Investigating seagrass and algal species distributions in the San Felipe Marine Reserve, Yucatán, Mexico

Niamh Barry and Anna Gallagher Gill

Durham University

Acknowledgements

We would like to thank Durham University Expedition Society, Collingwood College, and St Mary's College for their generous funding and for making this experience possible.

We would also like to thank Professor Jeremy Thomason and Andrea Gutierrez at Ecoteknica for their fantastic advice, support and knowledge in the months leading up to the project, during our time in Mexico and following our return. We are very grateful to Jeremy and his wonderful family, Patricia and Pearl, for making us feel so welcome and for hosting us in Merida. We are inspired by their commitment to the environment, and we hope to follow many of their values in our own lives.

We are also very grateful to Pedro Figueroa for his practical assistance and support every day of our fieldwork. And to our host family in San Felipe – Lucely, Devy, Yvied and Marisol- we could not be more pleased that we had the opportunity to spend a month with some of the kindest people we have ever met. Finally, we would like to give thanks to the people San Felipe, who warmly welcomed us into their community and showed us their way of life. Our time in Mexico was unforgettable.

Abstract

Seagrass meadows are an important coastal marine ecosystem which provide economic, social and environmental services; such as food production, water quality regulation, carbon sequestration and flood mitigation. These environments are facing increasing pressure from human activity. Coastal development, pollution and overfishing directly degrade seagrass habitat, while rising sea levels and sea surface temperatures associated with anthropogenic climate change threaten their stability from the cellular to ecosystem scale.

This study assesses the biodiversity and spatial distributions of seagrass and algal species in a protected coastal lagoon in San Felipe, Yucatán, Mexico. The Yucatán Peninsula hosts vibrant marine biodiversity, including fish, invertebrates and migratory birds. The health of the environment is intimitely linked to the local economy and quality of life in the village of San Felipe, which has a population of just over 2000 people.

The lagoon displayed high species richness, with over 12 species of seagrass and algae appearing throughout the habitat. Shoal grass (*Halodule wrightii*) was the most abundant species and covered the greatest area, reflecting its tolerance to a range of biotic and abiotic conditions, and its ability to rapidly adapt to change. Species did show trends in their distribution, with some showing a preference for the fresher waters by the mangroves to the east. On the whole though, both individual species distributions and patterns of species richness were very varied. This study helps to fill knowledge gaps regarding the status of marine biodiversity in Yucatán, and can inform coastal management and conservation efforts.

Contents

List of figures and tables

Introduction

Coastal marine ecosystems including mangrove forests, saltmarshes, and seagrass meadows provide vital economic, social, and environmental services. These habitats are crucial for food production, water quality regulation, flood mitigation, and carbon sequestration (Mtwana Nordlund *et al*., 2016; Cuellar-Martinez *et al*., 2020; Orth *et al*., 2020). They also support rich biodiversity and serve as nurseries for numerous commercially important species. Despite their value, coastal marine ecosystems remain understudied, limiting protection and restoration efforts.

Coastal marine ecosystems are under increasing stress from coastal development, pollution and overfishing. Currently around 40% of the global population lives within 100km of the coast (Bengtsson *et al*., 2006; Griffiths *et al*., 2020), and direct anthropogenic-induced degradation in these environments is expected to intensify as this figure increases. Coastal habitats are also vulnerable to rising global mean sea levels and sea surface temperatures (SST), as well as enhanced climatic variability, ocean acidification and an increasing frequency of extreme weather events (Duarte, 2002). It is essential to understand how the structure and function of coastal habitats will change in response to these multiple interacting stressors (Orth *et al*., 2020), particularly as the provision of ecosystem services is so closely tied to the abundance and diversity of their biological communities.

The Yucatán Peninsula, Mexico hosts rich marine biodiversity. The region is well-known for the development of Mayan communities and culture, which are intimately linked to the health of the environment (Duran-Garcia *et al*., 2016). The study site for this investigation is a protected coastal marine reserve in San Felipe, which had a human population of 2,118 in the 2020 census (City Population, n.d.). San Felipe supports diverse fish, invertebrates and migratory bird species, many of which depend directly or indirectly on the seagrass and algal habitats. The health of these habitats supports the local economy and quality of life, with fishing and eco-tourism being the primary sources of income in the village (Dewsbury *et al*., 2016; Anderson,1989).

Importantly, comprehensive data on the distribution and composition of seagrass and algal species in Yucatán are lacking. This study aims to address the knowledge gap by mapping the distribution of seagrass and algal species in the coastal waters near San Felipe, Yucatan. Using a combination of field surveys and spatial analysis, this study provides baseline data to inform conservation and sustainable management efforts. The study seeks to contribute to the broader understanding of these habitats and their role in supporting resilient coastal communities.

A secondary aim of this project is to investigate the spawning patterns of the American horseshoe crab (*Limulus polyphemus*) in San Felipe, contingent on available time. Horseshoe crabs are ecologically and economically significant, serving as bait in fishing, attracting ecotourism, providing prey for migratory birds, and acting as predators of bivalves (Botton, 2009; James-Pirri *et al.*, 2005). Additionally, their blood has been a crucial component in human vaccines for over 45 years, highlighting their biomedical importance. However, this has also led to increased pressure on their populations, with significant declines reported in recent years (Maloney *et al.*, 2018). Horseshoe crab surveys can provide insight into population health and vulnerability to further decline.

Methodology

Study location

The San Felipe Marine Reserve spans approximately 10 kilometres along the coastline and is situated to the west of the Rio Lagartos Biosphere Reserve, a region well-known for its biodiversity and ecotourism (Chuenpagdee *et al.*, 2002). Established in 1988 by local fishers without formal approval from higher governing bodies, the reserve is an important symbol of community-driven conservation efforts (Chuenpagdee *et al.*, 2002). The study area for this research focused on the lagoon in Figure 1, covering an approximate area of 3.336 km^2.

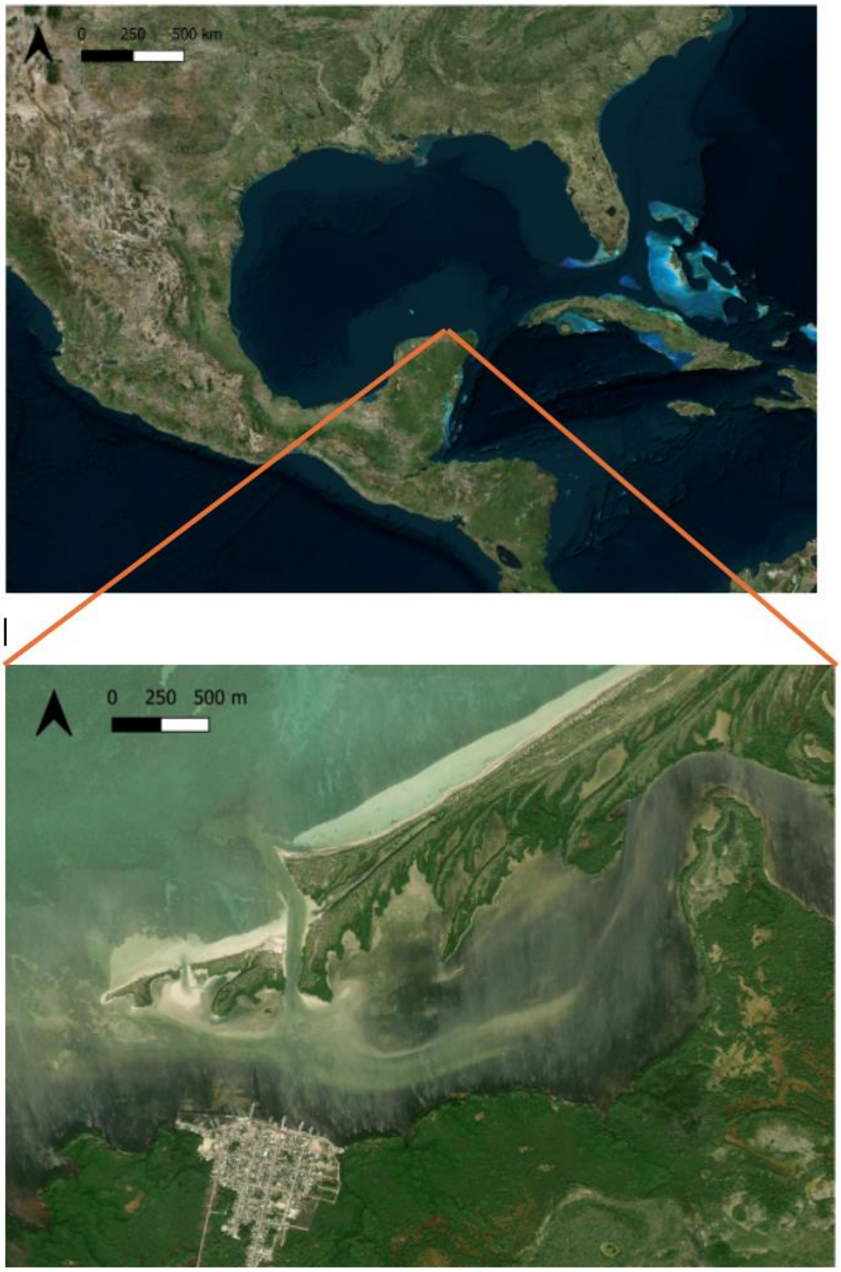


Figure 1: *Satellite imagery of the study site, generated using QGIS.*

Fieldwork and data analysis

Fieldwork was conducted over a four-week period between July 21 and August 15, 2024, with data collected twice daily. Morning sessions took place between 5:00 a.m. and 11:00 a.m., and afternoon sessions between 3:00 p.m. and 6:00 p.m., to avoid the peak midday heat. A kayak was used to navigate the lagoon, beginning at the western edge of the study site.

