Hot and fresh: Pervasive climate stressors of seagrass in a large Gulf coast estuary

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## Abstract

## 1 Introduction

Background: SST trends in Tampa Bay w/ EPC data, WFS, and deep GOM (Nickerson et al. 2023) showed that 1975 to 2022 trend for EPC was notable, but less so from 1998 to 2022. Also noted the trend was most pronounced in the winter, see Fig 3.

Heat stress combined with highlight accelerates decline of *E. acoroides*, used 36C (Zhang et al. 2023)

Widgeongrass colonization in Chesapeake Bay as an opportunistic, heat-tolerant species that has replaced Eelgrass, although former is sensitive to nutrient pulses. Paper provides an example of implications on climate change and nutrient management on foundation species and system resiliency (Hensel et al. 2023).

Focus on two time periods: full record and recent decline

Focus on two physical parameters: temperature and salinity

Temp background for TB: NOAA coastwatch trends

## 2 Methods

Seagrass changes over time in [Figure 1](#fig-seagrasschg).

Observed trends aggregated by year and bay segment across stations and months in [Figure 2](#fig-meteowqraw).

The conceptual stressor diagram [Figure 3](#fig-concept).

Salinity tolerance: Ruppia > Halodule> Thalassia > Syringodium

Halodule:

* Temp: 20-30 (range, Lewis III et al. (1985))
* Salinity: grows well in most salinity ranges (Lirman and Cropper 2003), like Syringodium but more tolerant (Lewis III et al. 1985), 10-35 (range) or < 10 (S. Scolaro)

Thalassia:

* Temp: 20-30 (range, Lewis III et al. (1985), Zieman (1975)), 30-31 (upper, from SS)
* Salinity: 25 (lower, Lewis III et al. (1985)); 30, lowest at 5 (lower, Lirman and Cropper (2003)), 33-38 (range, Phillips (1960)); 24-35 (range, Zieman (1975) citing Phillips (1960)); 15 (SS)

Syringodium:

* Temp: 20-30 (range, Lewis III et al. (1985)), 29 (upper from SS)
* Salinity: 20 (lower, Lewis III et al. (1985)), 25 (lower, Lirman and Cropper (2003)); 20

Lewis III et al. (1985) review of seagrass in Tampa Bay. Lirman and Cropper (2003) conducted exposure experiments to evaluate seagrass growth in response to a range of salinity conditions. McMillan and Moseley (1967) discusses growth of halodule, syringodium, thalassia, and ruppia in response to salinity increases (up to 75 psu), no info on lower limit. Cites Phillips (1960) for a salinity range of Thalassia in Florida of 33 - 38 psu. Zieman (1975) discusses seasonal variation of thalassia relative to temp and salinity

* Get FIM, Pinellas, Manatee data

### 2.1 Models

All models excluded Lower Tampa Bay because of minimal seagrass change over time. Also attempted to evaluate total and change as binary.

GLMs of percent change each year by Sal, Temp, with year and bay segment interactions. Attempted different windows of time from approximate seagrass sample date, 30 days to one year. The best model was one that included an effect of Salinity and an interaction with bay segment. Hillsborough Bay showed a strong response of increasing likelihood of seagrass loss with number of days when salinity was below the threshold.

Then GAMs were evaluated looking at total by Salinity, with interaction of year and bay segment. Also created a model looking at percent change vs Temp and year/bay segment interaction.

Show plots of both the glm and gams.

## 3 Results

For [Figure 2](#fig-meteowqraw), salinity shows much higher inter-annual variability, but lower intra-year variation among stations. Trends are similar for bottom vs top, temperature shows stronger trend than salinity.

Kendall test results are shown in [Figure 4](#fig-kendall).

An example of mixed effects models for two selected thresholds is shown in [Figure 5](#fig-mixeff).

