Assessing the impact of propeller scars on sea grass fragmentation in South Bay-Laguna Madre, Texas using UAS imagery

by

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I. Introduction

Laguna Madre has experienced substantial change caused by human activity in the area. Due to an increase in boating activity in Laguna Madre, seagrass meadows that once covered large expanses of the bay are now left heavily dissected (Heck and Johnson 2006). The main cause of habitat fragmentation are propeller scars left behind by boat motors. These boats travelled to too shallow of areas and in the worst cases became stuck. The propeller scars have altered ecosystem dynamics and continue to change the way in which marine species survive in this unique region. With the use of an Unmanned Aerial System (UAS) and open source software, I hope to show that modelling propeller scars can be easy and cost-efficient.

Worldwide, ecosystem fragmentation is one of the biggest threats to biodiversity (Heck, Johnson 2006). Environments that support a variety of wildlife are being dissected by various forms of human activity (Fourqurean et al. 2012). In marine environments, commercial and recreational fishing practices have modified the natural vegetation coverage. Along the Texas coastline seagrass covers most of the shallow bay floors. Globally, seagrass meadows account for approximately 15% of carbon sequestration (Fourqurean et al. 2012). In lower Laguna Madre, the dominant species of seagrass is Thalassia testudinum. Thalassia testundinum provides a habitat for a variety of benthic species, such as mollusks and crabs. It also provides shelter for small fish. Fragmentation of marine environments has been researched very little. This study aims to fill this knowledge gap as well as spark interest in marine habitats.

Laguna Madre is one of only five hypersaline coastal ecosystems in the world. The unique habitat supports a variety of life forms that have become accustomed to the harsh conditions. Some of these species, such as the redhead duck (Aythya Americana) and Kemp's Ridley Sea Turtle (Lepidochelys Kempii), are listed on the endangered species list (Onuf 2006). The animal and plant species that live in the area have adapted to live in a specific environment, which is now being heavily altered by human activities in the region.

Boat propellers are fragmenting seagrass meadow ecosystems within Laguna Madre, Texas. Boat propellers dredge material from the bottom and create deep scars that impact the various dynamics of the local ecosystems. These scars occur when boats stop in a shallow area and then use their propeller to maneuver through the shallow area. Prop scars found across Laguna Madre are evident from aerial imagery, which can easily be obtained with the use of an UAS. Fragmentation of seagrass beds ultimately results in decreased productivity and potential for further erosion/degradation to the habitat (Holmquist, Uhrin 2003). This study's focus is on turtle grass (Thalassia testudinum) located in South Bay-Laguna Madre, Texas. The studied area was selected because of its unique combination of shallow water, continuous turtle grass, high-boat traffic, and because it is habitat for a wide range of species including endangered sea turtles. The need to quantify the degree in which prop scars are altering the natural habitat is apparent when trying to understand how humans are affecting these ecosystems and the species living in them. This paper attempts to quantify the amount of habitat fragmentation that can be attributed to boat propeller scarring.

II. Background

Laguna Madre's seagrass meadows have been steadily decreasing over the past century (Holmquist, Uhrin 2003). Laguna Madre is a shallow bay that accounts for 40-51% of commercial fishing in Texas (Onuf 2002). The shores of Laguna Madre are largely undeveloped because of the large ranches. Some of these ranches include; the King Ranch on the western border and the Padre Island National Seashore, which is located on the eastern edge (Onuf 2002). As a result of dams along the Rio Grande River and the relatively flat coastal plains in South Texas, there is very little runoff that makes its way into the lagoon. With little in flow the water is generally clear and extremely salty.

Laguna Madre is one of only five bays in the world that's considered hypersaline ecosystems. The average depth of Laguna Madre is a shallow 3.3 feet (Onuf 2003). The clear water and shallow depths make Laguna Madre an ideal area for seagrass meadows to thrive. The seagrass meadows that once covered the entire bay have been reduced in size and heavily fragmented. Laguna Madre contains more than 75% of all seagrass meadow coverage along the Texas coast (Onuunf 2003). The fragmentation of the seagrass meadows has modified the local ecosystem, changing the hunter-prey dynamic (Holmquist, Uhrin 2003).