Within the lagoon, the boundaries of smaller polygonal regions were marked out electronically using a GPS-enabled mobile application. Several geotracking apps were tested for accuracy in Merida, prior to the fieldwork period, and the most reliable one was selected for the study. Within each polygon, all species of seagrass and algae were recorded, and their relative abundances were visually estimated. When species compositions were observed to shift, a new polygon was created. This did mean that polygons were highly heterogenous in size and shape. To assess species compositions, snorkelling equipment was used in areas where visibility from the kayak was limited. Species were identified using field guides, and these classifications were later verified online based on observable morphological features. Underwater photographs captured with a water-resistant camera facilitated this verification, as did the support of Jeremy and Andrea. No specimens of seagrass or algae were removed from the study site, adhering to important ethical considerations.

All data, both polygon boundaries and associated species abundances, were uploaded to QGIS. An overall polygon ‘layer’ was created; each row of its attribute table represented a single polygon from the study and detailed the relative abundances of each species recorded.

An anchor was used to stabilize the kayak during data collection; however, due to the dynamic nature of the lagoon's currents, it was not possible to survey every part of the study area. Nonetheless, over 90% of the lagoon was covered. Species compositions in unsampled areas, which generally were small slithers of habitat between two polygons, were inferred based on the polygon closest or to the north of that area and also based on additional observations recorded during swimming in the lagoon. Final maps were generated in QGIS to display species distributions and species richness across the lagoon.

Additionally, temperature and salinity measurements were taken at both high and low tides, using tide tables (www.tide-forecast.com) to determine tidal timings. Stratified sampling was used here, to select areas which may mark changes in abiotic conditions, including nearby the freshwater-filtering mangroves and closer to the entrance to the ocean in the west. A waterproof thermometer was employed to measure water temperature, while a salinometer was used for salinity readings. These measurements were taken for both the surface water and at the bottom of the water column (which was usually no more than 1m deep). Unfortunately, a full comprehensive dataset of temperature and salinity could not be achieved due to timing issues (particularly having been delayed by illness), and with the main priority being species distribution mapping.

A final, secondary aim, of the expedition was to collect data on the appearance of the American horseshoe crab (*Limulus polyphemus*). Excursions were made after sunset across the lagoon in a motorboat, with the assistance of Pedro Figueroa. Rough transect surveys were performed, although this investigation was hindered by low tides, which restricted access to several areas in the boat. This limited scope for observations. Furthermore, very few horseshoe crabs were spotted, despite the expertise of Pedro being very useful. This is likely attributable to the increasing light pollution in the area from nearby villages, which may be deterring the crabs from emerging at night.

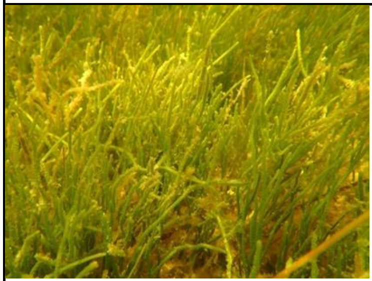
Results

12 species of seagrass and algae were identified in total in the lagoon, with 8 genera represented (Table 1).

Table 1: *All seagrass and algal species identified in the San Felipe lagoon.*

Picture	**Species Name**	**Seagrass or Algae**
	*Halodule Wrightii* (Shoal Grass)	Seagrass
	*Halimeda incrassata*	Algae
	*Thalassia testudium* (Turtle Grass)	Seagrass
	*Penicillus capitatus*	Algae

	*Udotea Fibrosa*	Algae
	*Rhodomelaceae Laurencia*	Algae
	*Caulerpa prolifera*	Algae
	*Avrainvillea digitata*	Seagrass
	*Caulerpa taxifolia*	Algae
	*Caulerpa mexicana*	Algae

	*Caulerpa sertularoides*	Algae
	*Ruppia maritima*	Seagrass

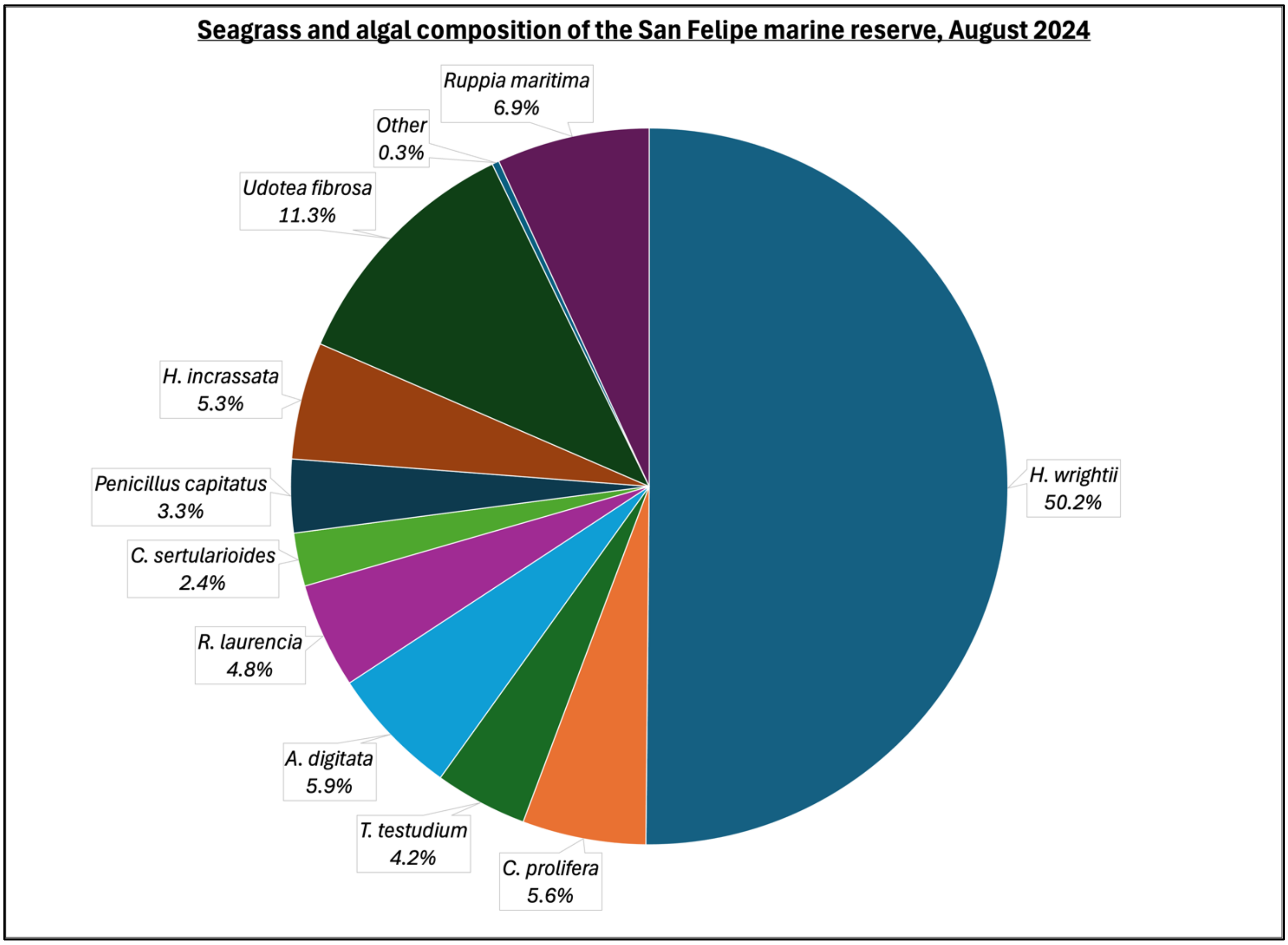


Figure 2: *Percentage composition of seagrass and algal species throughout the San Felipe Marine reserve, as a proportion of all vegetation coverage. To create this chart, the percentage composition of each species in each polygon was summed. The data did not include spaces in the lagoon that were 'filled in' with inferred data for map production.*

Figure 2 displays the seagrass and algal species composition for the San Felipe lagoon. Shoal grass (*H. wrightii)* was particularly dominant, representing over half of the vegetation coverage. *Udotea fibrosa* was the second most abundant species, at 11.3%, followed by *Ruppia maritima* at 6.9%.

