Discriminating Seagrass From Green Macroalgae in European Intertidal areas using high resolution multispectral drone imagery.

Simon Oiry

Bede Ffinian Rowe Davies

Pierre Gernez

Ana I. Sousa

Philippe Rosa

Maria Laura Zoffoli

Guillaume Brunier

Laurent Barillé

2024-02-27

Abstract

In September 2021, a significant jump in seismic activity on the island of La Palma (Canary Islands, Spain) signaled the start of a volcanic crisis that still continues at the time of writing. Earthquake data is continually collected and published by the Instituto Geográphico Nacional (IGN). …

# 1. Introduction

Coastal areas are vital hotshots for marine biodiversity, with intertidal seagrass meadows playing a crucial role at the interface between land and ocean (Unsworth et al. 2022). These meadows offer a myriad of ecosystem services to humanity, including limitation of coastline erosion, reducing the risk of eutrophication, carbon sequestration, and oxygen production. They serve as vital habitats for a diverse array of marine and terrestrial species, providing living, breeding, and feeding grounds (Gardner and Finlayson 2018 ; Zoffoli et al. 2022 ; Jankowska et al. 2019). Due to their proximity to human activities, seagrass meadows are directly exposed to and impacted by anthropogenic pressures. Global regression and fragmentation are currently observed due to diseases, disasters, coastal urbanization, sea reclamation, as well as fishing activities, dredging, sea level rise, coastal erosion, competition with alien species, and reduction in water quality (Nguyen et al. 2021 ; Soissons et al. 2018 ; Orth et al. 2006 ; Lin et al. 2018 ; Duffy et al. 2019). While improvements in water quality have been recently reported in European sites, allowing an overall recovery of seagrass ecosystems at the local scale, many other coastal waters worldwide are still subjected to strong eutrophication processes (Los Santos et al. 2019 ; Zoffoli et al. 2021). Coastal eutrophication has been associated to anomalous accumulation of green macroalgae, the so-called green tides. Green tides produce shade and suffication over seagrass individuals, thus threatening the health of seagrass ecosystems (**Duarte2002?** ; Wang et al. 2022).

The importance of seagrass meadows and the variety of ecosystem services they provide have led to the enhancement of global and regional monitoring programs for systematically surveying different Essential Oceanic Variable (Miloslavich et al. 2018) as seagrass coverage and composition; as well as Essential Biodiversity Variable (Pereira et al. 2013) such as seagrass taxonomic diversity; species distribution, population abundance, and phenology. Monitoring programs also prioritize the identification of threats to these ecosystems, particularly during early stages, to facilitate effective mitigation actions. Traditionally, these ecological parameters have been quantified through in situ measurements, although this approach faces several constraints over intertidal zones. Intertidal meadows are only partially exposed during low tide and can be situated in difficult-to-reach mudflats, potentially leading to inaccurate and limited estimations with conventional sampling techniques (Nijland, Reshitnyk, and Rubidge 2019). However, satellite data have been proven effective in complenmenting in situ surveys, allowing for the rapid and consitent retrieval of EOV’s over extensive seagrass meadows. (Zoffoli et al. 2021 ; Xu et al. 2021 ; Traganos and Reinartz 2018 ; Coffer et al. 2023)

Satellite remote sensing offers the advantage of acquiring large-scale data in real-time but presents its inherent challenges. Free access satellite data (e.g., Sentinel-2 and Landsat8/9) provide relatively low spatial resolution data (10 - 30 m) across a limited number of spectral bands. These characteristics can be a limitation to accurately discriminating seagrass from others co-existing macrophytes over the meadow. Chlorophyceae (Green Algae) and marine Magnoliopsida (Seagrass) share the same pigment composition (Ralph et al. 2002 ; Douay et al. 2022). As a result, their respective spectral signatures can be considered similar by a non-expert observer (Davies et al. 2023 ; Bannari, Ali, and Abahussain 2022). Recently, using a hyperspectral library, Davies et al. (2023) demonstrated that the spectral resolution of Sentinel-2, might be enough for the discrimination between Magnoliopsida and Chlorophyceae. However, green tide events occur at small spatial scales that are not observable using satellite imagery (Tuya et al. 2013), especially during the initial stage of the event.