Coastal areas support a wide variety of life that can be found in the water as well as on the shoreline. Turtlegrass covers a large portion of the study area and acts as structure for benthic species to take refuge. One of the fundamental ways to understand species behavior is to study the local terrain. By studying the local habitat of ecosystems, you can begin to understand the conditions that exist in the place where these species thrive. Conditions such as weather and soil can change the way in which species interact with their environment. By understanding the conditions and features that organisms navigate on a regular basis, we can study the way in which these species have become adapted to their environment. The specific adaptations that allow certain species to thrive in an environment can be the downfall of that species if their habitat is rapidly changing. The rapid changes in submerged vegetation coverage has lasting effects that scientists are beginning to explore. By quickly altering a unique environment like Laguna Madre, humans have left native animals to either quickly adapt or die off. In the case of seagrass, species dependent on these plants for survival are being removed from the ecosystem just as quickly as the seagrass. Recent studies indicate that seagrass density is negatively correlated to predator success (Canion and Heck, 2009).

Water complicates habitat modelling because the ground surface isn't easily visible or able to be mapped. Previously, underwater terrain has been mapped using technologies such as SONAR (Kalacska, Chmura, Lucanas, Be'rube', Arroyo-Mora 2017). Though SONAR is accurate, it is expensive and bulky. Meaning that it is usually found on large ships that travel in deep water. These ships would be limited to the intercoastal channels that dissect Laguna Madre and would be unable to reach the shallow seagrass meadows found throughout the bay.

III. Literature Review

Submerged vegetation is the most important structure for marine species. It is a place for the wildlife to take refuge from tides and predators. Lower Laguna Madre has seen a significant shift in submerged vegetation since the completion of the Gulf Intracoastal Waterway (GIWW) in 1949. Previous to 1949, 20-km (12-mi) separated Lower Laguna Madre from the northern portion. The completion of the GIWW has increased circulation of water between the two bays that were previously only connected in extreme high tide conditions. The circulation of water from Upper Laguna Madre into Lower Laguna Madre has changed water column properties in this unique hypersaline bay. As a consequence of this change the population of submerged vegetation and other species living in Lower Laguna Madre are threatened.

Lower Laguna Madre in the past was dominated by Halodule wrightii (Shoal Grass). The change in salinity and increase ship traffic has changed the amount of submerged vegetation since 1949. The GIWW requires regular dredging to maintain a clear channel for large ships to travel along the Gulf Coast. This process further increases the turbidity of this once clear hypersaline bay.

In recent decades there has been a major increase in the amount of recreational fishing boats inside Lower Laguna Madre. These smaller boats navigate through shallow portions of Laguna Madre in search of fish. Tides often dictate the areas that are safely accessible and deep enough for the outboard motors to not strike bottom. The issue is that some fishermen chase the bait into shallower waters looking for larger fish, their powerful outboard propeller then dredges the muddy bottom and destroys vegetation.

These “propeller scars” have long lasting effects on the local ecosystem and are still visibly present up to 7 years after the boat left that area. The amount of boats on the water today is making it nearly impossible for seagrass to regrow and fill in these bare patches. It is a losing battle that has been a concern for the State of Texas for years and in 2013 it passed state legislature making it illegal to uproot seagrass along the Texas Coast. This is a step forward in preserving what seagrass still grows in Lower Laguna Madre, but unfortunately there are few resources available to actively enforce this law.

Seagrass provides a wide variety of services to local ecosystems and worldwide carbon emissions. Seagrass oxygenates water and cleans pollutants from the water providing a clean habitat for marine species. Seagrass keeps bacteria from growing out of control and consuming all of the oxygen in the water. Seagrass is also a very important carbon sequester and its services worldwide are valued at $1.9 trillion. The environmental services that seagrass provide are slowly being diminished around the world.

Researchers have previously studied marine habitat fragmentation with a variety of different techniques. Thalassia testudinum is a seagrass common to the Gulf of Mexico and the Caribbean. This type of seagrass forms continuous seagrass meadows that provide shelter to various forms of marine life. This seagrass is of importance to researchers, because of the threat it faces from boat propellers that dig up and dissect seagrass meadows in shallow areas (Heck, Johnson 2006). The increase of edges by the action of boat propellers changes the predator-prey dynamics within the seagrass patch (Holmquist, Uhrin 2003).

