Standing stock gradients of calcareous green macroalage in Florida Bay, USA

BSC 6926 Final Project: Quantitative Ecology

Danielle Hatt

3/27/2020

# Introduction

Seagrasses ecosystems are highly productive and distributed globally (Fourqurean et al. [2012](#ref-Fourqurean2012)). Karstic sediments known to be produced by calcifying organisms (Hill et al. [2015](#ref-Hill2015); Ortegón-Aznar, Chuc-Contreras, and Collado-Vides [2017](#ref-Ortegon-Aznar2017)) support healthy seagrass ecosystems in the tropics and subtropics (Zieman, Fourqurean, and Iverson [1989](#ref-Zieman1989)). In tropical ecosystems, these seagrass beds are responsible for creating a stable environment and contributing to the protection of shorelines (Tussenbroek and Barba Santos [2011](#ref-VanTussenbroek2011)). Intermingled within these seagrass beds, calcareous green macroalgae (CGA) such as species of the Bryopsidales (*Udotea*, *Rhipocephalus*, *Penicillus*, and *Halimeda*) and Dasycladales (*Acetabularia*, *Cymopolia*, and *Neomeris*) play an important role as engineering species producing calcareous sediments that facilitate the development of these large seagrass beds in subtropical and tropical ecosystems (Hillis-Colinvaux [1980](#ref-Hillis-Colinvaux1980); Tussenbroek and Dijk [2007](#ref-VanTussenbroek2007)). Most of the marine carbonate found in tropical ecosystems are produced by calcareous algae (Hillis-Colinvaux [1980](#ref-Hillis-Colinvaux1980); Bach [1979](#ref-Bach1979)).

Florida Bay is a coastal subtropical lagoon that contains seagrass beds high in biodiversity and support many crucial and economically important organisms (Zieman, Fourqurean, and Iverson [1989](#ref-Zieman1989)). They make up approximately ten percent of the expanse of seagrass beds found in Florida Bay (Zieman, Fourqurean, and Iverson [1989](#ref-Zieman1989)). In Florida, the two most abundant genera of calcareous green macroalgae are *Halimeda* and *Penicillus*. The abundance of these genera fluctuates due to seasonal variability; there is more growth and calcification recorded in summer and autumn months from June to November when the sea surface temperatures are above 20oC (Wefer [1980](#ref-Wefer1980); Collado-Vides, Rutten, and Fourqurean [2005](#ref-Collado-Vides2005)). It is particularly important that the abundance of these communities be monitored due to increased anthropogenic activities affecting environmental factors such as temperature and salinity. Temperature is an important driver in biological activity in macroalgae, however, there is a large variation in optimal temperature ranges due to difference in habitats and algal morphological characteristics and at specific thresholds iphotosynthetic activity can drastically decrease (Bach [1979](#ref-Bach1979); Davison, Greene, and Podolak [1991](#ref-Davison1991)). It is important to determine how global fluctuations in temperatures due to increasing carbon dioxide emissions in the earth’s atmosphere will potentially shift algal communities.

At the local scale, there are other drivers of algal biomass. In the Everglades region, there has been a reduction of water flow due to the construction of canals, levees and pumping stations to divert water and allow urbanization of South Florida in the early 1900s. This resulted in a 70% decrease in the available water and continues to have devastating effects on surrounding ecosystems. The Comprehensive Everglades Restoration Program (CERP) aims to restore these historic water flow patterns over a thirty-year period which may cause fluctuations in salinity and therefore shifts in algal communities (Perry, [n.d.](#ref-Perry)). The Florida Coastal Everglades, Long Term Ecological Research (FCE LTER) program surveys calcareous algal communities at three sites representative of a salinity gradient in Florida Bay: Sprigger Bank, Bob Allen Keys and Duck Key. In this polyhaline estuary, Sprigger Bank is more stable in salinity compared to Bob Allen and Duck Key (Herbert and Fourqurean [2009](#ref-Herbert2009); Frankovich et al. [2009](#ref-Frankovich2009)). Spatiotemporal long-term studies like these helps to get a larger picture of changes occurring over time, changes in slow biological processes or changing ecological patterns that may not be evident otherwise (Franklin [1989](#ref-Franklin1989)). These studies can also help to forecast potential trends in biomass which can aid in managment of the CERP strategies and water management decisions as they continute to be implemented at Florida Bay. Drastic changes in water flow can affect levels of salinity thereby causing reduced production of organic and inorganic carbon between genera and among different locations where these calcareous algal communities are present in Florida Bay.

