Draft – Effect of Atmospheric Heatwaves on Reflectance and Pigment Composition of Intertidal *Nanozostera noltei* – Draft

Simon Oiry[a,*], Bede Ffinian Rowe Davies[a], Philippe Rosa[a], Augustin Debly[a], Pierre Gernez[a], Laurent Barillé[a]

[a] *Institut des Substances et Organismes de la Mer, ISOMer, Nantes Université, UR 2160, F-44000 Nantes, France,*

Abstract

To be written

Keywords: Remote Sensing, Pigment Composition, Seagrass, Coastal Ecosystems, Heatwaves

1. Introduction

Intertidal seagrasses play a crucial role in the ecosystem by providing habitats and feeding grounds for various marine species, supporting rich marine biodiversity, and contributing significantly to primary production and carbon sequestration [1, 2]. These seagrasses are essential in maintaining the health of coastal ecosystems by stabilizing sediments, filtering water, and serving as indicators of environmental changes due to their sensitivity to water quality variations [3]. The interactions between seagrass meadows and their associated herbivores further enhance the delivery of ecosystem services, including coastal protection and fisheries support [4, 5, 6]. Understanding and preserving these ecosystems are vital for maintaining the biodiversity and productivity of coastal regions [7, 8].

Despite their crucial role in marine ecosystems, intertidal seagrasses face numerous threats that compromise their health and functionality. Coastal development and human activities are primary threats. These activities not only reduce the available habitat for seagrasses but also increase water turbidity, which limits light penetration and hampers photosynthesis [9]. Seagrasses are also threatened by nutrient enrichment from agricultural and urban runoff, which can lead to eutrophication. This condition promotes the overgrowth of algal

*Corresponding author
Email address: oirysimon@gmail.com (Simon Oiry)

blooms that compete with seagrasses for light and nutrients, further stressing these important plants [10] (Oiry et al. 2024). Pollution from industrial and agricultural fields sources introduces harmful chemicals and heavy metals into coastal waters, posing toxic risks to seagrass health. These pollutants can affect the physiological processes of seagrasses, reducing their growth and survival rates [11] Additionally, invasive species can out compete native seagrasses for resources, altering community structure and function [12].

Heatwaves, exacerbated by climate change, pose a growing threat to seagrasses. Marine Heatwaves (MHW), defined by [13] as prolonged discrete anomalously warm water events, and Atmospheric Heatwaves (AHW), defined by [14] as periods of at least three consecutive days with temperatures exceeding the 90th percentile, cause severe physiological stress on seagrasses [15, 16]. At the interface between the land and oceans, intertidal seagrasses are exposed to both MHW and AHW. Heatwaves have profound impacts on seagrasses, with their effects varying based on species and geographic location. For instance, the seagrass *Zostera marina* exhibits high susceptibility to elevated sea surface temperatures during winter and spring, leading to advanced flowering, high mortality rates, and reduced biomass [15]. Similarly, *Cymodocea nodosa* shows increased photosynthetic activity during heatwaves but suffers negative effects on photosynthetic performance and leaf biomass during recovery [16]. Additionally, different populations of *Zostera marina* along the European thermal gradient exhibit varied photophysiological responses during the recovery phase of heatwaves, indicating differential adaptation capabilities among populations [17]. These events intensify other stressors, such as overgrazing and seed burial, compromising sexual recruitment [18].

Bleaching and browning events of seagrass beds have been observed following episodes of intense heat along the Brittany coast of France (Pers. obs.) then affecting leaf color, which are expected to alter leaf reflectance. Remote sensing is increasingly being utilized to monitor marine ecosystems, including seagrass meadows. By using spectral indices, such as the Normalized Difference Vegetation Index (NDVI) and the Soil-Adjusted Vegetation Index (SAVI), or by analyzing specific spectral patterns, remote sensing can effectively quantify vegetation health over time [19, 20, 21, 22]. Through the Water Framework Directive and the Marine Strategy Framework Directive, Europe is promoting remote sensing techniques for habitat mapping, as these methods enable the monitoring of extensive areas over time [23]. This study will experimentally test the hypothesis that warm events modify the pigment composition and reflectance of seagrass, linking these changes with satellite remote sensing.