Seagrass is an important indicator of ambient water quality and habitat health in marine environments (Greene 2018). Healthy seagrass meadows increase water quality and reduce erosion by slowing tidal flows. Seagrass in shallow coastal areas provide habitat for small fish, decapods and crustaceans (Bell et al. 2002). The seagrass meadows slow the tidal flows allowing small organisms, that would otherwise be at the mercy of tides, to move freely. Continuous seagrass meadows are also important hunting grounds for blue crabs. Blue crabs are an important part of the endangered Kemp's-Ridlely Sea Turtle's diet (Landry, Metz 2016). The health of submerged vegetation is important for species that rely on the seagrass for shelter. The degradation of seagrass meadows since 1967 has been cause for concern, because of the decrease in coverage as well as change in the types of seagrass that dominate Lower Laguna Madre.

A. Habitat Fragmentation

Habitat fragmentation is one of the biggest threats to biodiversity worldwide (Dixon et al. 2007). Fragmentation can lead to genetic isolation in native species, which in turn decreases population. In marine environments propeller scarring decreases native species population up to 5m away from the scar. In the past several decades data collection techniques have developed to a point in which high accuracy is not only achievable but becoming the norm. Several different types of technology can be used to accomplish similar results. In many cases the technology used for a study is based on the budget and location for a research project. Innovative technologies such as Light Detection and Ranging (LIDAR) create highly accurate three-dimensional models. LIDAR is a great tool, but the equipment required is costly and beyond the budget of most researchers. Recently a cost efficient 3D modelling technique, that uses cameras instead of expensive lasers, has become more popular.

B. Photogrammetry

Photogrammetry is a technique in which multiple camera angles allow the user to make accurate measurements using only photographs. Photogrammetry is particularly useful in studying change over time and has been used to monitor melting glaciers, changing riverbeds and eroding gullies. This technique was developed in the 1990's. Although it has origins in the computer vision community, which started in the 1980's. In recent years, developments in soft-copy triangulations and image-based terrain modelling algorithms have made it possible for users to create accurate 3D models at a fraction of the cost of LIDAR.

A new photogrammetric technique, known as "Structure From Motion" or SfM, only requires the physical location, angle and focal length of the camera to create three-dimensional models. By merging all of the pictured angles from a specific portion of a larger area we can create a three-dimensional points, which is called a point cloud. This point cloud represents millions of points that have been triangulated between multiple camera angles. As you rotate the point cloud you see different perspectives of the same point, which was generated by merging separate images from around the study area.

C. Underwater Surface Mapping Techniques

Recent developments in surveying technologies have greatly improved the efficiency and accuracy in which we study topography (Dietrich 2017). LiDAR has been at the fore front of this recent revolution in surveying techniques. Though LiDAR can model terrain fairly quickly, the technology is very expensive, and the equipment is bulky. LiDAR may soon be replaced by image processing algorithms such as Structure from Motion. Structure from Motion is a recently developed technology that can build orthomosaic images and 3D point cloud models in a short amount of time (Leon et al. 2015). Structure from Motion or (SfM) doesn't require bulky equipment but simply images from a digital camera and precise gps coordinates of the location of each image. This allows researchers working on a budget to obtain high-resolution imagery without paying large sums of cash to aerial imagery companies. Consumer-grade UAS have highly accurate GPS units with high-definition cameras to provide the perfect platform for this developing technology. These new technologies enabled this study to use up-to-date high-resolution imagery of the study area.

D. UAS in Shallow Water Environments

Shallow coastal areas in South Texas, such as Laguna Madre, are in a constant state of movement. These movements that are normally due to slow tidal flows are being accelerated by large storms. These storms can rearrange sand bars and underwater debris in a span of just a few hours. This constant change complicates mapping of the coast and requires constant updating which can be costly using traditional methods. UAS's have enabled scientists to study areas in a way that were previously too laborious or had ineffective costs. SfM can be useful for biologist studying habitat of local species such as the endangered Kemp's Ridley Sea Turtle. Terrain modelling technologies such as LiDAR and SONAR would be very expensive and difficult to repeatedly use in shallow coastal areas like Laguna Madre. Once three-dimensional models are constructed, they can be used to analyze ground surface terrain and support other studies in need of highly accurate point cloud data.