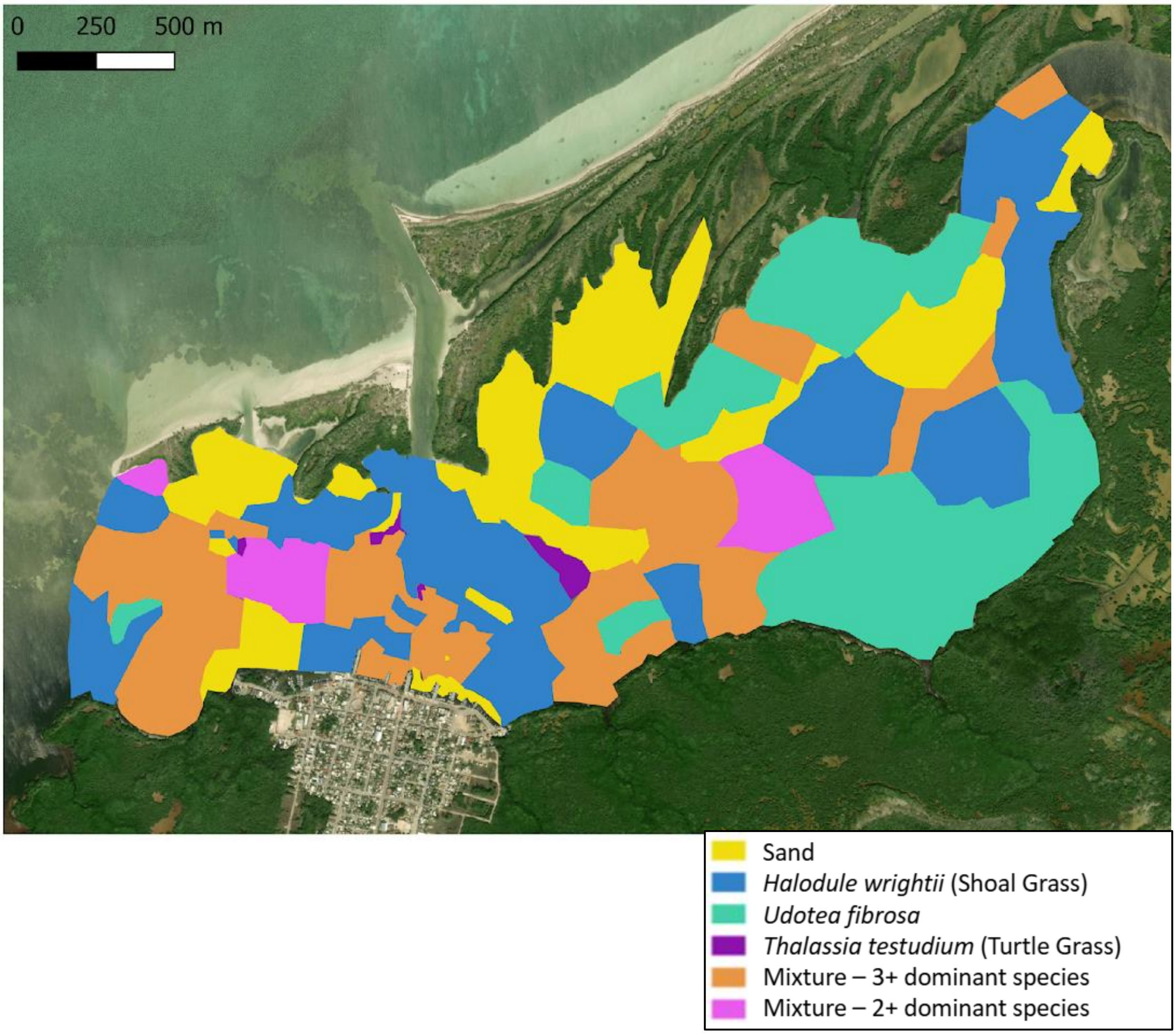


Figure 3: *Most dominant seagrass and algal species across the San Felipe lagoon. This figure was produced in QGIS and is a slightly simplified version of the results of this study. This map was produced for a poster which will be displayed in the village. 'Dominant' species was defined as the most common species in a polygon, except where 2, 3 or more species all showed similar percentage abundances (e.g. Halodule wrightii, 20%, Udotea fibrosa, 20%, Thalassia testudium, 20%).*

Figure 3 depicts the most dominant species (or habitat type where sand was dominant) found across the lagoon. Several areas of the lagoon were dominated by sand, particularly centrally and towards the sea entrance to the west. *Halodule wrightii, Udotea fibrosa* and *Thalassia testudium* were all dominant in particular areas of the lagoon, although *Thalassia testudium* in much smaller areas. *Udotea fibrosa* was particularly abundant in the east section of the lagoon, away from the sea entrance, while *Halodule wrightii* appears to show no clear pattern in terms of the locations at which it was dominant. In some parts of the lagoon, two or three species were all dominant. The species within these mixed-dominance sections of the lagoon varied spatially as figures 4-10 reveal.

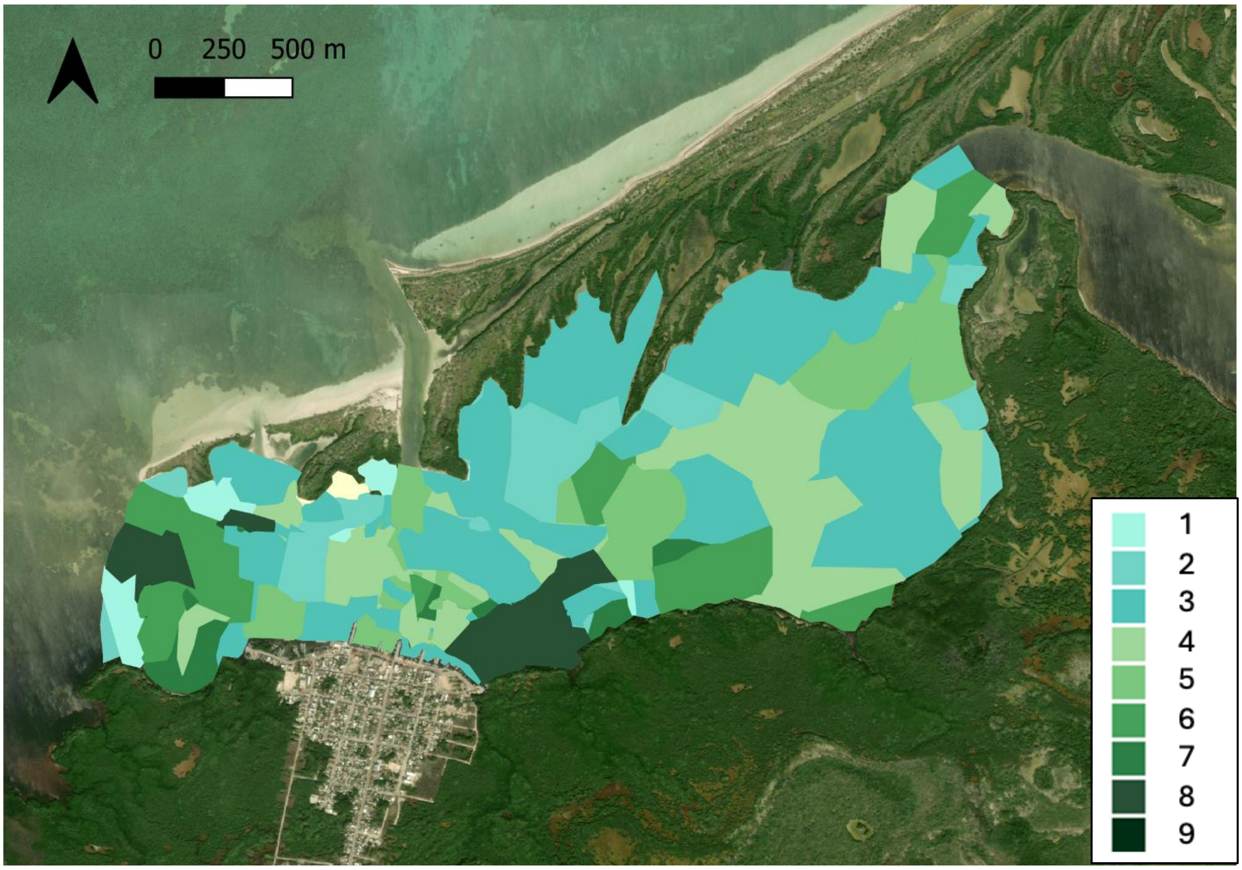


Figure 4: *Total number of seagrass and algal species identified per polygon (species richness).*

Figure 4 displays species richness across the lagoon, for seagrasses and algae. Species richness is highly heterogenous. Very few areas show only one species present. The polygons with the highest number of different species (9) are relatively close to the port (in the centre), and to the west by the entrance to the ocean. There are some cases in which one polygon contains 8 or 9 species, while an adjacent polygon contains 3 or fewer species.