NMS results in [Figure 6](#fig-nms) and seagrass decline results in [Figure 7](#fig-sgmod)

## 4 Discussion

Other areas showing seagrass loss - Florida Bay is different, less water flowing out of everglades and compounding SLR has elevated salinity and likely stress in other direction. Also, Biscayne Bay and IRL is a lot like OTB, poor flushing for example.

Viral/disease effects on seagrass change, (Van Bogaert et al. 2018) for TB and (Duffin et al. 2021) for Florida Bay.

OTB seagrass loss and role of pyrodinium, optimal temperatures from 28-31 (Lopez et al. 2021). For salinity, highest growth rates at 24 psu and above, with decline in growth rates at 20 psu (Usup, Kulis, and Anderson 1994), in Florida growth has occurred in psu 10-45, bloom concentrations observed above 15 psu (Phlips et al. 2006; Lopez et al. 2021). Optimal salinity range between 20-32 psu (Lopez et al. 2021).

## 5 Acknowledgments

## Figures

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| Figure 1: Seagrass changes over time in Tampa Bay for (a) areal coverage and (b) frequency occurrence of major species. Changes are shown for major bay segments. Note the different time scale between (a) and (b); coverage maps in (a) began in 1988 and seagrass transect monitoring in (b) began in 1998. Red lines in (a) show approximate capacity of seagrass coverage based on the baywide target of 40,000 acres. OTB: Old Tampa Bay, HB: Hillsborough Bay, MTB: Middle Tampa Bay, LTB: Lower Tampa Bay. |

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| Figure 2: Long-term air temperature, precipitation, hydrologic load, Standard Precipitation Index (SPI), water temperature, and salinity trends from 1999 to 2022. Points for salinity and water temperature are colored by sampling location in the water column and show the average (95% confidence interval) across all stations and sampling months for each year in each bay segment. OTB: Old Tampa Bay, HB: Hillsborough Bay, MTB: Middle Tampa Bay, LTB: Lower Tampa Bay. |

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| Figure 3: Conceptual stressor diagram |

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| Figure 4: Trends from 1998 to 2022 for temperature and salinity measurements at long-term monitoring stations in Tampa Bay. Results for (a) seasonal Kendall tests by station and monitoring location (top or bottom of the water column) are shown in (a) with color and shape corresponding to the estimated annual slope as change per year (yr-1). Summarized seasonal trends by month are shown for (b) top and (c) bottom measurements as the percent of stations in each bay segment with significant increasing (temperature) or decreasing (salinity) trends. Bay segment outlines are shown in (a); OTB (northwest): Old Tampa Bay, HB (northeast): Hillsborough Bay, MTB: Middle Tampa Bay, LTB: Lower Tampa Bay. |

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| Figure 5: Example of mixed effects models for the estimated number of days by year that temperature (red) or salinity (blue) were above or below thresholds of 30 degrees C or 25 psu, respectively. The bottom row (black) shows the number of days when both temperature and salinity were above or below the thresholds. The models included station as a random effect for each bay segment, with grey lines indicating individual station trends and thicker lines indicating the overall model fit. Slopes for significant models are shown in the bottom right of each facet. OTB: Old Tampa Bay, HB: Hillsborough Bay, MTB: Middle Tampa Bay, LTB: Lower Tampa Bay. |

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| Figure 6: Ordination plots of Nonmetric Multidimensional Scaling results for annual estimates in each bay segment for total seagrass frequency occurrence (Freq. Occ.), counts of days above the temperature threshold (Temp.), counts of days below the salinity threshold (Sal.), and counts of days above or below for both, respectively. The left plot excludes counts of days with both temperature and salinity above and below the threshods, whereas the right plot excludes the separate temperature and salinity metrics. Points are sized by seagrass frequency occurrence. 95% confidence ellipses are shown for observations in each major bay segment OTB: Old Tampa Bay, HB: Hillsborough Bay, MTB: Middle Tampa Bay. |