2. Material & Methods

2.1. Heatwaves detection and characterisation

2.1.1. Air temperature

Since January 1, 2024, Meteo France weather data has been freely and openly accessible. Hourly air temperature data (°C) for the French coast of the Atlantic and the Channel has been downloaded using a custom script, as no API has been developed for downloading this data at the date of this study. Weather stations located within 10 kilometers of the coastline were considered, but only those with a minimum of 30 years of data were included to ensure accurate climatology reconstruction. Among the 156 weather stations comprised within the 10km of coastline, only 36 had enough data to reconstruct the climatology. Hourly data has been aggregated to daily mean temperatures at each stations.

2.1.2. Water temperature

not done yet !

2.2. Experiment

2.2.1. Sampling and Acclimation of seagrasses

Seagrass was sampled from a *Nanozostera noltei* (dwarf eelgrass, syn. Zostera noltei) meadow on Noirmoutier Island, France (46°57'32.0"N 2°10'37.0"W) at low tide in June 2024. A shovel was used to sample seagrass from an area of 30 cm by 15 cm and 5 cm deep, maintaining the sediment structure and avoiding damage to the rhizomes and the leafs of the seagrass. The seagrass, along with sediment, meiofauna, and macrofauna, was placed in plastic trays. To avoid hydric stress during transportation, seawater was added to each tray. Simultaneously, seawater was sampled from a nearby site and transported to the lab, where it was filtered using a 0.22 µm nitrocellulose filter to remove all suspended particulate matter. This seawater was used in the acclimation tank and the intertidal chambers. The seagrasses were acclimated at high tide for one weeks with a water temperature of 17°C, matching the temperature at the time of sampling, and with light of 150 µmol.s-1.m-2 of PAR photons [22]. A wave generator was used in the tank to circulate and reoxygenate the water.

2.2.2. Experimental design

Two intertidal chambers from ElectricBlue were used to simulate tidal cycles and control water temperature during high tide and air temperature during low tide. One chamber served as the control, while the other was used for the experimental treatment. The control chamber was maintained at temperatures representative of the typical seasonal conditions: water temperatures between 18°C and 19°C and air temperatures between 18°C and 23°C, following circadian temperature variability (Figure 1). For the experimental treatment, the air temperature was set to mimic an atmospheric heatwave that occurred over the seagrass meadow of Porh Saint-Guénël, Plouharnel, France (47°35'40.0"N, 3°07'30.0"W) from August 26, 2021, to September 6, 2021. On the first day of the experiment, air temperatures in the experimental chamber were set to range from 23°C at night to 35°C during the day, with a daily increase of 1°C. The water temperature in the experimental chamber was similarly adjusted to reflect the heatwave conditions, starting from the normal seasonal range (18°C) and gradually increasing to simulate the rising temperatures experienced during the heatwave (+0.5°C daily). This setup aimed to replicate the thermal stress experienced by the seagrass meadow during the actual heatwave event (Figure 1).

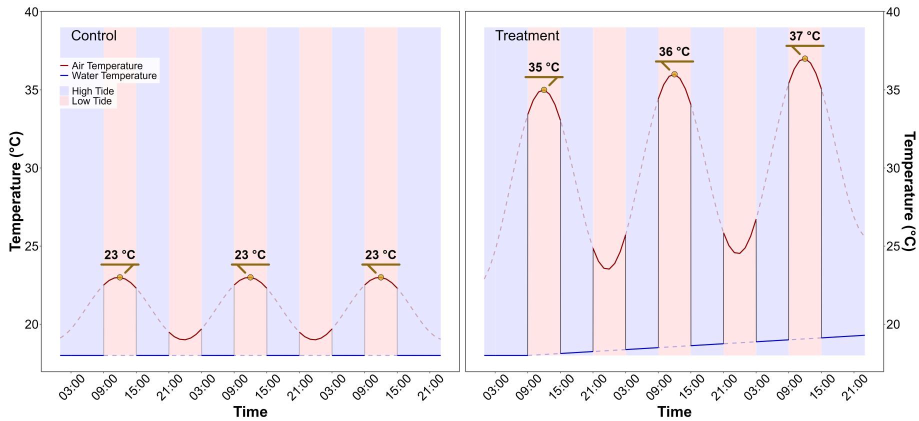

Figure 1: Temperature profiles of both the control (left) and the treatment (right) followed during the heatwave experiment. The red line indicates air temperature, whereas the blue line indicates water temperature. Due to the tidal cycle followed during the experiment, the seagrasses only experience temperatures representade by solid lines.