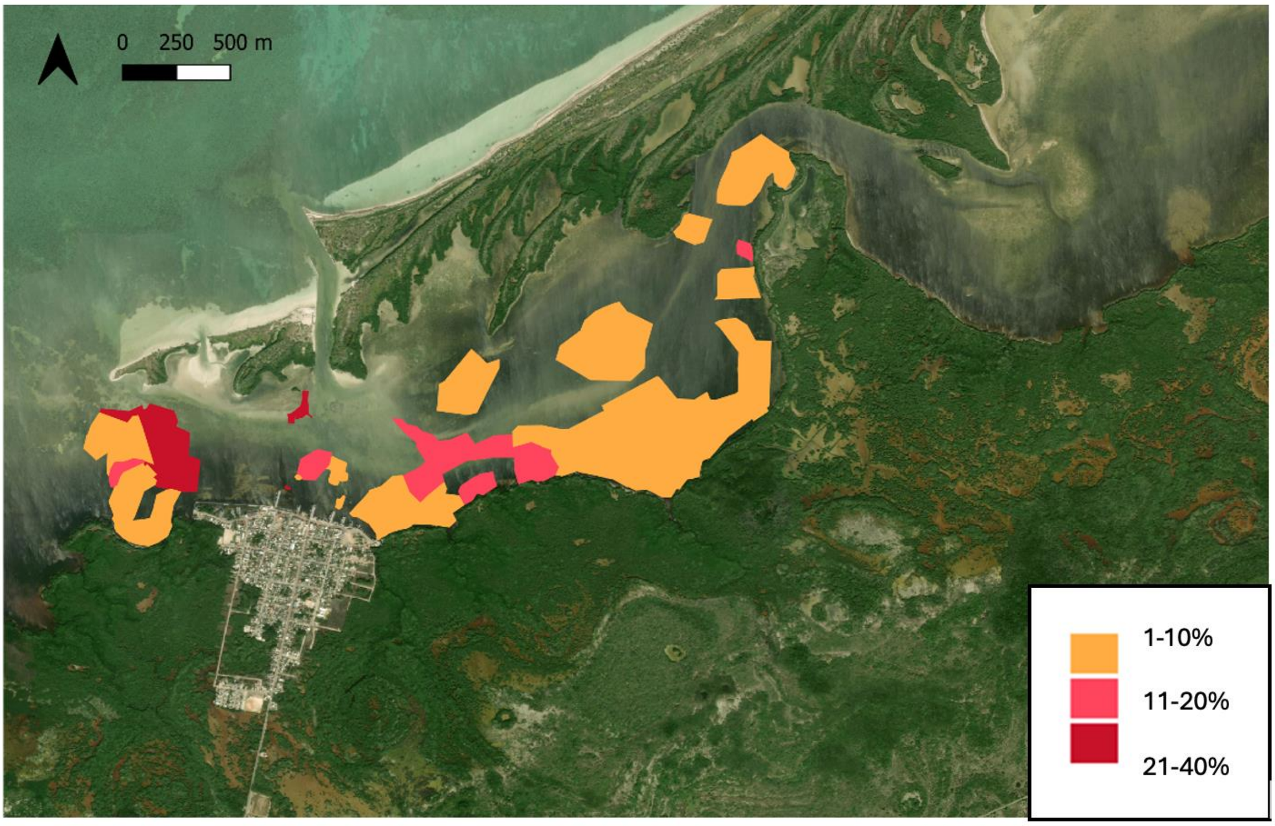


Figure 5: *Percentage abundance of Halimeda incressata in the lagoon.*

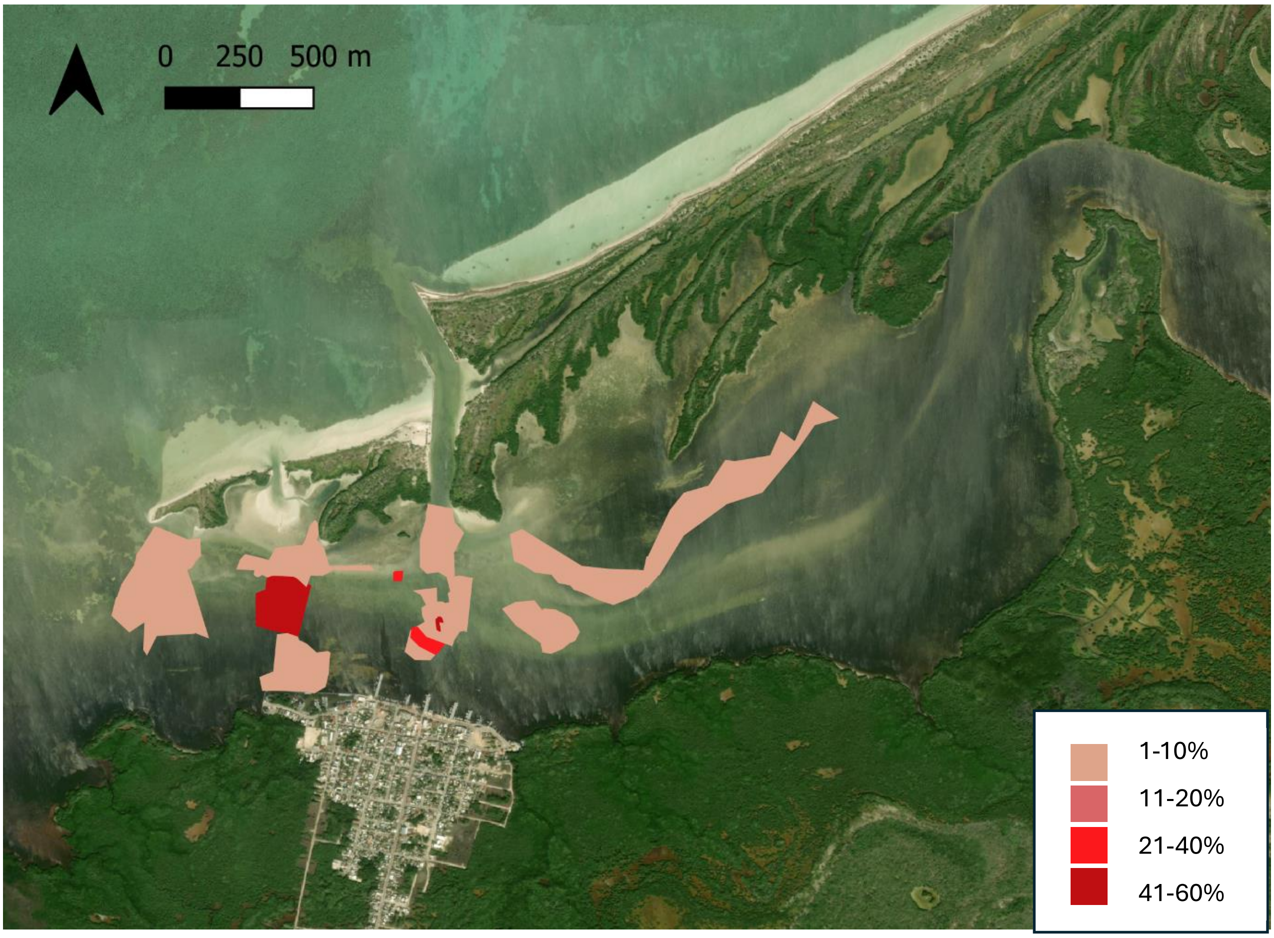


Figure 6: *Percentage abundance of turtle grass (Thalassia testudium) in the lagoon.*

Figure 7: *Percentage abundance of Caulerpa prolifera in the lagoon.*

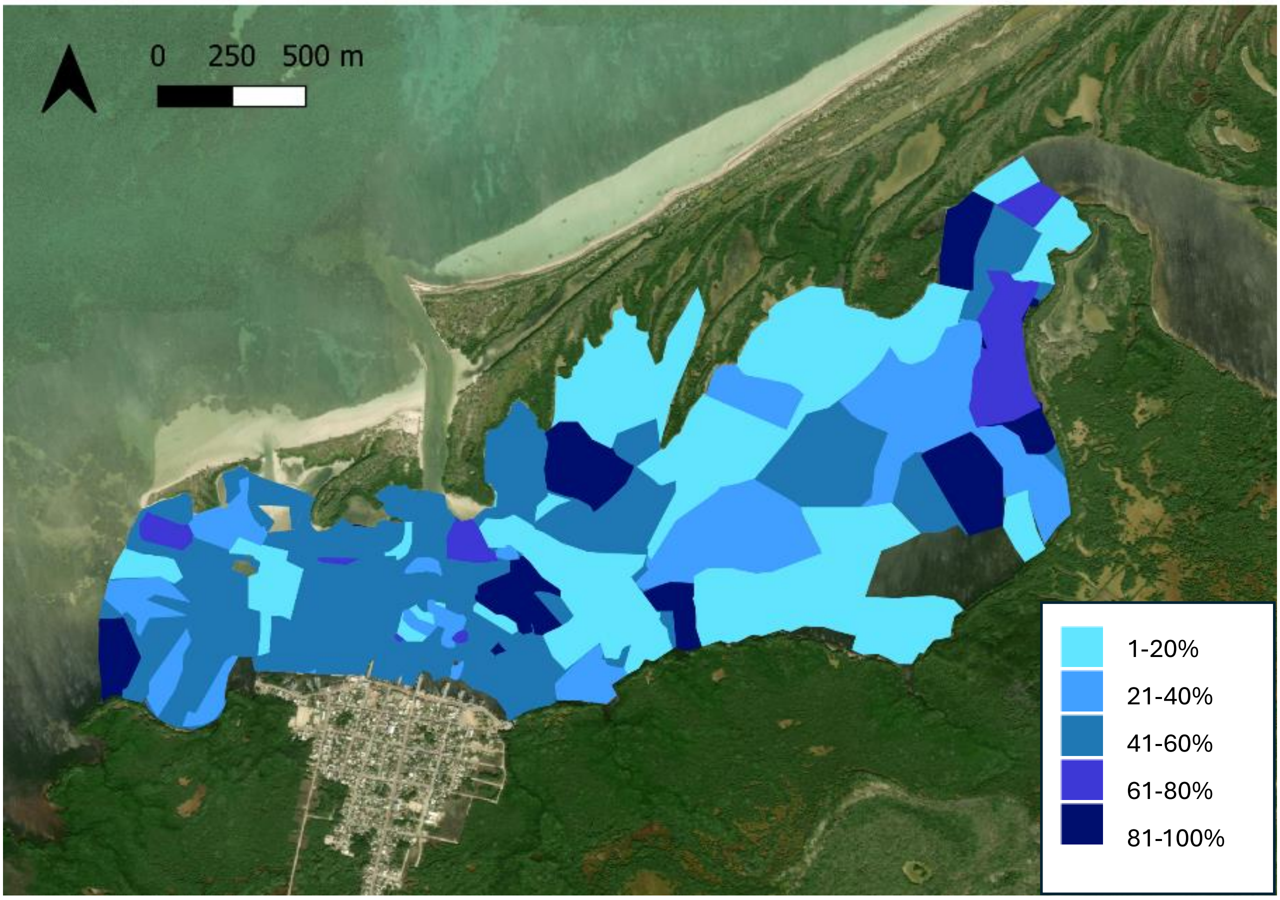


Figure 8: *Percentage abundance of shoal grass (Halodule wrightii) in the lagoon.*