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| Figure 7: Predicted results from generalized linear models evaluating seagrass decline as (a) percent change between years and (b) probability of decline versus number of days when salinity was below the threshold. Models evaluated the response variable on the y-axes as a function of salinity days and interactions with year category (seagrass recovery prior to 2016, seagrass decline 2016 to present) and bay segment. Shaded areas are 95% confidence intervals. Colored lines in (b) as rug plots show instances of seagrass increase (blue) or decrease (red) by year. |

## Tables

Summary of mixed-effects models evaluating increases in the number of days each year from 1974 to 2022 when temperature or salinity were above or below critical thresholds, respectively. The slope estimates in the “Both” column indicate trends in the number of days when both temperature and salinity were above or below critical thresholds. \*\* p < 0.005, \* p < 0.05, - no model. OTB (northwest): Old Tampa Bay, HB (northeast): Hillsborough Bay, MTB: Middle Tampa Bay, LTB: Lower Tampa Bay.

|  | Thresholds | | Slopes | | |
| --- | --- | --- | --- | --- | --- |
| Bay Segment | Temperature | Salinity | Temperature | Salinity | Both |
| OTB |  |  |  |  |  |
|  | 29 | 15 | 1.42\*\* | 0.06 | 0.02 |
|  | 29 | 20 | 1.42\*\* | 0.97\*\* | 0.49\*\* |
|  | 29 | 25 | 1.42\*\* | 1.96\*\* | 1.44\*\* |
|  | 30 | 15 | 1.04\*\* | 0.06 | -0.01 |
|  | 30 | 20 | 1.04\*\* | 0.97\*\* | 0.15\*\* |
|  | 30 | 25 | 1.04\*\* | 1.96\*\* | 0.81\*\* |
|  | 31 | 15 | 0.12\* | 0.06 | -0.01 |
|  | 31 | 20 | 0.12\* | 0.97\*\* | -0.02 |
|  | 31 | 25 | 0.12\* | 1.96\*\* | 0.07 |
| HB |  |  |  |  |  |
|  | 29 | 15 | 1.23\*\* | 0.06 | 0.04\* |
|  | 29 | 20 | 1.23\*\* | 0.51\*\* | 0.47\*\* |
|  | 29 | 25 | 1.23\*\* | 0.86\* | 1.23\*\* |
|  | 30 | 15 | 1.01\*\* | 0.06 | 0.02\* |
|  | 30 | 20 | 1.01\*\* | 0.51\*\* | 0.23\*\* |
|  | 30 | 25 | 1.01\*\* | 0.86\* | 0.8\*\* |
|  | 31 | 15 | 0.17\*\* | 0.06 | - |
|  | 31 | 20 | 0.17\*\* | 0.51\*\* | - |
|  | 31 | 25 | 0.17\*\* | 0.86\* | 0.09\*\* |
| MTB |  |  |  |  |  |
|  | 29 | 15 | 1.29\*\* | -0.01 | - |
|  | 29 | 20 | 1.29\*\* | 0.04 | 0.08\*\* |
|  | 29 | 25 | 1.29\*\* | 0.67\*\* | 0.73\*\* |
|  | 30 | 15 | 1.06\*\* | -0.01 | - |
|  | 30 | 20 | 1.06\*\* | 0.04 | 0.02\* |
|  | 30 | 25 | 1.06\*\* | 0.67\*\* | 0.37\*\* |
|  | 31 | 15 | 0.14\*\* | -0.01 | - |
|  | 31 | 20 | 0.14\*\* | 0.04 | - |
|  | 31 | 25 | 0.14\*\* | 0.67\*\* | 0.03 |
| LTB |  |  |  |  |  |
|  | 29 | 15 | 1.08\*\* | - | - |
|  | 29 | 20 | 1.08\*\* | -0.01 | - |
|  | 29 | 25 | 1.08\*\* | -0.06 | 0.01 |
|  | 30 | 15 | 0.92\*\* | - | - |
|  | 30 | 20 | 0.92\*\* | -0.01 | - |
|  | 30 | 25 | 0.92\*\* | -0.06 | 0 |
|  | 31 | 15 | 0.23\*\* | - | - |
|  | 31 | 20 | 0.23\*\* | -0.01 | - |
|  | 31 | 25 | 0.23\*\* | -0.06 | - |