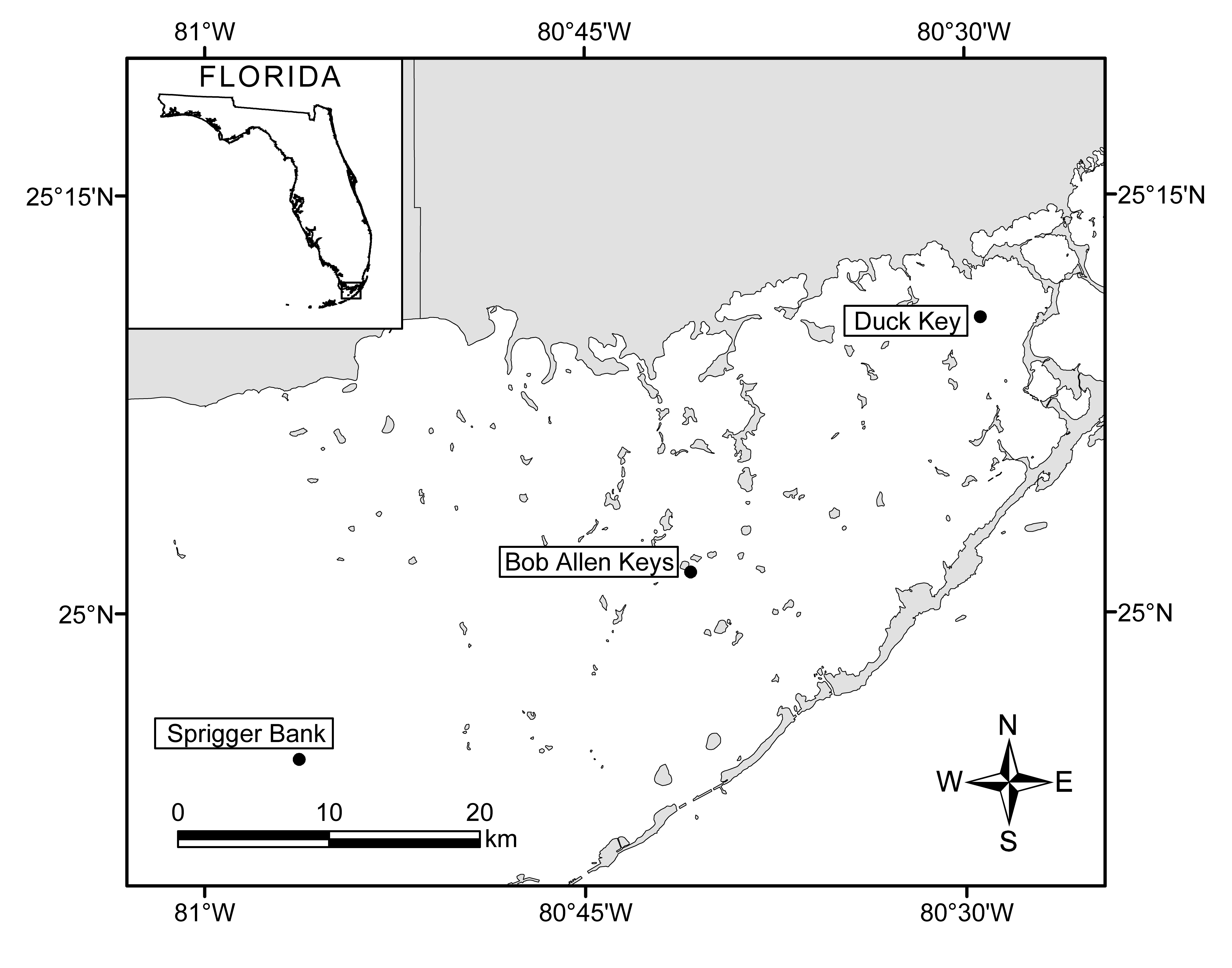
Therefore, this reserach aims to analyze spatiotemporal long-term trends of calcareous marcroalgae in Florida Bay in order to understand potential impacts of fluctuating temperature and salinity across the bay as a result of increased anthropogenic activities. The hypotheses we propose are that (1)