Structure form Motion has been previously explored as an efficient way to make bathymetric measurements in shallow streams (Brasington, Caruso and Javernick 2014). This research has paved the way for quickly building digital surface models of inundated areas, that were previously out of reach (Obanawa 2016). One goal of this research is to show that it is possible to create highly accurate digital surface models with a consumer grade UAS and open source SfM software and fragmentation statistics provided by Fragstats. These are quickly evolving tools that more earth scientists should become familiar with and possibly implement into their own research.

UAS can be a very efficient and accurate tool for modelling terrain or other imagery applications. Recent developments in terrain modelling technology has made data collection more efficient. Sensors have evolved over time to become more powerful in smaller packages. High-quality digital cameras have become small enough to be lifted by a consumer-grade UAS. This evolution of different technologies has come together to provide a powerful and affordable tool for researchers to utilize.

On top of these great advances in efficiency for this relatively new technology, recent advances in consumer-grade UAS have cut costs of this technology to a fraction of what LiDAR costs (Fonstad, Dietrich, Courville, Jensen, Carbonneau 2013, 421-30). This efficient technology enables shallow coastal research to view and study coastal issues from a new perspective. Researchers will soon be able to efficiently collect high quality data of a study area without expensive aircraft and satellite sensors. The high-resolution imagery that can be obtained by these relatively affordable devices can help us understand the magnitude to which recreational boating fragments seagrass meadows.

The explosion of UAS technology has encouraged computer scientists to create new algorithms to process high quality imagery into new data products. One such algorithm is SfM which uses GPS coordinates and focal lengths of images to create 3D terrain models with overlaying (Chesley, Leier, White, Torres 2017,1-8). SfM is a powerful image processing software that produces visually appealing three-dimensional point clouds that maintain color attributes of the original locations in the images. This software enables researchers to obtain point cloud data in a much cheaper and more efficient way. In terms of coastal studies this new technology is quickly growing as tool to measure change over time.

IV. Methodology

South Bay, in Lower Laguna Madre, is the southern-most bay in Texas, located at 26° 02' 15" N 97° 11' 00". A narrow inlet on the northern edge of this shallow bay opens to a bay that is approximately 13 square kilometers in size. South Bay is a popular area for recreational fishing, as well as, commercial fishing. This area supports a wide variety of marine life and is habitat for the endangered Kemp's Ridley sea turtles. South Bay has several channels that allow boats to travel through the surrounding shallow seagrass meadows.

When looking for an area of Laguna Madre to collect images, it was decided that the study area should have the same species of grass across the whole area. "Tabletop" seagrass meadow in South Bay, Laguna Madre was selected because of the concentration of Thalassia testudinum. The bay is very shallow, except three distinct channels that fan out from the only inlet into the bay. The deep channels along the southern edge of the study area made it possible to sample a continuous seagrass bed without further disturbing the natural vegetation. It was decided that eight sample sites would be selected along a transect (Figure 2). This transect represents areas with similar depths and varying degrees of boat propeller degradation. The images were collected in four rows of five images along the transect. Images were then processed using the SfM software known as Web Open Drone Map (WebODM) to create a seamless orthomosaic and digital surface model.

This orthomosaic provided a clear view of the seagrass, natural sand holes and propeller scars so that they could be digitized separately (Figure 1). Each orthomosaic was clipped to an identical sized circles with a diameter of approximately 25 meters. The features were then digitized so that they could be used in Fragstats. Once all the features were digitized, a separate feature class was created with only the natural sand holes and seagrass. The two layers were compared to show the effect that propeller scars have on seagrass habitat.

Fragstats is a computer program that was designed to compute a wide variety of landscape metrics. In this study Fragstats was used to produce various statistics to show the extent to which these areas have been fragmented by boat propellers. The polygons digitized for the propeller scars, natural sand holes and seagrass were converted to rasters. The raster datasets will then be used in Fragstats as input files and patch metrics will be used to analyze these datasets.

Several landscape metrics were selected to demonstrate the effects of propeller scars on seagrass meadows. The Total Edge metric will show the total amount of polygon edges found in each location. This landscape metric can help understand how much more seagrass/sand boundary a predator fish can patrol. The Mean Area metric was used to show general fragmentation of the environment. Mean Area refers to the mean size of each polygon found in each layer. This metric is a good representation of fragmentation within a landscape.