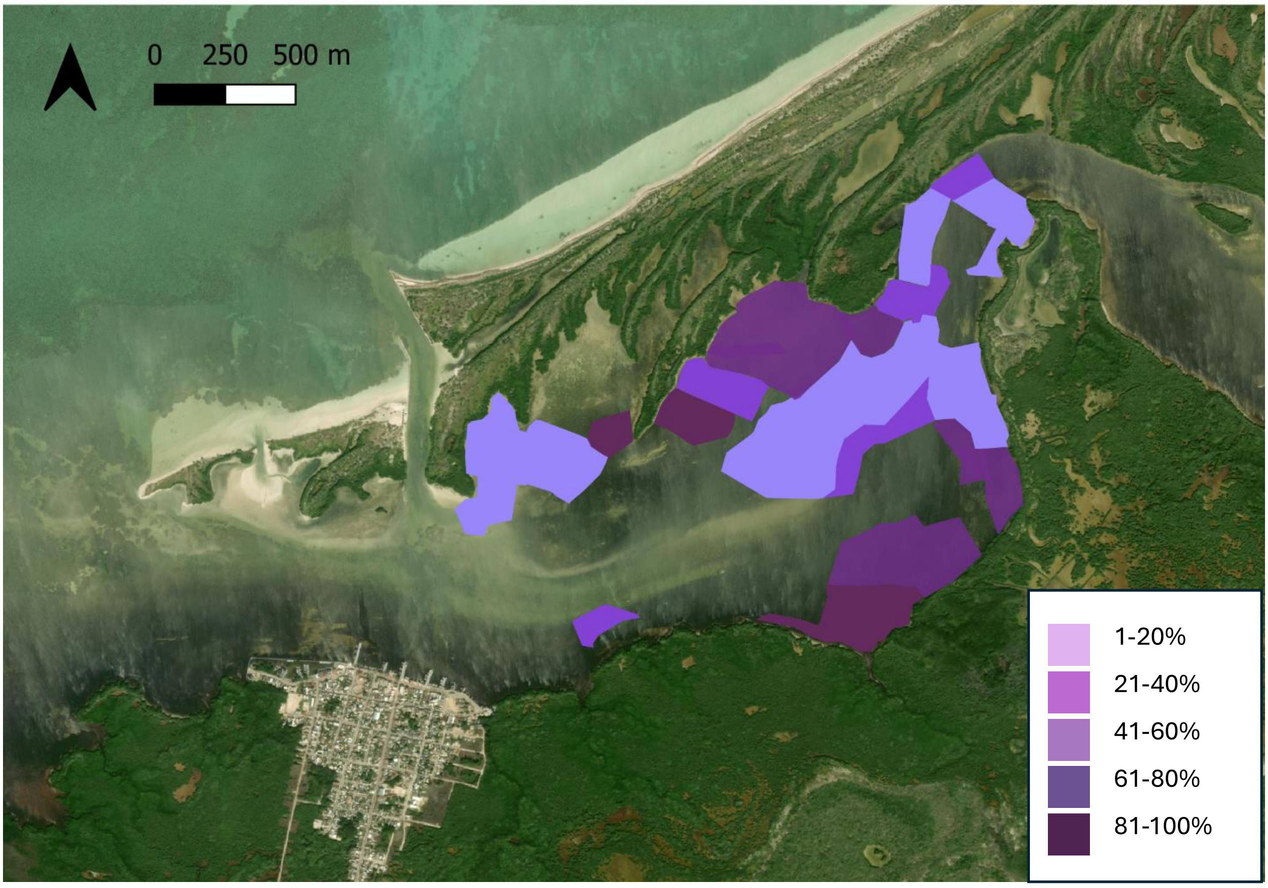


Figure 9: *Percentage abundance of Udotea fibrosa in the lagoon.*

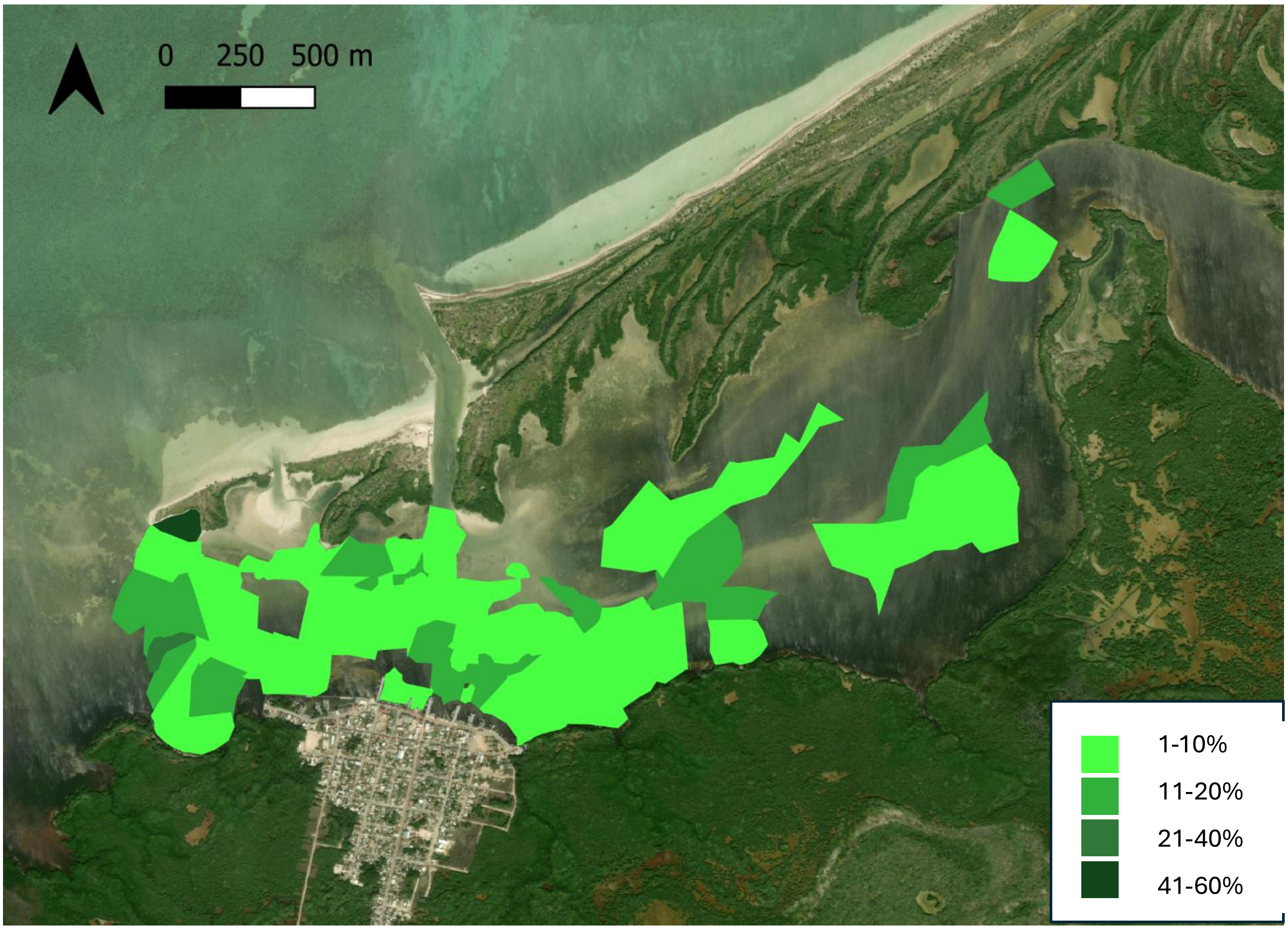


Figure 10: *Percentage abundance of Avrainvillea digitata in the lagoon*.

Figures 5-10 display the percentage abundances of select species of seagrass and algae in the lagoon. *Halimeda incressata* is found in the southern part of the lagoon and to the west, near the entrance to the sea, although its abundance does not exceed 40%, and is mostly 10% or less. *Caulerpa prolifera* shows a similar distribution to *Halimeda incressata*, also located in the southernmost parts of the lagoon, with higher abundances very close to the port. Its abundance also is rarely above 20% of the surveyed area. *Thalassia testudium* is not widespread across the lagoon; it is found away from the mangrove forests along the outskirts of the lagoon (particularly in the east). It is most abundant towards the west of the lagoon, and is also found close to the port in places.