Number of days at the beginning and end of the period of record when temperature or salinity were above or below critical thresholds, respectively. Values are the estimated mean number of days (plus standard error) from 1974 to 2022. Columns for “Both” indicate the estimated number of days when both temperature and salinity were above or below critical thresholds. Note that not all models are significant (see table 1). \*\* p < 0.005, \* p < 0.05, - no model. OTB (northwest): Old Tampa Bay, HB (northeast): Hillsborough Bay, MTB: Middle Tampa Bay, LTB: Lower Tampa Bay.

|  | Thresholds | | Temperature | | Salinity | | Both | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Bay Segment | Temperature | Salinity | Start | End | Start | End | Start | End |
| OTB |  |  |  |  |  |  |  |  |
|  | 29 | 15 | 40 (3.4) | 105 (3.4) | 4 (2.3) | 6 (2.3) | 0 (0.7) | 1 (0.7) |
|  | 29 | 20 | 40 (3.4) | 105 (3.4) | 23 (7.9) | 68 (7.8) | 0 (2.9) | 22 (2.9) |
|  | 29 | 25 | 40 (3.4) | 105 (3.4) | 128 (13.2) | 219 (13.2) | 6 (3.8) | 72 (3.8) |
|  | 30 | 15 | 8 (3.3) | 56 (3.3) | 4 (2.3) | 6 (2.3) | 1 (0.4) | 0 (0.4) |
|  | 30 | 20 | 8 (3.3) | 56 (3.3) | 23 (7.9) | 68 (7.8) | 1 (2.1) | 8 (2.1) |
|  | 30 | 25 | 8 (3.3) | 56 (3.3) | 128 (13.2) | 219 (13.2) | 0 (2.8) | 37 (2.7) |
|  | 31 | 15 | 2 (2.3) | 8 (2.3) | 4 (2.3) | 6 (2.3) | 0 (0.4) | 0 (0.4) |
|  | 31 | 20 | 2 (2.3) | 8 (2.3) | 23 (7.9) | 68 (7.8) | 2 (1.4) | 1 (1.4) |
|  | 31 | 25 | 2 (2.3) | 8 (2.3) | 128 (13.2) | 219 (13.2) | 2 (1.9) | 5 (1.9) |
| HB |  |  |  |  |  |  |  |  |
|  | 29 | 15 | 47 (3.8) | 103 (3.7) | 2 (1.8) | 5 (1.7) | 0 (0.7) | 2 (0.7) |
|  | 29 | 20 | 47 (3.8) | 103 (3.7) | 11 (5.3) | 35 (5.1) | -2 (2.5) | 20 (2.4) |
|  | 29 | 25 | 47 (3.8) | 103 (3.7) | 131 (12.5) | 171 (11.8) | 12 (3.6) | 68 (3.3) |
|  | 30 | 15 | 8 (4.9) | 55 (4.8) | 2 (1.8) | 5 (1.7) | 0 (0.3) | 1 (0.3) |
|  | 30 | 20 | 8 (4.9) | 55 (4.8) | 11 (5.3) | 35 (5.1) | -2 (1.3) | 9 (1.2) |
|  | 30 | 25 | 8 (4.9) | 55 (4.8) | 131 (12.5) | 171 (11.8) | -2 (2.8) | 35 (2.7) |
|  | 31 | 15 | -1 (1.4) | 7 (1.4) | 2 (1.8) | 5 (1.7) | - | - |
|  | 31 | 20 | -1 (1.4) | 7 (1.4) | 11 (5.3) | 35 (5.1) | - | - |
|  | 31 | 25 | -1 (1.4) | 7 (1.4) | 131 (12.5) | 171 (11.8) | -1 (0.7) | 4 (0.7) |