Radius of Gyration is a measure of how far across a landscape a patch extends. Elongated polygons would have a greater Radius of Gyration than more compactly shaped polygons. The Radius of Gyration is a measure of how far an organism can be expected to travel within a patch before meeting a patch boundary from a random starting point. When looking at the class or landscape scale Radius of Gyration provides the average level of connectivity and difficulty to traverse for a patch type. For a dissected seagrass meadow this would mean how far a small marine organism can travel without leaving the safety of the continuous seagrass.

In this study we collected our images using a DJI Phantom 4 Pro V2 equipped with a 1" CMOS (complementary metal oxide semiconductor) 20 megapixel sensor. The UAS collected images at an altitude of approximately 21 m over several different areas of the seagrass meadow. The eight sample sites were selected along a transect stretching in a westerly direction from the eastern edge of the seagrass meadow. The eight samples collected along this transect consisted of 20 images per site. The images were then inputted into individual projects in WebODM and common nodes were created between them. Those nodes formed a dense 3D point cloud representation of the sample site. This procedure was replicated for each of the eight sample sites. For the purpose of this study, WebODM was also used to create an orthomosaic scene using the 20 images collected. This is done for each of the eight sites. The eight different mosaicked sample sites were then imported into ArcMap 10.4.1. The sample sites were then reduced to uniformly sized circular areas, measuring 25 meters in diameter. Then a union was performed between the circular polygons for all eight mosaicked sites. The propeller scars and natural sand holes of each sample site were then manually digitized into polygons. The polygons could then be used to quantify the amount that propeller scars have fragmented these sample sites. A feature class was created and the propeller scars and natural sandy regions of the study area were digitized separately. A separate layer was created without the digitized polygons of the propeller scars so that a before and after comparison could be made on the propeller scars polygons. These two layers were then converted to rasters and save in the ERDAS Imagine file format so that layers could be used in Fragstats.

V. Results

Lower Laguna Madre is being degraded more rapidly than the seagrass can be replaced. This study shows that the amount of propeller scars present today will only increase. The dissection of seagrass meadows in Lower Laguna Madre is destroying the habitat of small marine organisms that are the main food source of the game fish that these fishermen are trying to catch. This forces the game fish into shallower areas in search of prey which in turn brings fishermen in search of the game fish.

The results of the analysis show that propeller scars drastically increase the length of the Total Edge between seagrass and sand. The increase in total edge allows predators to patrol more grass-line and feed on prey along these grass boundaries. By creating corridors for predators to travel further into seagrass meadows this increases the likelihood that the predator will come across prey, thus altering the predator/prey dynamic. Table 1 shows that boat propellers have more than tripled the Total Edge length for the grass/sand boundary. These propeller scars isolate populations of small marine organisms that rely on the seagrass for shelter or food. This can lead to population decrease of prey species.

Table 1. Landscape Level Fragstats Analysis Results

ID	Total Area (acres)	Total Edge (m)	Area Mean (sq. m)	Mean Radius of Gyration (m)
Propeller scars	0.36	1093.70	19.83	2.61
Without Propeller Scars	0.36	296.20	48.97	2.98

Table 1 shows that at the landscape level propeller scars have an average patch area (Area Mean) that is less than half the size of the layer with only grass and sand (19.829 sq. m. and 48.966 sq. m.). This metric provides us with the average sized patch of either seagrass or sandy bottom. This is an important metric because it provides a picture of the extent to which small marine organism are isolated within patches of this ecosystem.

The Radius of Gyration refers to the mean distance an organism is expected to travel before meeting a barrier. Prey survival rates drastically increase with an increase in submerged vegetation. In seagrass meadow habitats this equation can help demonstrate how far prey can travel within the seagrass meadow before meeting an open sandy bottom. Propeller scars have enabled predators to patrol the sand/grass interface deep into previously dense seagrass.