# Methods

##### *Site Information*

Florida Bay is a shallow coastal subtropical lagoon that contains one of the largest expanses of seagrass beds in the world extending approximately 5500 km2, ranging from the Everglades to the Florida Keys (Fourqurean, Zieman, and Powell [1992](#ref-Fourqurean1992)). The dominant seagrasses in the bay are *Thalassia testudinum*, *Halodule wrightii* and *Syringodium filiforme* with intermixed rhizophitic macroalgae species of the genera *Halimeda*, *Penicillus*, *Udotea*, *Caulerpa*, and other red algae such as species of the genera *Laurencia* and *Amphiroa* (Frankovich and Fourqurean [1997](#ref-Frankovich1997)).

Across the bay, seasonal patterns in temperature were similar with minimum values of 17.5oC and maximum values of 32.9oC over the 11 year period. The climate is subtropical moist and is dominated by a wet (June to November) and dry season (December to May). Surveys of calcareous green algae were conducted at three sites representative of a salinity gradient in Florida Bay: Sprigger Bank (24°91’N, 80°93’W), Bob Allen (25°02’N, 80°68’W) and Duck Key (25°17’N, 80°48’W) (Figure 1). Sprigger Bank is the only site where both *Halimeda* and *Penicillus* were present. *Penicillus* was observed at all three sites. Water depth at all three sites were below 2 meters (Herbert and Fourqurean [2009](#ref-Herbert2009)). Sprigger Bank is impacted by the flow of water from the Gulf and characterized by high density of seagrasses dominated by *T. testudinum*, stable salinity and high phosphorous availability (Zieman, Fourqurean, and Iverson [1989](#ref-Zieman1989); Herbert and Fourqurean [2009](#ref-Herbert2009)). Bob Allen Keys and Duck Key are a mix of flat subtidal basins and shallow intertidal regions both impacted by the flow of freshwater sources. These sites are characterized by limited abundance of *H. wrightii*, *T. testudinum* and *Penicillus*, low tidal energy and variable salinity due to their proximity to freshwater sources from the Everglades and higher availability of nitrogen (Zieman, Fourqurean, and Iverson [1989](#ref-Zieman1989); Fourqurean, Zieman, and Powell [1992](#ref-Fourqurean1992); Frankovich and Fourqurean [1997](#ref-Frankovich1997); Herbert and Fourqurean [2009](#ref-Herbert2009)).



**Figure 1 showing study sites at Florida Bay**

##### *Data Collection*

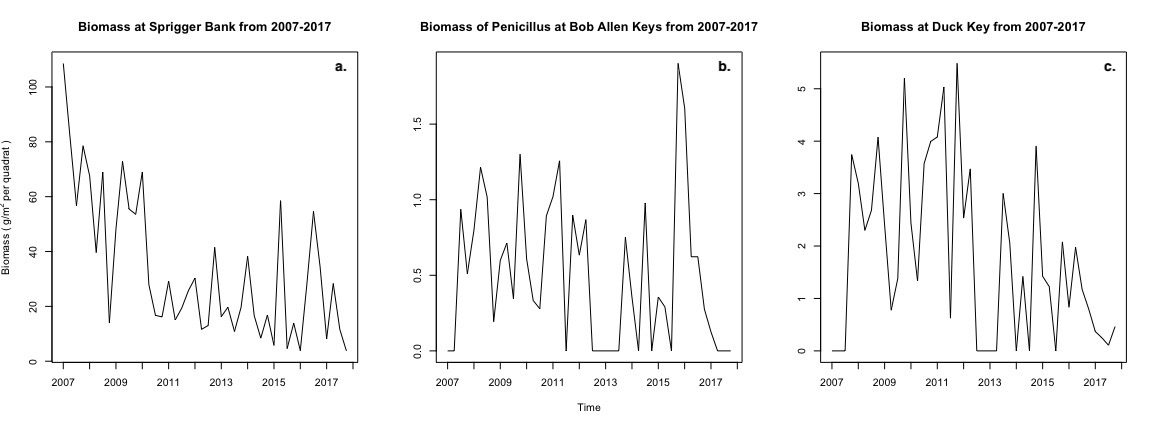
Surveys were conducted four times a year at the study site from 2007 to 2017. At each survey, divers used three randomly placed 0.25m2 quadrats along a transect line to collect macroalgae by hand. All samples were brought back to the lab, cleaned and separated on the genus level for each quadrat at each site. The samples were dried for 48 hours in an oven set to 70oC. Samples for each quadrat were weighed and this was recorded as the dry weight. The samples were ashed using the Loss on Ignition method (LOI) in an oven at 400oC for 5 hours (Fourqurean et al. [2012](#ref-Fourqurean2012)). These ashes were weighed and were recorded as calcium carbonate (CaCO3). CaCO3 was used as a proxy for inorganic carbon. The weight of the CaCO3 recorded was subtracted from the dry weight previously obtained and this new weight was used as the amount of biomass for each quadrat. Biomass was used as a proxy for organic carbon.