Remote sensing drone acquisitions are presented as a tool that can potentially fill gaps left by satellite and in situ data. Drone can cover large expanses while recording imagery at significantly higher spatial resolutions than satellite (pixel size from cm to mm) and still capturing data at multi-spectral resolution (Fairley et al. 2022 ; Oh, Kim, and Lee 2017). The versatility of drones allows for their application across a diverse thematic range , from coastal zone management (Adade et al. 2021 ; Casella et al. 2020 ; Angnuureng et al. 2022) to mapping the spatial distribution of species (Joyce, Fickas, and Kalamandeen 2023 ; Tallam et al. 2023 ; Roca et al. 2022 ; Román et al. 2021 ; Brunier et al. 2022). However, when applied to coastal habitat mapping, many studies showcase their findings with study case limited to a single flight, restricting the generalizability of their application to other sites (Román et al. 2021 ; Collin et al. 2019 ; Rossiter et al. 2020 ; Brunier et al. 2022). This study aimed to analyze the potential of a drone equipped with a multispectral sensor for maping intertidal macrophytes, with a particular focus on discriminating Magnoliopsida and Chlorophyceae. Ten drone flights were performed over soft-bottom intertidal areas along two European countries (France and Portugal), covering a wide range of habitats, from monospecific seagrass meadows to meadows mixed with green or red algae. A deep learning algorithm was trained and validated for macrophyte discrimination, emphasizing applicability across diverse sites without a loss of accuracy in predictions.

Adade, Richard, Abiodun Musa Aibinu, Bernard Ekumah, and Jerry Asaana. 2021. “Unmanned Aerial Vehicle (UAV) Applications in Coastal Zone Management—a Review.” *Environmental Monitoring and Assessment* 193: 1–12.

Angnuureng, Donatus B, KE Brempong, PN Jayson-Quashigah, OA Dada, SGI Akuoko, J Frimpomaa, PA Mattah, and Rafaël Almar. 2022. “Satellite, Drone and Video Camera Multi-Platform Monitoring of Coastal Erosion at an Engineered Pocket Beach: A Showcase for Coastal Management at Elmina Bay, Ghana (West Africa).” *Regional Studies in Marine Science* 53: 102437.

Bannari, Abderrazak, Thamer Salim Ali, and Asma Abahussain. 2022. “The Capabilities of Sentinel-MSI (2A/2B) and Landsat-OLI (8/9) in Seagrass and Algae Species Differentiation Using Spectral Reflectance.” *Ocean Science* 18 (2): 361–88.

Brunier, Guillaume, Simon Oiry, Yves Gruet, Stanislas F. Dubois, and Laurent Barillé. 2022. “Topographic Analysis of Intertidal Polychaete Reefs (Sabellaria Alveolata) at a Very High Spatial Resolution.” *Remote Sensing 2022, Vol. 14, Page 307* 14 (January): 307. <https://doi.org/10.3390/RS14020307>.

Casella, Elisa, Jan Drechsel, Christian Winter, Markus Benninghoff, and Alessio Rovere. 2020. “Accuracy of Sand Beach Topography Surveying by Drones and Photogrammetry.” *Geo-Marine Letters* 40: 255–68.

Coffer, Megan M, David D Graybill, Peter J Whitman, Blake A Schaeffer, Wilson B Salls, Richard C Zimmerman, Victoria Hill, et al. 2023. “Providing a Framework for Seagrass Mapping in United States Coastal Ecosystems Using High Spatial Resolution Satellite Imagery.” *Journal of Environmental Management* 337: 117669.

Collin, Antoine, Stanislas Dubois, Dorothée James, and Thomas Houet. 2019. “Improving Intertidal Reef Mapping Using UAV Surface, Red Edge, and Near-Infrared Data.” *Drones* 3 (3): 67.

Davies, B F R, Pierre Gernez, Andréa Geraud, Simon Oiry, Philippe Rosa, Maria Laura Zoffoli, and Laurent Barillé. 2023. “Multi- and Hyperspectral Classification of Soft-Bottom Intertidal Vegetation Using a Spectral Library for Coastal Biodiversity Remote Sensing.” *Remote Sensing of Environment* 290: 113554. <https://doi.org/10.1016/j.rse.2023.113554>.