Table 2 provides a look at the class level that shows the effects propeller scars have on the landscape. In table 2 you can see that the propeller scar class has a smaller area than sand and grass. Table 2 also shows that propeller scars have a much higher radius of gyration than grass even though grass is much larger. This demonstrates that propeller scars allow organisms swimming through them to travel further before being impeded by a barrier. For predators, these propeller scars are corridors that they can use to patrol grass edges and search for prey. Propeller scars have a large radius of gyration because organisms can travel hundreds of feet into previously dense seagrass without being hindered by seagrass. While propeller scars don't take up much area in the landscape they are altering the environment in a way that effects the lowest trophic levels first. While predators use propeller scars as corridors to swim through, to prey organisms propeller scars are barriers that dissect their habitat. As more propeller scars are created populations of organisms that rely on seagrass beds for shelter are being isolated. The effects off propeller scars not only decrease prey populations through habitat destruction and isolation due to fragmentation but also by allowing predators to travel to areas of seagrass beds that would've previously been inaccessible to predators of a certain size. The effects of this change in the landscape are being transferred up the trophic levels and impact all aspects of the food chain.

Table 2. Class Level Fragstats Analysis Results With Propeller Scars

Type	Class Area (sq. m)	Mean Radius of Gyration (m)
Grass	1291.35	2.9516
Propeller Scar	78.10	5.6614
Sand	95.91	1.0314

Table 3. Class Level Fragstats Analysis Results Without Propeller Scars

Type	Class Area (sq. m)	Mean Radius of Gyration (m)
Grass	1368.24	7.05
Sand	97.12	1.24

In a perfect world without propeller scars we would see statistics similar to the numbers found in Table 3. This table represents a seagrass environment without propeller scars. In this environment the largest class, which is seagrass, has the greatest radius of gyration 7.05. This means that marine organisms that live exclusively in seagrass can move much further before meeting a boundary. Natural sand patches have a much smaller area and therefore a smaller radius of gyration 2.95. Organisms that live in these sand patch environments will be much more likely to be stopped by a boundary.

Boat propeller scars have lasting impacts on the landscape and in turn the behavior of predator and prey local to the scar. The increase in fragmentation caused by boat propellers isolates populations of marine life that rely on continuous seagrass meadows. In addition to decreasing populations through isolation the propeller scars also serve as corridors for predators to travel deeper into areas that were previously inaccessible for large fish. This change in habitat and in turn predator/prey behavior lasts for years after the propeller scar was created. Propeller scars can take up to 7 years for the natural vegetation to regrow. These scars can range from 5 to 300 m. There are ways for boat captains to minimize seagrass destruction, but many boat captains are unaware of these techniques.

Seagrass environments worldwide are in danger of becoming fragmented and losing their ability to recover. This will not only affect the marine life underwater but also the loss of seagrass across the world means there is less plant life available to sequester carbon from the atmosphere. Seagrass health may be more closely related to the quality of the air we breathe everyday than most people realize. The public needs to be made aware of the ways in which they are affecting marine life and shown ways they can prevent the destruction of seagrass meadows.

The State of Texas has passed laws making the destruction of seagrass illegal. Unfortunately, there are few fines being issued to people that destroy seagrass environments. The public needs to be educated on how boat propellers are affecting the seagrass and the marine life that relies on this submerged vegetation. More signs are needed near shallow areas in Texas Bays to warn boats of sensitive areas so that boat captains can make more educated decisions. Boats are travelling too shallow and bottoming out, creating these propeller scars out of lack of knowledge of the area. If we had an extensive system of signs to warn boat traffic of sensitive shallow portions of the bay, I believe there would be a reduction in the amount of new propeller scars.

The use of UAS and SfM technology was shown to be an efficient tool for studying seagrass destruction. The UAS platform is easy to deploy and can fly for up to 35 minutes of data collection. This research could be expanded to cover large expanses of Laguna Madre. A polarized lens, while expensive, could improve image quality by reducing glare across the water. Large mosaics of Lower Laguna Madre could be achieved with a few UAS pilots and a computer to process the imagery.

The State of Texas currently has a seagrass monitoring program that is not utilizing this powerful tool to record seagrass change. Three agencies are responsible for data collection and maintenance of seagrass health in Texas (TCEQ, TGLO and TPWD). The implementation of UAS in seagrass data collection would aid in quantifying the amount of propeller scars that are currently in Lower Laguna Madre. Annual UAS seagrass surveys could be implemented to establish the rate at which boats are dissecting these seagrass meadows.