Avrainvillea digitata was found generally throughout the whole lagoon, however, it was found more frequently towards the west side, centrally and closer to the port. It only representated greater than 40% of the area of one polygon, which was found very close to the sea entrance in the west. *Udotea fibrosa* is not as widespread across the whole lagoon and is found close to the mangroves across the east side of the lagoon. However, it is found in relatively high abundances where present. The species with the greatest spatial coverage is *Halodule wrightii*, found across the vast majority of the lagoon. Its abundance is greater than 80% at several spots, and often at greater than 40%. Its relative abundance is heterogenous across the lagoon.

Discussion

This study provides a baseline understanding of the biodiversity of key primary producers, in a complex environment of interacting abiotic and biotic stressors along the coast of San Felipe. 12 species of seagrass and algae were identified within the lagoon, and their distribution was spatially heterogenous. There is also great taxonomic diversity, with most species being members of different genera. Figure 4 shows that species richness was highest towards the west side of the lagoon closer to the sea entrance and closer to the port. This was somewhat unexpected; it was thought that species richness would be lower closer to the port due to higher levels of pollution from petrol-based fishing boats (e.g., Zhang *et al.*, 2023). However, pollution may only be a moderate disturbance in this ecosystem, given the protected nature of the lagoon, which limits fishing activity.

Overall, the lagoon is more diverse and displayed greater vegetation coverage than expected, particularly given recent hurricane disturbance across the Yucatán Peninsula (for example, from Hurricane Beryl and Helene in 2024) and the imminent effects of anthropogenic climate change. Its diversity may relate to the Intermediate Disturbance Hypothesis (e.g., Madon *et al.*, 2023), which suggests that species richness can be higher when the ecosystem is subject to intermediate levels or frequencies of disturbance, as this can prevent competitive exclusion without completely eliminating species. This creates opportunities for a mix of tolerant and opportunistic species to coexist (Madon *et al.*, 2023). It may explain the high species richness close to the port, and also its persistence despite damaging hurricane disturbance, with varying intensity, occurring over seasonal and interannual timescales. Hurricanes are recognised as a key disturbance to marine ecosystems on the coasts of Yucatán (e.g., Gómez *et al.*, 2022). They are associated with both physical and physiological damage, due to the physical force of the winds and wave action, sedimentation, increased freshwater run-off, also associated thermal changes (typically sudden drops in temperature) (Gómez *et al.*, 2022; Van Tussenbroek *et al.*, 2006). Van Tussenbroek *et al.* (2006) identified damage to the reproductive cycles of important seagrass species in response to hurricane-induced thermal anomalies.

Shoal grass (*Halodule wrightii*) was both the most spatially extensive species in the lagoon (Figure 8), and the most abundant species overall, representing over half of total vegetation coverage in the lagoon (Figure 2). Shoal grass represented at least 80% of the surveyed area at several sites across the lagoon; in the centre of the lagoon, at the entrance to the ocean in the west, and close to the mangroves and entrance to the Rio Lagartos reserve in the east. Shoal grass can tolerate relatively high levels of disturbance, and a broader range of conditions compared to other species, including relatively high pollution and disturbance from shipping closer to the port, as well as higher salinities towards the ocean and lower salinities around the mangroves (e.g., Biber, 2022). A recent study revealed the species could tolerate particularly low salinities in Mississippi, having survived over 12 months at 5 parts per thousand (ppt), a considerably lower salinity than its typical environmental conditions (Biber, 2022). Shoal grass is widely distributed along the coasts of Mexico, as well as the eastern United States and Brazil. It is also found along the coasts of India, and the east and west coasts of the African continent. Its distribution across different latitudes and under the influence of varying nutrient availabilities, temperatures, sediment accumulation, ocean currents and tidal patterns reflects its ability to survive in a diverse range of conditions (Figure 11; Rivera-Guzmán *et al.*, 2017). Rivera-Guzmán *et al.* (2017) also note the species' ability to survive atmospheric exposure at low tide times, and that its most ideal conditions are summer surface-water temperatures of over 20°C, which suits the Yucatán Peninsula very well. The traits discussed mean it is unsurprising that the species was most dominant in the San Felipe marine reserve.

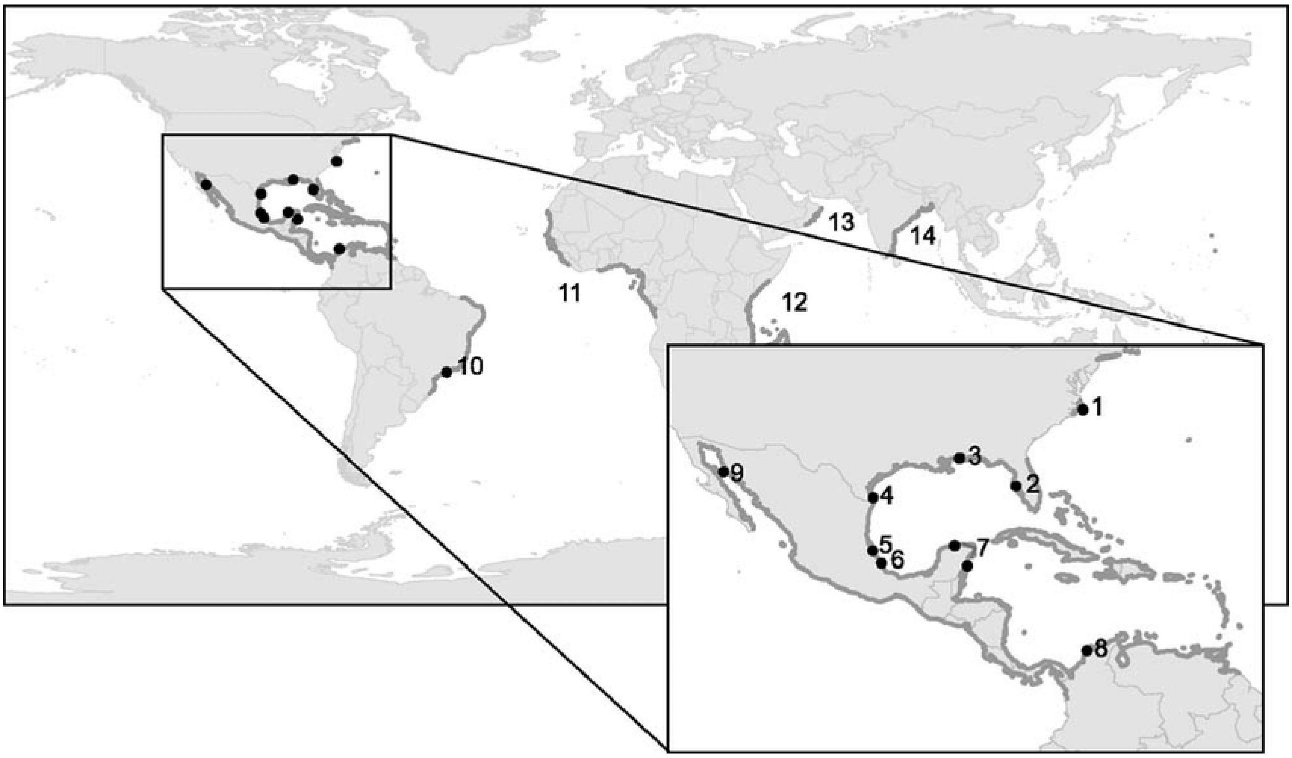


Figure 11: *The distribution of Halodule wrightii globally, taken from Rivera-Guzmán et al. (2017). The numbers refer to study sites in the researchers' study, so can be ignored in the context of this report.*

Ruppia maritima was the second most abundant species in the lagoon (Figure 2). This species commonly cooccurs with *Halodule wrightii (*e.g., Pulich, 1985; Dunton, 1990). *Avrainvillea digitata w*as found across the lagoon. While it was not the most dominant species in many polygons, its wide distribution also reflects its relatively broad environmental tolerances. Interestingly, Avrainvillea species in the Yucatán contain important antioxidants and protective enzymes, which can provide defence against UV radiation in tropical environments (Zubia *et al.*, 2007). *Udotea fibrosa* was also highly abundant across the lagoon, although it showed a slightly more nuanced spatial pattern than *Halodule wrightii*, with it being more abundant towards the east of the lagoon. This may reflect a preferred tolerance for slightly lower salinities further from the ocean, and its distribution close to the mangroves also suggests it may be able to withstand freshwater inputs. *Udotea* species have been shown to be relatively resistance to disturbance, being one of the first genera to dominate following a Harmful Algal Bloom (HAB) in 2011-2012 on the northern coast of Yucatán (Aguilar-Trujillo *et al.*, 2017). There is less generally research available for *Udotea* species in comparison to *Halodule*, however, perhaps as it is less widespread globally.

The biological characteristics of *Halodule wrightii* and other seagrass species in the San Felipe lagoon promote their success. Bercovich *et al*. (2019) studied seagrasses along environmental gradients in the Lagoa da Conceição coastal lagoon in South Brazil, and found two seagrass species, including *Halodule wrightii*, to be very tolerant of a broad range of environmental conditions across the lagoon. The authors suggest that phenotypic plasticity displayed at different organisational levels in different species, is important for their tolerance. *Halodule wrightii* focussed its phenotypic responses at the biochemical level and at the meadow / shoot level. These modifications support its long lifespan and allow it to alter its photosynthetic performance in response to varying light, water and carbon dioxide levels. *Halodule wrightii* also responded to sediment size, with higher shoot densities observed in fine sands (Bercovich *et al*., 2019). Intraspecific differences in the morphology and function of the seagrass species within the same lagoon allows the species to be found in a wide range of conditions (Barros and Rocha-Barreira, 2014; Sordo *et al*., 2011).