Douay, Florian, Charles Verpoorter, Gwendoline Duong, Nicolas Spilmont, and François Gevaert. 2022. “New Hyperspectral Procedure to Discriminate Intertidal Macroalgae.” *Remote Sensing* 14 (2). <https://doi.org/10.3390/rs14020346>.

Duffy, J Emmett, Lisandro Benedetti-Cecchi, Joaquin Trinanes, Frank E Muller-Karger, Rohani Ambo-Rappe, Christoffer Boström, Alejandro H Buschmann, et al. 2019. “Toward a Coordinated Global Observing System for Seagrasses and Marine Macroalgae.” *Frontiers in Marine Science* 6: 317.

Fairley, Iain, Benjamin J Williamson, Jason McIlvenny, Nicholas King, Ian Masters, Matthew Lewis, Simon Neill, et al. 2022. “Drone-Based Large-Scale Particle Image Velocimetry Applied to Tidal Stream Energy Resource Assessment.” *Renewable Energy* 196: 839–55.

Gardner, Royal C, and C Finlayson. 2018. *Global Wetland Outlook: State of the World’s Wetlands and Their Services to People*.

Jankowska, Emilia, Loı̈c N Michel, Gilles Lepoint, and Maria Włodarska-Kowalczuk. 2019. “Stabilizing Effects of Seagrass Meadows on Coastal Water Benthic Food Webs.” *Journal of Experimental Marine Biology and Ecology* 510: 54–63.

Joyce, Karen E, Kate C Fickas, and Michelle Kalamandeen. 2023. “The Unique Value Proposition for Using Drones to Map Coastal Ecosystems.” *Cambridge Prisms: Coastal Futures* 1: e6.

Lin, Haiying, Tao Sun, Yi Zhou, Ruiting Gu, Xiaomei Zhang, and Wei Yang. 2018. “Which Genes in a Typical Intertidal Seagrass (Zostera Japonica) Indicate Copper-, Lead-, and Cadmium Pollution?” *Frontiers in Plant Science* 9: 1545.

Los Santos, Carmen B de, Dorte Krause-Jensen, Teresa Alcoverro, Núria Marbà, Carlos M Duarte, Marieke M Van Katwijk, Marta Pérez, et al. 2019. “Recent Trend Reversal for Declining European Seagrass Meadows.” *Nature Communications* 10 (1): 3356.

Miloslavich, Patricia, Nicholas J. Bax, Samantha E. Simmons, Eduardo Klein, Ward Appeltans, Octavio Aburto-Oropeza, Melissa Andersen Garcia, et al. 2018. “Essential Ocean Variables for Global Sustained Observations of Biodiversity and Ecosystem Changes.” *Global Change Biology* 24 (June): 2416–33. <https://doi.org/10.1111/GCB.14108>.

Nguyen, Hung Manh, Peter J Ralph, Lázaro Marı́n-Guirao, Mathieu Pernice, and Gabriele Procaccini. 2021. “Seagrasses in an Era of Ocean Warming: A Review.” *Biological Reviews* 96 (5): 2009–30.

Nijland, Wiebe, Luba Reshitnyk, and Emily Rubidge. 2019. “Satellite Remote Sensing of Canopy-Forming Kelp on a Complex Coastline: A Novel Procedure Using the Landsat Image Archive.” *Remote Sensing of Environment* 220: 41–50.

Oh, Jaehong, Duk-jin Kim, and Hyoseong Lee. 2017. “Use of a Drone for Mapping and Time Series Image Acquisition of Tidal Zones.” *Journal of the Korean Institute of Intelligent Systems* 27 (2): 119–25.

Orth, Robert J, Tim JB Carruthers, William C Dennison, Carlos M Duarte, James W Fourqurean, Kenneth L Heck, A Randall Hughes, et al. 2006. “A Global Crisis for Seagrass Ecosystems.” *Bioscience* 56 (12): 987–96.

Pereira, Henrique Miguel, Simon Ferrier, Michele Walters, Gary N Geller, Rob HG Jongman, Robert J Scholes, Michael William Bruford, et al. 2013. “Essential Biodiversity Variables.” *Science* 339 (6117): 277–78.

