaf length as a surrogate. Five representative shoots of each species were collected within each quadrat and brought to the boat. There the length of the longest blade on each of five shoots was measured to the nearest 0.1

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cm. In 2012, canopy height was estimated only for species with percent coverage of 20% or greater within the quadrat, but in 2014 and 2015 leaf length was measured for every species present in the quadrat, regardless of cover. In some cases, this meant that fewer than five shoots could be collected. Leaf length was defined as the portion of the seagrass shoot that is green and above the sediment line. In 2012, leaf length from all seagrass species were measured this way. However, *R. maritima* exhibits a branching growth form associated with reproduction that produces very long rhizomes above the sediment that forms a tall canopy. In 2014 and 2015, the protocol for measuring *R. maritima* was adjusted to account for this; canopy height was estimated by measuring the entire length of the rhizome from the sediment surface to the tip of the rhizome. Voucher specimens and/or photos were collected when necessary for later verification of species identification.

Data management and analysis.–Data were transcribed from field sheets into a custom Microsoft Access (2007) database. Calculations were programmed into the database for summary statistics (mean, standard deviation, standard error). Data transcription was manually checked against field sheets (at least 10% of data). Data analysis was conducted using SAS Enterprise Guide 4.3 (SAS Institute, Inc., Cary, NC). Data set distributions were analyzed using the SAS procedures PROC UNIVARIATE. Repeated measured analysis of variance was conducted on percent coverage and canopy height data sets using PROC MIXED (SAS Institute, Inc., 2013). Neckles et al. (2012) found this to be the best analysis for seagrass monitoring data conducted regularly at fixed stations. The advantage of this design is in its statistical power and efficiency (Vickers 2003). Specifically, this is because the within-station variance of repeated measures is typically lower than the between-station variance of a simple one-way design. The error variance associated with the treatment is smaller in the cast of repeated measures than that expected in a design using independent samples. Year was the fixed effect (single factor) and station the random effect. Percent coverage data were arcsin transformed before analysis. Analysis was run using unstructured covariance and the between-within degrees of freedom method.

RESULTS

Cost and Level of Effort.–In 2012, TPWD spent approximately $24,007 and 501 hours on one-time, setup costs. Operating cost was estimated at $17,914 and 361 hours. Personnel costs comprised the majority, about 80%, of costs. Travel, including mileage, was the second highest cost for operating. In 2014 and 2015, monitoring was accomplished in less than two days using around nine crew operating out of three boats. Staff time, vehicle and boat fuel, and travel costs were absorbed by project participants in their regular operating budgets.

Three seagrass species were observed over the course of the study: *Halodule wrightii*, *Halophila engelmannii*, and *Ruppia maritima*. Average percent coverage of the dominant species, *H. wrightii*, decreased from 77% to 38% across the three years of study (Table 1). Average percent coverage of *H. engelmannii* ranged from 0.0% to 2.3%, and that of *R. maritima* from 1.7% to 16.1%.

Mixed-model analysis of variance indicated that *H. wrightii* percent coverage differed significantly among the three sampling events (Table 2; Fig. 2). Mixed-model analysis of variance was conducted separately for *H. engelmanii* and *R. maritima* percent coverage, even though these two species occurred at relatively low frequency. Results indicated that *H. engelmanii* and *R. maritima* percent coverage differed significantly among the three years. However, roughly two-thirds of the data set for each of these species consists of zeroes. Residual plots from the analysis for *H. engelmannii* show a poor fit, probably because so many of the data points are zeroes.

Mean leaf length of *H. wrightii*, as a surrogate for canopy height, decreased each year of the study, from 23.1 cm in 2012 to 19.0 cm in 2014, and 16.6 cm in 2015 (Table 3). Mean leaf length of *H. engelmanii* also decreased over the course of the study, from 6.8 cm in 2012, to 5.1 cm in 2014, and 3.5 cm in 2015. Mean leaf length of *R. maritima*, by contrast, increased from 6.7 cm in 2012 to 17.1 cm in 2014, and 19.7 cm in 2015. The low value in 2012 is influenced by the change in measurement protocol following that year of the study, which was made

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Table 1. Average percent coverage by seagrass species at monitoring stations in each of the three years of study (mean ± standard deviation (N)). Species coverage at each station was averaged from four subsamples.

Species/Year	2012	2014	2015
Halodule wrightii	76.7 ± 20.9 (50)	59.7 ± 27.7 (50)	37.6 ± 35.3 (47)
Halophila engelmanii	1.1 ± 5.1 (50)	2.3 ± 7.3 (50)	0.0 ± 0.0 (47)
Ruppia maritima	1.8 ± 10.9 (50)	1.7 ± 5.4 (50)	16.1 ± 22.8 (47)

Table 2. Mixed-model analysis of variance results; effect of year on transformed percent coverage.