##### *Statistical Analysis*

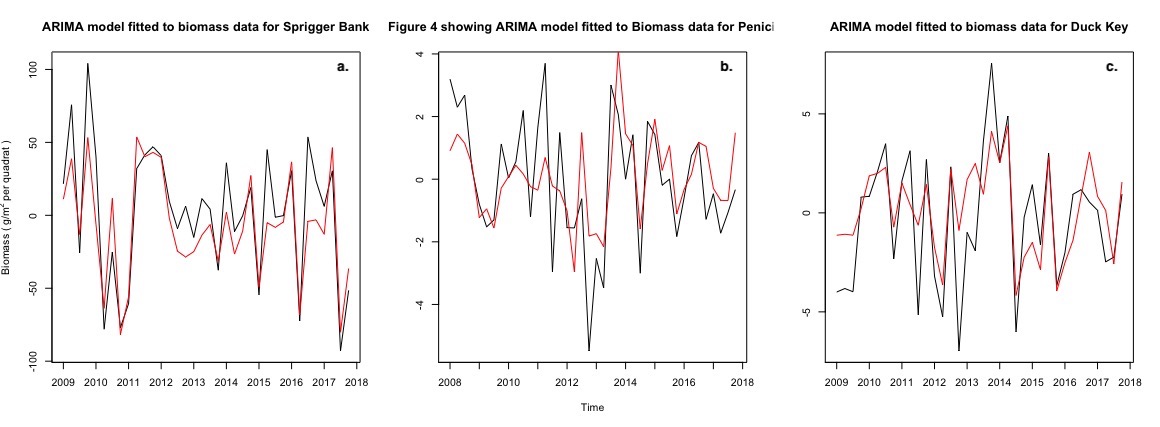
The data for 2007 to 2017 was separated for each site and an average for each of the three quadrats was obtained so that there were four points representing seasonality for each year. The data cleaned in order to remove any anomalies and then plotted to observe seasonal and annual patterns in biomass trends for each site. The cleaned data was decomposed using a multiplicative time series analysis to confirm seasonal trends and to reveal any underlying overall trends in biomass. The Augmented Dickey Fuller test (ADF) in conjunction with autocorrelation functions (ACF) and partial autocorrelation functions (PACF) were used as tools to determine if differentiation of the data was necessary based on stationarity and autocorrelation. If the data at each site was not stationary, the data was transform using differentiation either once or twice depending the variance within the data and re-tested using these analytical tests. Once the data was stationary, an autoregressive integrated moving average model (ARIMA) was fitted to determine the temporal trends. The goodness of fit of the model and its test for independence was examined by carrying out the Ljung- Box test on its residuals. Data on temperature and salinity were used as explanatory variables both separately and in conjunction to attempt to improve the ARIMA models. The Akaike information criterion (AIC) was then carried out to compare the models. The best fit models were then used to forecast potential trends in biomass at each site for the next 5 years. Statistical analyses were performed using the program RStudio (RStudio, Inc.) and associated packages.

