

# DISCOV-Gracilaria Paper

Simon Oiry<sup>1</sup>      Bede Ffinian Rowe Davies<sup>1</sup>      Pierre Gernez<sup>1</sup>  
Laurent Barillé<sup>1</sup>

2024-11-17

To be Written

1

## 1 Introduction

Coastal ecosystems are among the most dynamic and productive environments on Earth, providing ecosystem services and supporting biodiversity (Barbier et al., 2011; Unsworth et al., 2022; Watanabe et al., 2018). These ecosystems, spanning mangroves, salt marshes, seagrass meadows, and rocky intertidal zones, play a pivotal role in carbon sequestration, nutrient cycling, and shoreline stabilization (Liquete et al., 2013; Mehvar et al., 2018). They also serve as habitats for numerous species, many of which are commercially or ecologically significant (De Valck et al., 2023; Seitz et al., 2014). Coastal areas are densely populated, with billions of people globally depending on their resources for livelihoods, fisheries, and tourism (Mukherjee et al., 2023; Small and Nicholls, 2003). However, coastal ecosystems face mounting pressures from human activities such as land reclamation, pollution, and overfishing, compounded by the impacts of climate change (Hall-Spencer and Harvey, 2019; Lu et al., 2018). Sea level rise, ocean acidification, and increasing storm intensity further exacerbate the vulnerability of these systems, threatening their resilience and the services they provide (He and Silliman, 2019).

One of the significant threats to coastal ecosystems is biological invasions by non-native species, which can disrupt native biodiversity and alter ecosystem functions (Capdevila et al., 2019; Krueger-Hadfield, 2018; Liu et al., 2020). *Gracilaria vermiculophylla*, an invasive red macroalga native to the northwest Pacific, exemplifies this issue. Over the last century, this species has spread extensively across temperate estuaries in North America, Europe, and other regions, facilitated by aquaculture and maritime activities (Krueger-Hadfield et al., 2017;

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<sup>1</sup>Institut des Substances et Organismes de la Mer, ISOMer, Nantes Université, UR 2160, F-44000 Nantes, France

Rueness, 2005; Weinberger et al., 2008). Its success as an invader stems from its tolerance to a wide range of environmental stressors, including temperature (Sotka et al., 2018), salinity (Weinberger et al., 2008), and nutrient variability (Abreu et al., 2011), as well as its ability to establish in soft sediment habitats traditionally devoid of macroalgae (Ramus et al., 2017). While *G. vermiculophylla* can provide some ecosystem services, such as habitat for invertebrates and juvenile fish, it often outcompetes native vegetation, alters sediment composition (Nyberg et al., 2009), and disrupts trophic interactions (Ginneken et al., 2018). In regions like the Baltic Sea and the eastern United States, it has been documented to negatively affect native fucoids and seagrasses (Thomsen et al., 2013; Van Katwijk, 2003). These impacts underscore the importance of monitoring and managing the spread of *G. vermiculophylla*, particularly as climate change and anthropogenic pressures continue to facilitate biological invasions.

Remote sensing has revolutionized our ability to monitor and manage ecosystems, offering efficient and scalable methods for detecting environmental changes over large areas (Davies et al., 2024a, 2024b; Zoffoli et al., 2021). Among these technologies, drone-based remote sensing has emerged as a particularly promising tool for studying coastal environments (Román et al., 2024, 2023). Equipped with high-resolution cameras and multispectral or hyperspectral sensors, drones can capture fine-scale spatial and spectral data, enabling researchers to identify and map vegetation, detect stress in plants, and monitor changes over time. Unlike traditional satellite imagery, drones provide the flexibility to operate in overcast conditions, achieve higher spatial resolution, and target specific areas of interest. For invasive species like *G. vermiculophylla*, drones equipped with multispectral sensors can differentiate it from native vegetation based on its unique spectral reflectance characteristics. This capability not only enhances detection accuracy but also reduces the time and labor associated with traditional field surveys. As the cost of drone technology continues to decrease and advancements in machine learning facilitate data analysis, drone-based remote sensing is becoming increasingly accessible and impactful for ecological research and management.

In this study, we aim to harness the potential of drone-based multispectral remote sensing to map *Gracilaria vermiculophylla* in intertidal zones. Bla bla what are we going to do ? bla bla

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