Species	Degrees of Freedom	*F* value	*P*
Halodule wrightii	2, 95	84.69	<0.0001
Halophila engelmanii	2, 95	9.35	0.0002
Ruppia maritima	2, 95	55.58	<0.0001

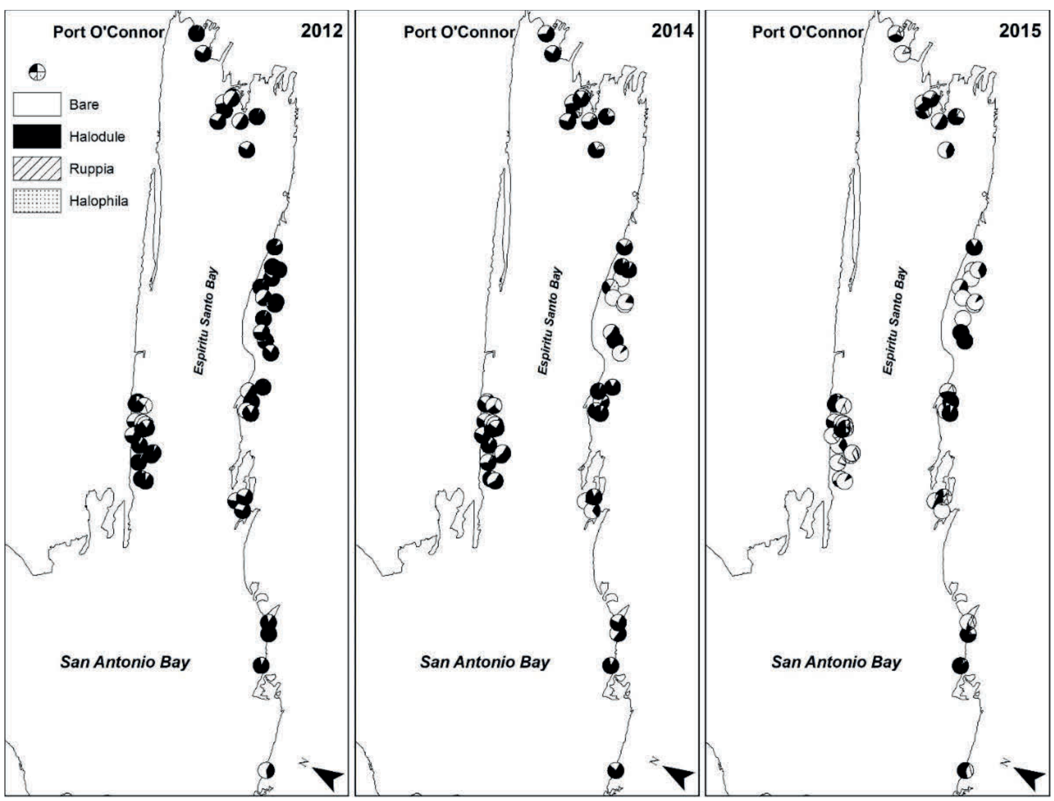

Figure 2. Mean percent coverage by seagrass species at each monitoring station, each year. “Bare” = percent bare ground, “Halodule” = percent *Halodule wrightii,* “Ruppia” = percent *Ruppia maritima,* and “Halophila” = percent *Halophila engelmannii*.

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Table 3. Leaf length (cm) as a surrogate for canopy height of seagrass species in each of the three years of study reported as means ± standard deviation (N=number of stations where leaves were measured). Means are averaged from station means, which are weighted averages of leaf lengths since variable numbers of leaves were measured at a station, depending on whether a given species was present within each quadrat.

Species/Year	2012	2014	2015
Halodule wrightii	23.1 ± 5.6 (49)	19.0 ± 6.1 (47)	16.6 ± 4.8 (37)
Halophila engelmanii	6.8 ± - (1)	5.1 ± 1.7 (11)	3.5 ± 1.0 (2)
Ruppia maritima	6.7* ± - (1)	17.1 ± 8.1 (11)	19.7 ± 11.0 (30)

* Leaf length of *R. maritima* was measured differently in 2012 (see Methods)

to take into account the taller canopy of *R. maritima* due to its growth habit when flowering.

Mixed-model analysis of variance on *H. wrightii* canopy height indicated a significant decrease over time (Table 4). For *H. engelmannii*, there were not enough data points to complete the analysis. For *R. maritima,* there was a significant time effect between years, driven by the difference between the first year of the study (2012) and the other two years. However, the method for measuring this parameter changed after the first year of the study, which complicates interpretation of this result.