Figure 1. Data preparation process. (a) Raw mosaic image of a sample site. (b) Polygon used to clip the sample sites to a uniform size (based on the largest diameter circle that fits into the smallest image mosaic). (c) Clipped image mosaic (d) Sample study site with polygons drawn for propeller scars, sand patches and seagrass.

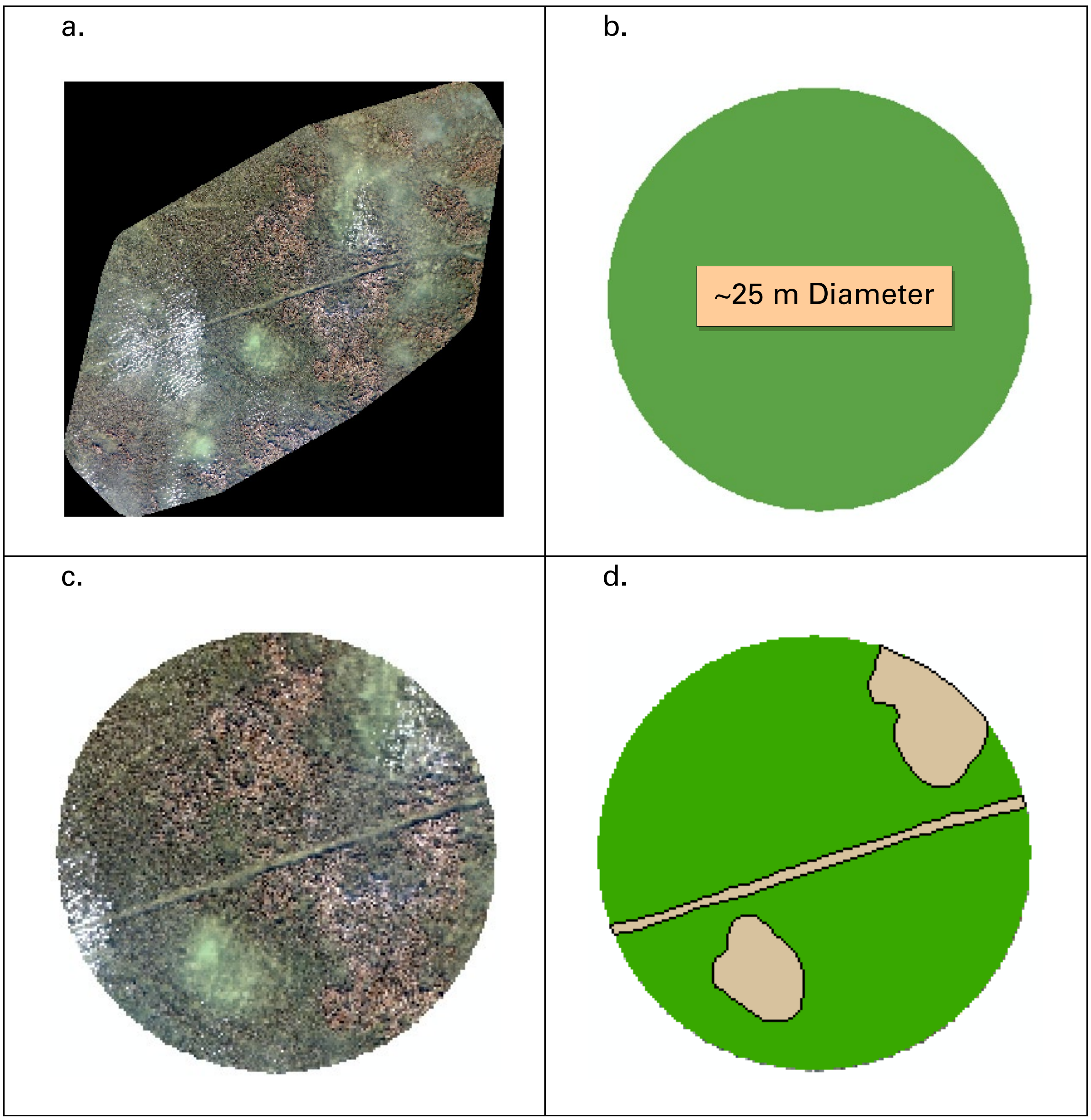

Figure 2. Overview of South Bay, Lower Laguna Madre. The redbox highlights the area that in which the eight sample sites were selected.

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