| MTB |  |  |  |  |  |  |  |  |
|  | 29 | 15 | 47 (2.7) | 107 (2.7) | 0 (0.2) | 0 (0.2) | - | - |
|  | 29 | 20 | 47 (2.7) | 107 (2.7) | 4 (1.8) | 6 (1.8) | 0 (0.6) | 3 (0.6) |
|  | 29 | 25 | 47 (2.7) | 107 (2.7) | 51 (11) | 82 (11) | 1 (3.1) | 34 (3.1) |
|  | 30 | 15 | 9 (3.1) | 57 (3.1) | 0 (0.2) | 0 (0.2) | - | - |
|  | 30 | 20 | 9 (3.1) | 57 (3.1) | 4 (1.8) | 6 (1.8) | 0 (0.3) | 1 (0.3) |
|  | 30 | 25 | 9 (3.1) | 57 (3.1) | 51 (11) | 82 (11) | -1 (1.7) | 16 (1.7) |
|  | 31 | 15 | 0 (0.9) | 6 (0.9) | 0 (0.2) | 0 (0.2) | - | - |
|  | 31 | 20 | 0 (0.9) | 6 (0.9) | 4 (1.8) | 6 (1.8) | - | - |
|  | 31 | 25 | 0 (0.9) | 6 (0.9) | 51 (11) | 82 (11) | 0 (0.5) | 2 (0.5) |
| LTB |  |  |  |  |  |  |  |  |
|  | 29 | 15 | 58 (2.8) | 108 (2.8) | - | - | - | - |
|  | 29 | 20 | 58 (2.8) | 108 (2.8) | 0 (0.1) | 0 (0.1) | - | - |
|  | 29 | 25 | 58 (2.8) | 108 (2.8) | 4 (1.3) | 1 (1.3) | 0 (0.3) | 1 (0.3) |
|  | 30 | 15 | 21 (3.5) | 63 (3.5) | - | - | - | - |
|  | 30 | 20 | 21 (3.5) | 63 (3.5) | 0 (0.1) | 0 (0.1) | - | - |
|  | 30 | 25 | 21 (3.5) | 63 (3.5) | 4 (1.3) | 1 (1.3) | 0 (0) | 0 (0) |
|  | 31 | 15 | 0 (1.5) | 10 (1.5) | - | - | - | - |
|  | 31 | 20 | 0 (1.5) | 10 (1.5) | 0 (0.1) | 0 (0.1) | - | - |
|  | 31 | 25 | 0 (1.5) | 10 (1.5) | 4 (1.3) | 1 (1.3) | - | - |

Summary of a Generalized Additive Model evaluating frequency occurrence of seagrass versus year, number of days in a year when temperature exceeded the threshold, number of days in a year when salinity was below the threshold, and number of days in a year when both temperature and salinity were above or below thresholds. All variables were fit as main effects, including interactions with year. edf: estimate degrees of freedom, ref.df: reference degrees of freedom, F: F-statistic. \* p < 0.05, \*\* p < 0.005.

| Effect | Term | edf | ref.df | F |
| --- | --- | --- | --- | --- |
| Main |  |  |  |  |
|  | Year | 2.95 | 3.42 | 8.13\*\* |
|  | Temp | 2.67 | 3.19 | 3.78\* |
|  | Sal | 1.00 | 1.00 | 0.3 |
|  | Both | 2.62 | 3.07 | 1.26 |
| Interaction |  |  |  |  |
|  | Temp,Year | 1.00 | 1.00 | 5\* |
|  | Sal,Year | 2.33 | 2.81 | 4.09\* |
|  | Both,Year | 1.00 | 1.00 | 0.96 |

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