Discussion & Conclusions

Level of Effort.–In all three years, San Antonio Bay stations were monitored in approximately two days, using three boats. Boat crew size ranged from two to four people, with three or four being the preferred crew size. Crews averaged 14 sites monitored per day. Travel time between stations was the limiting factor in maximizing the number of stations monitored each day. This is one of the reasons that only locations accessible using small motorboats were included in the monitoring program. Once anchored at a station, estimating percent coverage and uprooting shoots for leaf length measurement were the most time-consuming element of monitoring. Crews found it efficient to deploy four quadrats immediately upon anchoring at a station, then to put two crew members in the water to estimate percent coverage and collect shoots, leaving one crew member on deck to measure shoots and record data.

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Table 4. Mixed-model analysis of variance results; effect of year on leaf length (as surrogate for canopy height).

Species	Degrees of Freedom	*F* value	*P*
Halodule wrightii	2, 81	221.50	<0.0001
Halophila engelmanii	2, 0	6.42	*
Ruppia maritima	2, 9	12.24	0.0027

*analysis could not be completed due to small sample size

Special Equipment.–Shallow draft boats were required in the shallower bays in order to access all seagrass areas. Having a hydraulic anchoring system and a push pole provided a safe way to anchor the boat at a station so monitoring could be completed. Monitoring equipment was simple and inexpensive, and most items were already on hand for other field work, such as GPS units. Dive masks were used when estimating percent coverage in the water. PVC quadrats were inexpensive and easy to construct. Measuring boards or tapes sufficed to capture canopy height.

Representativeness of sampling stations.–Stations were not located uniformly in all areas of the bay which support seagrass growth (Figure 1). Areas which were not easily accessible by small motorboats did not get monitored. This raises the question of whether results from the monitored areas can be extrapolated to the non-monitored seagrass beds. This would likely be an issue in other bays where significant stands of seagrass grow in areas inaccessible to small motorboats. Use of airboats is one potential solution when working very shallow areas (<0.3 m). However, airboats are generally more expensive to purchase and maintain, and require more staff training. Airboats are not easy or comfortable to operate on open water when seas are choppy. It is easier to traverse open water in small motorboats, for example when moving between the nearshore seagrass beds in San Antonio Bay and those adjacent to Matagorda Island (Figure 1). Despite the disadvantage of not being able to monitor certain areas of San Antonio Bay, crews were able to thrice complete a rapid annual seagrass survey with existing staff and equipment, and minimal cost.

Statistical considerations.–Percent coverage data ranges from 0 to 100 and is not always normally distributed. Neckles et al. (2012) used

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an arcsin transformation if percent coverage data sets were not normal. Even with the arcsin transformation San Antonio Bay percent coverage data sets did not pass normality tests. This is a concern since one of the assumptions of the repeated-measures analysis of variance test is normality of the data. However, when analyzing the *H. wrightii* percent coverage and canopy height data, normal probability plots showed a reasonable agreement between the theoretical and actual distribution of the residuals (i.e. the residuals were "well-behaved").

Influence of freshwater inflows on seagrass species composition.–In contrast to an overall decline in percent coverage of *H. wrightii* over the three years of the study, there was a relatively large increase in percent coverage of *R. maritima* the final year of the study. Differences in salinity tolerances of the two species is one possible explanation for the shift in species composition. *H. wrightii* in Texas is considered an obligate halophyte that requires average annual salinities of at least 20 (McMillan and Moseley 1967). *R. maritima*, on the other hand, is more euryhaline. Bay salinities in San Antonio Bay averaged 28 in 2012 and 2014, but the average salinity for 2015 was only 20 (TPWD, unpublished data). Increased freshwater inflows may also equate to higher average turbidities in the bays, which could could compromise seagrass survival. Turbidity or light penetration was not measured in this study. Leaf length of the dominant species, *H. wrightii*, decreased from year to year over the three years of the study. Both percent coverage and leaf length are seagrass condition indicators, and expected to be generally higher when ambient environmental conditions are better.

Conclusions.–Monitoring seagrass beds in San Antonio Bay was relatively inexpensive and easy to accomplish on an annual basis using state government resources. Information derived includes percent coverage by species and canopy height. Comparing data across three years showed significant differences between the years. The statistical approach used by Neckles et al. (2012) detected differences among years, but almost any statistical test would likely have confirmed the apparent differences among percent coverage and canopy height. This study was focused on monitoring seagrass condition, but did not attempt to evaluate environmental changes that may impact seagrass

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condition, including anthropogenic water quality impacts. Ideally, a robust water quality monitoring effort focusing on suspended sediment and nutrient levels will accompany seagrass monitoring efforts. Large-scale changes in freshwater inflows have an influence on seagrass distribution. It may be challenging to tease out pollution-related changes to seagrass beds from those influenced by hydrologic events or large storms. Regular monitoring of seagrass beds will strengthen the ability of resource managers to discern changes in seagrasses due to hydrologic events from those mediated by water quality degradation.

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