It is important to consider exactly what the protected area status of the San Felipe lagoon means for its coastal ecosystems. The reserve was established by a community initiative, and its main focus is the management of fisheries. It is important to note that the reserve receives only limited financial support from its municipality and is not officially recognised by federal governments or the state (Chuenpagdee *et al*., 2002). Nevertheless, the restrictions on fishing imposed by the local community likely support the seagrass and algae assemblages indirectly via the reduction of pollution and physical damage from fishing boats, and via the maintenance of herbivory which can in turn prevent the competitive exclusion of particular vegetation species.

Limitations of the study

The irregularity in shape and size of the polygons is not particularly ideal; it makes comparison trickier and creates the impression of sharp transitions between habitat types and species assemblages, when the reality is often smoother and more nuanced. If more time was available, it would be great to conduct the study using even smaller polygon sizes, perhaps allowing us to capture this complexity better. A gridded approach, with relatively small grid cells, would allow the production of raster maps which may make visualisation easier.

There is uncertainty across different stages of the study. For example, in snorkelling to identify species and in taking care not to damage the underwater habitat, it will have been possible to miss species hiding below others or covered by sediment. In creating the maps in GIS, there may also have been issues when filling in the small areas of habitat with no direct associated data, and it is not possible to know whether this data filling was accurate, although this was done in the fairest way possible.

Of course, additional limitations include the issues with collecting temperature and salinity, and horseshoe crab data. Low tides and light pollution limited data collection for the latter. Nevertheless, the main priority of the expedition, to assess species distributions across the entire lagoon, was achieved successfully.

Future research

Several further investigations could be performed in the same lagoon to extract more insight into the ecological and biogeochemical dynamics of seagrass ecosystems in an increasingly hostile climate. Perhaps an identical study could run in a year or several years, to facilitate understanding of the stability or fragility of current species compositions. Ideally, the study would also be performed following hurricane disturbance, to assess the resilience of the ecosystems to extreme weather events and perhaps to test the Intermediate Disturbance Hypothesis in this setting. This is particularly important, as hurricanes are expected to increase in frequency and strength under anthropogenic climate change in the Yucatán Peninsula, and given that Yucatán already has the highest rates of major hurricane landfall in Mexico (Appendini *et al.*, 2019). It would be interesting to explore whether there is a threshold beyond which the Intermediate Disturbance Hypothesis perhaps does not hold true in its stimulation of biodiversity in these coastal settings, although such study may require expensive modelling and long-term monitoring.

It would be interesting to monitor the rate at which particular species reappear following disturbance, although the frequency of monitoring required for such study may be logistically and financially taxing. In the coming years, remote sensing techniques could be applied for this monitoring, although the spatial resolution required to identify particular species is not yet possible in widely-available satellite data. The use of unmanned aerial vehicles (UAVs) or underwater drones would help to achieve surveys with greater spatial scale than fieldwork currently allows, although again, this work would be expensive. Something that would be more feasible but perhaps equally as valuable would be to maintain communication with the local people of San Felipe, whose livelihoods are so intertwined with the marine environment and whose knowledge is temporally extensive. Changes in fish stocks noted by local fisher people can provide insight into the health of the seagrass ecosystems which they rely upon for shelter and food. Several studies have noted that changes in the structure of seagrass communities can drive changes in fish assemblages (e.g. Jones *et al*., 2021). Local traditional knowledge will be essential in the conservation of Yucatecan sea grass ecosystems in the coming decades (e.g., Newmaster *et al*., 2011).

It would be useful to explore parameters such as biomass and shoot density of species in the lagoon, for example (as done by Biber, 2022 for *Halodule wrightii* in Mississippi). This data could provide greater insight into the growth responses of particular species to variables like temperature, salinity and turbidity. It would also allow better estimation of the biospheric carbon storage within these coastal Yucatan ecosystems. Ideally, this study would be performed at intervals of a year of several years to explore whether key biological characteristics are changing under sea level rise and increased storm frequencies.

A final avenue for further research would be to explore the impact of protected area status on the Yucatán coast. Perhaps the study could be performed at a different site along the coastline which is not afforded the same level of environmental protection, to give insight into the extent to which these policies may impact biodiversity. It is important to be critical of the protected area status here; perhaps it would be useful to quantify, say, the number of fishing outings per day in each location, for better comparison.

Conclusion

In summary, seagrass and algal species richness across San Felipe's marine reserve was relatively high; likely due to a combination of environmental management efforts (i.e., the creation of a protected area), intermediate disturbances such as storm activity and pollution from fishing boats limiting the competitive exclusion of species, and the tolerance of many species to a broad range of conditions. The study could be improved by conducting species surveys in smaller polygonal areas to better capture the nuanced transitions between habitat types in the lagoon. Future research may consider further the impact of protected area status on coastal communities along the coast of the Yucatán Peninsula by making comparison with a lesser protected area; or delve deeper into the biochemical and physiological growth responses of species to changes in temperature, sea level and the dynamics of extreme weather events associated with anthropogenic climate change.

An account of the expedition

(Extract from Niamh Barry's report for Collingwood College Student Opportunities Fund)

In the summer of 2024, we undertook a five-week research expedition in the Yucatán Peninsula, Mexico. The main aim of the expedition was to explore the distributions and ecological characteristics of seagrass and algal species in the coastal waters of San Felipe, a small fishing village. Seagrass ecosystems provide important habitats for diverse fish and invertebrates, and efficiently sequester carbon dioxide, so their conservation is particularly important in the fight against climate change. The project operated in collaboration with the local people of San Felipe, the Comisión Nacional de Áreas Naturales Protegidas (CNANP) and Ecoteknica (an environmental consultancy based in Merida, Mexico).

We were fortunate enough to stay with a local family for the duration of the expedition, allowing us to become immersed in a new culture, improve our Spanish and develop a more personal understanding of how coastal communities are likely to be impacted by environmental change.

The expedition began in the city of Merida, where we planned our research methodology and undertook training for the expedition. This included snorkelling and kayaking practice! It was also great to explore the city of Merida and the surrounding areas – we visited Mayan ruins and ate delicious street food! It was great to spend time with Professor Jeremy Thomason and Andrea Gutierrez and learn about their work; this opened our eyes to various academic and industrial opportunities that we had not previously considered!

We then travelled to San Felipe, where we carried out our fieldwork for just over a month. This research involved identification of seagrass and algal species on the sea floor of the coastal lagoon. We noted species compositions and exact geolocations and later used GIS software to create maps of the underwater world. We experienced incredible sunsets from our kayak before we finished work for the day, with flamingos flying over our heads!

We produced a poster to be displayed in the village centre of San Felipe, and on the final day of the expedition we presented our results to the mayor.

Aside from our fieldwork, it was great to form close bonds with our host family and their extended family members too. We laughed so much despite the language barrier! We ate traditional food, attended religious services, and experienced incredible dancing and music at the fiesta de Santiago, a week-long celebration in the village.

There were of course some challenges along the way, including adjusting to the high temperatures of over 40°C, having an allergic reaction to mosquito bites, and learning to sleep comfortably in a hammock!

This opportunity allowed us to improve our knowledge of coastal marine biology, and the economic importance of these habitats. It has enhanced our desire to work to conserve valuable ecosystems in a way that supports local communities whose lives are intertwined with the health of the environment.

We are grateful for the generous support of the Durham University Expedition Society. We hope to 'give back' in the future through our work to conserve important ecosystems and support communities vulnerable to climate change.

References

Aguilar-Trujillo, A.C., Okolodkov, Y.B., Herrera-Silveira, J.A., Merino-Virgilio, F.D.C. and Galicia-García, C., 2017. Taxocoenosis of epibenthic dinoflagellates in the coastal waters of the northern Yucatan Peninsula before and after the harmful algal bloom event in 2011–2012. *Marine pollution bulletin*, *119*(1), pp.396-406.

Anderson, E.E., (1989). Economic benefits of habitat restoration: seagrass and the Virginia hard-shell blue crab fishery. *North American Journal of Fisheries Management*, *9*(2), pp.140-149.

Appendini C.M., Meza-Padilla R.J., Adud-Russell S., Proust S., Barrios R., Fajardo F.S., (2019). Effect of climate change over landfilling hurricanes at the Yucatan Peninsula. *Climate Change*. Vol. 157 (4).

Barros K.V.S., Rocha-Barreira C.A., (2014). Influence of environmental factors on a Halodule wrightii ascherson meadown in the Norheastern Brazil. *Aquatic Science Technology*. Vol. 18(2), pp. 31-41.

Bengtsson, M., Shen, Y. and Oki, T., (2006). A SRES-based gridded global population dataset for 1990–2100. *Population and Environment*, *28*, pp.113-131.

Bercovich, M.V., Schubert, N., Saá, A.C.A., Silva, J. and Horta, P.A., 2019. Multi-level phenotypic plasticity and the persistence of seagrasses along environmental gradients in a subtropical lagoon. *Aquatic Botany*, *157*, pp.24-32.

Biber P., (2022). Prolonged low salinity tolerance in *Halodule wrightii* Asch. *Aquatic Botany*. Vol. 178.

Botton, M.L., (2009). The ecological importance of horseshoe crabs in estuarine and coastal communities: a review and speculative summary. *Biology and conservation of horseshoe crabs*, pp.45-63.