# Results

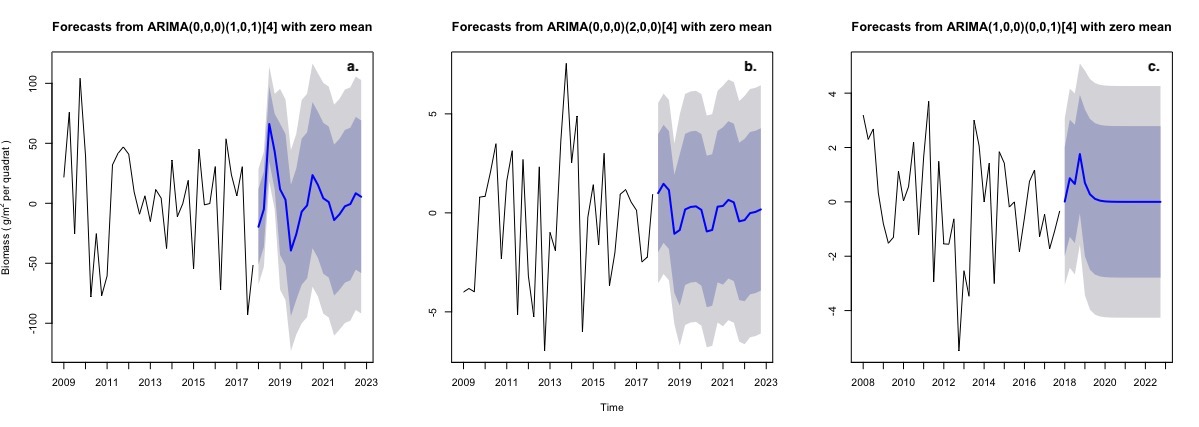
Across the 11 year survey period, biomass at Sprigger Bank (Figure 2a), the site southwest of the bay was higher and more variable than the biomass observed at both Bob Allen Keys (Figure 2b) and Duck Key (Figure 2c), the sites to the northeast of the bay. Decomposition of trends for biomass showed seasonal fluctuation with 10 distinct peaks at each site. Both Sprigger Bank (Figure 3a) and Duck Key (Figure 3c) showed an overall decreasing trends in biomass across the 11 year survey period. With the lowest values of biomass compared to the other sites (Figure 2b), Bob Allen Keys had an overall fluctuating trend in biomass during the survey period (Figure 3b).



**Figure 2 showing the four collections of biomass of macroalgae from the site Sprigger Bank, Florida Bay from 2007 to 2017.**



**Figure 4 showing the ….**



**Figure 4 showing the ….**

# Discussion

# References

Bach, Steven D. 1979. “STANDING CROP, GROWTH AND PRODUCTION OF CALCAREOUS SIPHONALES (CHLOROPHYTA) IN A SOUTH FLORIDA LAGOON.” 2. Vol. 29. <https://www.ingentaconnect.com/content/umrsmas/bullmar/1979/00000029/00000002/art00005?crawler=true{\&}mimetype=application/pdf{\&}casa{\_}token=t5CU9TbnLX8AAAAA:BaQbRyYY{\_}x7hfpwx3NTQnsQ6Jime{\_}5ShVKa2PLe7X3NAdf9tzmV3zYaliAN-SVXVILWUY{\_}q7GvRSb1f13w>.

Collado-Vides, Ligia, Leanne M Rutten, and James W Fourqurean. 2005. “SPATIOTEMPORAL VARIATION OF THE ABUNDANCE OF CALCAREOUS GREEN MACROALGAE IN THE FLORIDA KEYS: A STUDY OF SYNCHRONY WITHIN A MACROALGAL FUNCTIONAL-FORM GROUP 1.” *Journal of Phycology* 41: 742–52. <https://doi.org/10.1111/j.1529-8817.2005.00099.x>.

Davison, I R, R M Greene, and E J Podolak. 1991. “Temperature acclimation of respiration and photosynthesis in the brown alga Laminaria saccharina \*.” Vol. 110. <https://link.springer.com/content/pdf/10.1007/BF01344363.pdf>.

Fourqurean, James W., Carlos M. Duarte, Hilary Kennedy, Núria Marbà, Marianne Holmer, Miguel Angel Mateo, Eugenia T. Apostolaki, et al. 2012. “Seagrass ecosystems as a globally significant carbon stock.” *Nature Geoscience* 5 (7). Nature Publishing Group: 505–9. <https://doi.org/10.1038/ngeo1477>.

Fourqurean, James W., Joseph C. Zieman, and George V. N. Powell. 1992. “Phosphorus limitation of primary production in Florida Bay: Evidence from C:N:P ratios of the dominant seagrass Thalassia testudinum.” *Limnology and Oceanography* 37 (1). John Wiley & Sons, Ltd: 162–71. <https://doi.org/10.4319/lo.1992.37.1.0162>.