2.2.3. Measurment and Sampling

2.2.3.1. Radiomertric measurment.

Throughout the experiment, hyperspectral signatures of both the control and treatment seagrasses were taken using an ASD HandHeld 2 equipped with a fiber optic, allowing measurements to be taken directly inside the chamber without opening it. An average reflectance spectrum of five spectra, each with an integration time of 544 ms, was taken every minute. Every 10 minutes, the fiber optic was switched from on benthic chamber to the other, in order to measure reflectance in both treatment and control. Reflectance calibration of the instrument was performed each morning at the very first moment of low tide using a Spectralon white reference with 99% Lambertian reflectivity. The 2nd derivative of reflectance spectra has been calculated to retrieve absorption features and compare it variability over time. Two radiometric indices where also followed over time :

- The Normalized Difference Vegetation Index (NDVI, [24]), as a proxy of the concentration of chlorophyll-a (Equation 1)

$$NDVI = \frac{R(840nm) - R(668nm)}{R(840nm) + R(668nm)} \tag{1}$$

where $R(840nm)$ is the reflectance at 840 nm and $R(668nm)$ is the reflectance at 668 nm.

- The Green Leaf Index (GLI, [25]), as a measurment of the greenness of seagrass leafs (Equation 2)

$$GLI = \frac{[R(550nm) - R(668nm)] + [R(550nm) - R(450nm)]}{(2 \times R(550nm)) + R(668nm) + R(450nm)} \tag{2}$$

where $R(668nm)$ is the reflectance in the red at 668 nm, $R(550nm)$ is the reflectance in the green at 550 nm and $R(450)$ is the refletance in the blue at 450 nm.

Bibliography

[1] R. K. Unsworth, L. C. Cullen-Unsworth, B. L. Jones, R. J. Lilley, The planetary role of seagrass conservation, Science 377 (6606) (2022) 609–613.

[2] A. I. Sousa, J. F. da Silva, A. Azevedo, A. I. Lillebø, Blue carbon stock in zostera noltei meadows at ria de aveiro coastal lagoon (portugal) over a decade, Scientific reports 9 (1) (2019) 14387.

[3] M. L. Zoffoli, P. Gernez, L. Godet, S. Peters, S. Oiry, L. Barillé, Decadal increase in the ecological status of a north-atlantic intertidal seagrass meadow observed with multi-mission satellite time-series, Ecological Indicators 130 (2021) 108033.

[4] E. Jankowska, L. N. Michel, G. Lepoint, M. Włodarska-Kowalczuk, Stabilizing effects of seagrass meadows on coastal water benthic food webs, Journal of Experimental Marine Biology and Ecology 510 (2019) 54–63.

[5] M. L. Zoffoli, P. Gernez, S. Oiry, L. Godet, S. Dalloyau, B. F. R. Davies, L. Barillé, Remote sensing in seagrass ecology: coupled dynamics between migratory herbivorous birds and intertidal meadows observed by satellite during four decades, Remote Sensing in Ecology and Conservation 9 (3) (2023) 420–433.

[6] R. C. Gardner, C. Finlayson, Global wetland outlook: state of the world's wetlands and their services to people, in: Ramsar convention secretariat, 2018, pp. 2020–5.

[7] A. L. Scott, P. H. York, C. Duncan, P. I. Macreadie, R. M. Connolly, M. T. Ellis, J. C. Jarvis, K. I. Jinks, H. Marsh, M. A. Rasheed, The role of herbivory in structuring tropical seagrass ecosystem service delivery, Frontiers in Plant Science 9 (2018) 127.

[8] C. Ramesh, R. Mohanraju, Seagrass ecosystems of andaman and nicobar islands: Status and future perspective., Environmental & Earth Sciences Research Journal 7 (4) (2020).