Ralph, PJ, SM Polk, KA Moore, RJ Orth, and WO Smith Jr. 2002. “Operation of the Xanthophyll Cycle in the Seagrass Zostera Marina in Response to Variable Irradiance.” *Journal of Experimental Marine Biology and Ecology* 271 (2): 189–207.

Roca, Mar, Martha Bonnet Dunbar, Alejandro Román, Isabel Caballero, Maria Laura Zoffoli, Pierre Gernez, and Gabriel Navarro. 2022. “Monitoring the Marine Invasive Alien Species Rugulopteryx Okamurae Using Unmanned Aerial Vehicles and Satellites.” *Frontiers in Marine Science* 9 (October). <https://doi.org/10.3389/fmars.2022.1004012>.

Román, Alejandro, Antonio Tovar-Sánchez, Irene Olivé, and Gabriel Navarro. 2021. “Using a UAV-Mounted Multispectral Camera for the Monitoring of Marine Macrophytes.” *Frontiers in Marine Science*, 1225.

Rossiter, Thomas, Thomas Furey, Tim McCarthy, and Dagmar B Stengel. 2020. “UAV-Mounted Hyperspectral Mapping of Intertidal Macroalgae.” *Estuarine, Coastal and Shelf Science* 242: 106789.

Soissons, Laura M, Eeke P Haanstra, Marieke M Van Katwijk, Ragnhild Asmus, Isabelle Auby, Laurent Barillé, Fernando G Brun, et al. 2018. “Latitudinal Patterns in European Seagrass Carbon Reserves: Influence of Seasonal Fluctuations Versus Short-Term Stress and Disturbance Events.” *Frontiers in Plant Science* 9: 88.

Tallam, Krti, Nam Nguyen, Jonathan Ventura, Andrew Fricker, Sadie Calhoun, Jennifer O’Leary, Mauriça Fitzgibbons, Ian Robbins, and Ryan K Walter. 2023. “Application of Deep Learning for Classification of Intertidal Eelgrass from Drone-Acquired Imagery.” *Remote Sensing* 15 (9): 2321.

Traganos, Dimosthenis, and Peter Reinartz. 2018. “Mapping Mediterranean Seagrasses with Sentinel-2 Imagery.” *Marine Pollution Bulletin* 134: 197–209. <https://doi.org/10.1016/j.marpolbul.2017.06.075>.

Tuya, Fernando, Harue Hernandez-Zerpa, Fernando Espino, and Ricardo Haroun. 2013. “Drastic Decadal Decline of the Seagrass Cymodocea Nodosa at Gran Canaria (Eastern Atlantic): Interactions with the Green Algae Caulerpa Prolifera.” *Aquatic Botany* 105: 1–6.

Unsworth, Richard KF, Leanne C Cullen-Unsworth, Benjamin LH Jones, and Richard J Lilley. 2022. “The Planetary Role of Seagrass Conservation.” *Science* 377 (6606): 609–13.

Wang, Zhongyuan, Zhixiang Fang, Jianfeng Liang, and Xiao Song. 2022. “Assessment of Global Habitat Suitability and Risk of Ocean Green Tides.” *Harmful Algae* 119: 102324.

Xu, Shaochun, Shuai Xu, Yi Zhou, Shidong Yue, Xiaomei Zhang, Ruiting Gu, Yu Zhang, Yongliang Qiao, and Mingjie Liu. 2021. “Long-Term Changes in the Unique and Largest Seagrass Meadows in the Bohai Sea (China) Using Satellite (1974–2019) and Sonar Data: Implication for Conservation and Restoration.” *Remote Sensing* 13 (5): 856.

Zoffoli, Maria Laura, Pierre Gernez, Laurent Godet, Steef Peters, Simon Oiry, and Laurent Barillé. 2021. “Decadal Increase in the Ecological Status of a North-Atlantic Intertidal Seagrass Meadow Observed with Multi-Mission Satellite Time-Series.” *Ecological Indicators* 130 (November): 108033. <https://doi.org/10.1016/j.ecolind.2021.108033>.

Zoffoli, Maria Laura, Pierre Gernez, Simon Oiry, Laurent Godet, Sébastien Dalloyau, Bede Ffinian Rowe Davies, and Laurent Barillé. 2022. “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*, December. <https://doi.org/10.1002/rse2.319>.