Franklin, Jerry F. 1989. “Importance and Justification of Long-Term Studies in Ecology.” In *Long-Term Studies in Ecology*, 3–19. New York, NY: Springer New York. <https://doi.org/10.1007/978-1-4615-7358-6_1>.

Frankovich, Thomas A., Anna R. Armitage, Ania H. Wachnicka, Evelyn E. Gaiser, and James W. Fourqurean. 2009. “NUTRIENT EFFECTS ON SEAGRASS EPIPHYTE COMMUNITY STRUCTURE IN FLORIDA BAY.” *Journal of Phycology* 45 (5). John Wiley & Sons, Ltd: 1010–20. <https://doi.org/10.1111/j.1529-8817.2009.00745.x>.

Frankovich, Thomas A, and James W Fourqurean. 1997. “Seagrass epiphyte loads along a nutrient availability gradient, Florida Bay, USA.” Vol. 159. <https://www.int-res.com/articles/meps/159/m159p037.pdf>.

Herbert, Darrell A., and James W. Fourqurean. 2009. “Phosphorus Availability and Salinity Control Productivity and Demography of the Seagrass Thalassia testudinum in Florida Bay.” *Estuaries and Coasts* 32 (1). Springer: 188–201. <https://doi.org/10.1007/s12237-008-9116-x>.

Hill, Ross, Alecia Bellgrove, Peter I. Macreadie, Katherina Petrou, John Beardall, Andy Steven, and Peter J. Ralph. 2015. “Can macroalgae contribute to blue carbon? An Australian perspective.” *Limnology and Oceanography* 60 (5). John Wiley & Sons, Ltd: 1689–1706. <https://doi.org/10.1002/lno.10128>.

Hillis-Colinvaux, Llewellya. 1980. “Ecology and Taxonomy of Halimeda: Primary Producer of Coral Reefs.” *Advances in Marine Biology* 17 (January). Academic Press: 1–327. <https://doi.org/10.1016/S0065-2881(08)60303-X>.

Ortegón-Aznar, Ileana, Andrea Chuc-Contreras, and Ligia Collado-Vides. 2017. “Calcareous green algae standing stock in a tropical sedimentary coast.” *Journal of Applied Phycology* 29 (5). Springer Netherlands: 2685–93. <https://doi.org/10.1007/s10811-017-1057-y>.

Perry, William. n.d. “Elements of South Florida’s Comprehensive Everglades Restoration Plan.” <www.saj.usace.army.mil/projects/index.html.>

Tussenbroek, Brigitta I. van, and M. Guadalupe Barba Santos. 2011. “Demography of Halimeda incrassata (Bryopsidales, Chlorophyta) in a Caribbean reef lagoon.” *Marine Biology* 158 (7). Springer: 1461–71. <https://doi.org/10.1007/s00227-011-1662-2>.

Tussenbroek, Brigitta I. van, and Jent Kornelis van Dijk. 2007. “SPATIAL AND TEMPORAL VARIABILITY IN BIOMASS AND PRODUCTION OF PSAMMOPHYTIC <i>HALIMEDA INCRASSATA</i> (BRYOPSIDALES, CHLOROPHYTA) IN A CARIBBEAN REEF LAGOON.” *Journal of Phycology* 43 (1). John Wiley & Sons, Ltd: 69–77. <https://doi.org/10.1111/j.1529-8817.2006.00307.x>.

Wefer, Gerold. 1980. “Carbonate production by algae Halimeda, Penicillus and Padina.” Vol. 285. <https://www.nature.com/articles/285323a0.pdf?origin=ppub>.

Zieman, Joseph C, James W Fourqurean, and Richard L Iverson. 1989. “DISTRIBUTION, ABUNDANCE AND PRODUCTIVITY OF SEAGRASSES AND MACROALGAE IN FLORIDA BAY.” 1. Vol. 44. <https://www.ingentaconnect.com/content/umrsmas/bullmar/1989/00000044/00000001/art00024?crawler=true{\&}casa{\_}token=opOrRAUO-uMAAAAA:uwe8u30Jk47-Xx2jqbvlwsNPp48AGfzmUl1DPqc9e5xyc4LQc2D7Tl2Bg0FeI70-brvnuU3KofL2yiGP{\_}g>.