[9] M. Waycott, C. M. Duarte, T. J. Carruthers, R. J. Orth, W. C. Dennison, S. Olyarnik, A. Calladine, J. W. Fourqurean, K. L. Heck Jr, A. R. Hughes, et al., Accelerating loss of seagrasses across the globe threatens coastal ecosystems, Proceedings of the national academy of sciences 106 (30) (2009) 12377–12381.

[10] E. Thomsen, L. S. Herbeck, I. G. Viana, T. C. Jennerjahn, Meadow trophic status regulates the nitrogen filter function of tropical seagrasses in seasonally eutrophic coastal waters, Limnology and Oceanography 68 (8) (2023) 1906–1919.

[11] K. Sevgi, S. Leblebici, Bitkilerde ağır metal stresine verilen fizyolojik ve moleküler yanıtlar, Journal of Anatolian Environmental and Animal Sciences 7 (4) (2022) 528–536.

[12] T. S. Simpson, T. Wernberg, J. I. McDonald, Distribution and localised effects of the invasive ascidian didemnum perlucidum (monniot 1983) in an urban estuary, PLoS One 11 (5) (2016) e0154201.

[13] A. J. Hobday, L. V. Alexander, S. E. Perkins, D. A. Smale, S. C. Straub, E. C. Oliver, J. A. Benthuysen, M. T. Burrows, M. G. Donat, M. Feng, et al., A hierarchical approach to defining marine heatwaves, Progress in oceanography 141 (2016) 227–238.

[14] S. E. Perkins, L. V. Alexander, On the measurement of heat waves, Journal of climate 26 (13) (2013) 4500–4517.

[15] Y. Sawall, M. Ito, C. Pansch, Chronically elevated sea surface temperatures revealed high susceptibility of the eelgrass zostera marina to winter and spring warming, Limnology and Oceanography 66 (12) (2021) 4112–4124.

[16] A. Deguette, I. Barrote, J. Silva, Physiological and morphological effects of a marine heatwave on the seagrass cymodocea nodosa, Scientific Reports 12 (1) (2022) 7950.

[17] G. Winters, P. Nelle, B. Fricke, G. Rauch, T. B. Reusch, Effects of a simulated heat wave on photophysiology and gene expression of high-and low-latitude populations of zostera marina, Marine Ecology Progress Series 435 (2011) 83–95.

[18] L. Guerrero-Meseguer, A. Marín, C. Sanz-Lázaro, Heat wave intensity can vary the cumulative effects of multiple environmental stressors on posidonia oceanica seedlings, Marine Environmental Research 159 (2020) 105001.

[19] A. R. Huete, Vegetation indices, remote sensing and forest monitoring, Geography Compass 6 (9) (2012) 513–532.

[20] S. Kloos, Y. Yuan, M. Castelli, A. Menzel, Agricultural drought detection with modis based vegetation health indices in southeast germany, Remote Sensing 13 (19) (2021) 3907.

[21] I. Cârlan, B.-A. Mihai, C. Nistor, A. Große-Stoltenberg, Identifying urban vegetation stress factors based on open access remote sensing imagery and field observations, Ecological Informatics 55 (2020) 101032.

[22] M. Akbar, P. Arisanto, B. Sukirno, P. Merdeka, M. Priadhi, S. Zallesa, Mangrove vegetation health index analysis by implementing ndvi (normalized difference vegetation index) classification method on sentinel-2 image data case study: Segara anakan, kabupaten cilacap, in: IOP Conference Series: Earth and Environmental Science, Vol. 584, IOP Publishing, 2020, p. 012069.

[23] E. Papathanasopoulou, S. Simis, K. Alikas, A. Ansper, J. Anttila, A. Barillé, L. Barillé, V. Brando, M. Bresciani, M. Bučas, et al., Satellite-assisted monitoring of water quality to support the implementation of the water framework directive, EOMORES white paper (2019).

[24] J. W. Rouse, R. H. Haas, J. A. Schell, D. W. Deering, et al., Monitoring vegetation systems in the great plains with erts, NASA Spec. Publ 351 (1) (1974) 309.

[25] M. Louhaichi, M. M. Borman, D. E. Johnson, Spatially located platform and aerial photography for documentation of grazing impacts on wheat, Geocarto International 16 (1) (2001) 65–70.