Chuenpagdee R., Morgan L.E., Maxwell S.M., Norse E.A., Pauly D., (2003). Shifting Gears: Assessing Collateral Impacts of Fishing Methods in US Waters. Frontiers in Ecology and the Environment. Vol. 1, no. 10, pp. 517-524.

City Population, n.d., San Felipe, Available online at: https://citypopulation.de/en/mexico/yucatan/31065__san_felipe/

Cuellar-Martinez, T., Ruiz-Fernández, A.C., Sanchez-Cabeza, J.A., Pérez-Bernal, L., López-Mendoza, P.G., Carnero-Bravo, V., Agraz-Hernández, C.M., van Tussenbroek, B.I., Sandoval-Gil, J., Cardoso-Mohedano, J.G. and Vázquez-Molina, Y., (2020). Temporal records of organic carbon stocks and burial rates in Mexican blue carbon coastal ecosystems throughout the Anthropocene. *Global and Planetary Change*, *192*, p.103215.

Dewsbury, B.M., Bhat, M. and Fourqurean, J.W., (2016). A review of seagrass economic valuations: gaps and progress in valuation approaches. *Ecosystem Services*, *18*, pp.68-77.

Duarte, C.M., (2002). The future of seagrass meadows. *Environmental conservation*, *29*(2), pp.192-206.

Dunton, K.H., 1990. Production ecology of Ruppia maritima L. sl and Halodule wrightii Aschers, in two subtropical estuaries. *Journal of Experimental Marine Biology and Ecology*, *143*(3), pp.147-164.

Durán-GarcíaR., Méndez-González M., Larqué-Saavedra A. (2016). The Biodiversity of the Yucatan Peninsula: A Natural Laboratory. In: Cánovas, F., Lüttge, U., Matyssek, R. (eds). *Progress in Botany*, Vol. 78.

Gomez, I., Silva, R., Lithgow, D., Rodriguez, J., Banaszak, A.T. and van Tussenbroek, B., 2022. A review of disturbances to the ecosystems of the Mexican Caribbean, their causes and consequences. *Journal of Marine Science and Engineering*, *10*(5), p.644.

Griffiths, L.L., Connolly, R.M. and Brown, C.J., (2020). Critical gaps in seagrass protection reveal the need to address multiple pressures and cumulative impacts. *Ocean & Coastal Management*, *183*, p.104946.

James-Pirri, M.J., Tuxbury, K., Marino, S. and Koch, S., (2005). Spawning densities, egg densities, size structure, and movement patterns of spawning horseshoe crabs, Limulus polyphemus, within four coastal embayments on Cape Cod, Massachusetts. *Estuaries*, *28*, pp.296-313.

Jones, B.L., Nordlund L.M., Unsworth R.K.F., Jiddawi N.S., Eklof J.S., (2021). Seagrass strcutural traits drive fish assesmblages in small-scale fisheries. Vol. 8.

Madon B., David R., Torralba A., Jung A., Marengo M., Thomas H., (2023). A review of biodiversity research in ports: let's not overlook everyday nature! *Ocean and Coastal Management*. Vol. 242.

Maloney, T., Phelan, R. and Simmons, N., (2018). Saving the horseshoe crab: A synthetic alternative to horseshoe crab blood for endotoxin detection. *PLoS biology*, *16*(10), p.e2006607.

Mtwana Nordlund, L., Koch, E.W., Barbier, E.B. and Creed, J.C., (2016). Seagrass ecosystem services and their variability across genera and geographical regions. *Plos one*, *11*(10), p.e0163091.

Newmaster A.F., Berg K.J., Ragupathy S., Mookkan P., Kathirvelu S., (2011). Local knowledge and conservation of seagrass in the Tamil Nadu state of India. *Journal of Ethnobiology and Ethnomedicine*. Vol. 7(1).

Orth, R.J., Lefcheck, J.S., McGlathery, K.S., Aoki, L., Luckenbach, M.W., Moore, K.A., Oreska, M.P., Snyder, R., Wilcox, D.J. and Lusk, B., (2020). Restoration of seagrass habitat leads to rapid recovery of coastal ecosystem services. *Science Advances*, *6*(41), p.eabc6434.

Pulich Jr, W.M., 1985. Seasonal growth dynamics of Ruppia maritima Lsl and Halodule wrightii Aschers. in southern Texas and evaluation of sediment fertility status. *Aquatic Botany*, *23*(1), pp.53-66.

QGIS Development Team, (2009). QGIS Geographic Information System. Open source Geospatial Foundation. URL http://qgis.org

Rivera-Guzman N.E., Moreno-Casasola P., Cejudo E., Lazos Ruiz A.E., Vega C.M., Pelaez L.A.P., Sanchez-Higueredo L.E., Rodriguez-Medina K., Aguayo K.V.S., (2017). The Biological Flora of Coastal Dunes and Wetlands: Halodule wrightii Ascherson. *Journal of Coastal Research*. Vol. 33(4), pp. 938-948.

Sordo L., Fournier J., de Oliveira V.M., Gern F, de Castro Panizza A. and da Cunha Lana P. (2011). Temporal variations in morphology and biomass of vulnerable *Halodule wrightii* meadows at their southernmost distribution limit in the southwestern Atlantic. *Botanica Marina*.

van Tussenbroek, B.I., Barba Santos, M.G. and van Dijk, J.K., 2006. Unusual synchronous spawning by green algae (Bryopsidales), after the passage of Hurricane Wilma (2005).

Vivanco-Bercovich M., Schubert N., Almeida Saa A.C., Silva J., Horta P.A., (2019). Multi-level phenotypic plasticity and the persistence of seagrasses along environmental gradients in a subtropical lagoon. *Aquatic Biology*. Vol. 157, pp. 24-32.

Zhang Y., Yu X., Chen Z., Wang Q., Zuo J., Yu S., Guo R., (2023). A review of seagrass bed pollution. *Water*. Vol. 15(21).

Zubia, M., Robledo, D. and Freile-Pelegrin, Y., 2007. Antioxidant activities in tropical marine macroalgae from the Yucatan Peninsula, Mexico. *Journal of applied phycology*, *19*, pp.449-458.

Appendix

Below is a copy of the poster produced for the village of San Felipe and presented to the mayor of the town on the final day of the expedition.

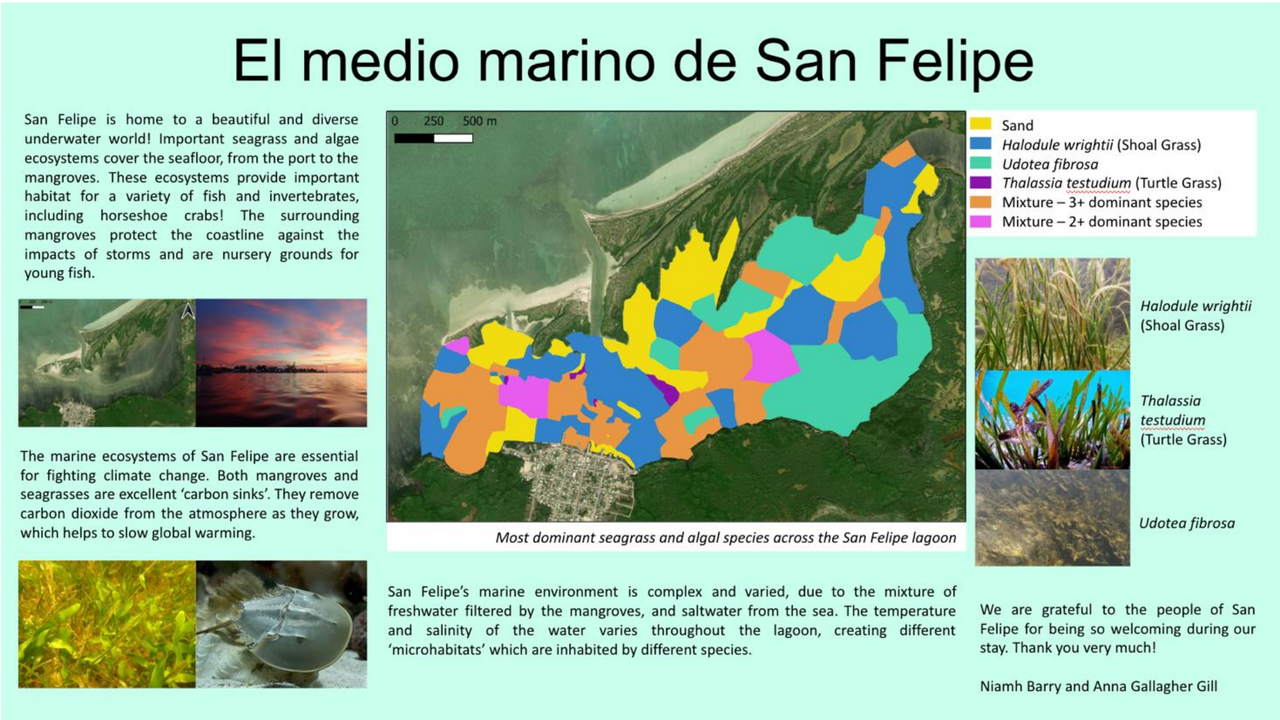


Figure 12: *A copy of the poster produced for the village of San Felipe***.**

Medical matters

There were no serious medical matters during the expedition. The only issues were a reaction to mosquito bites (Niamh), which was solved using cream from a local pharmacy, and on the second weekend of the trip, Niamh had some stomach issues, which were also treated with some tablets from the pharmacy.