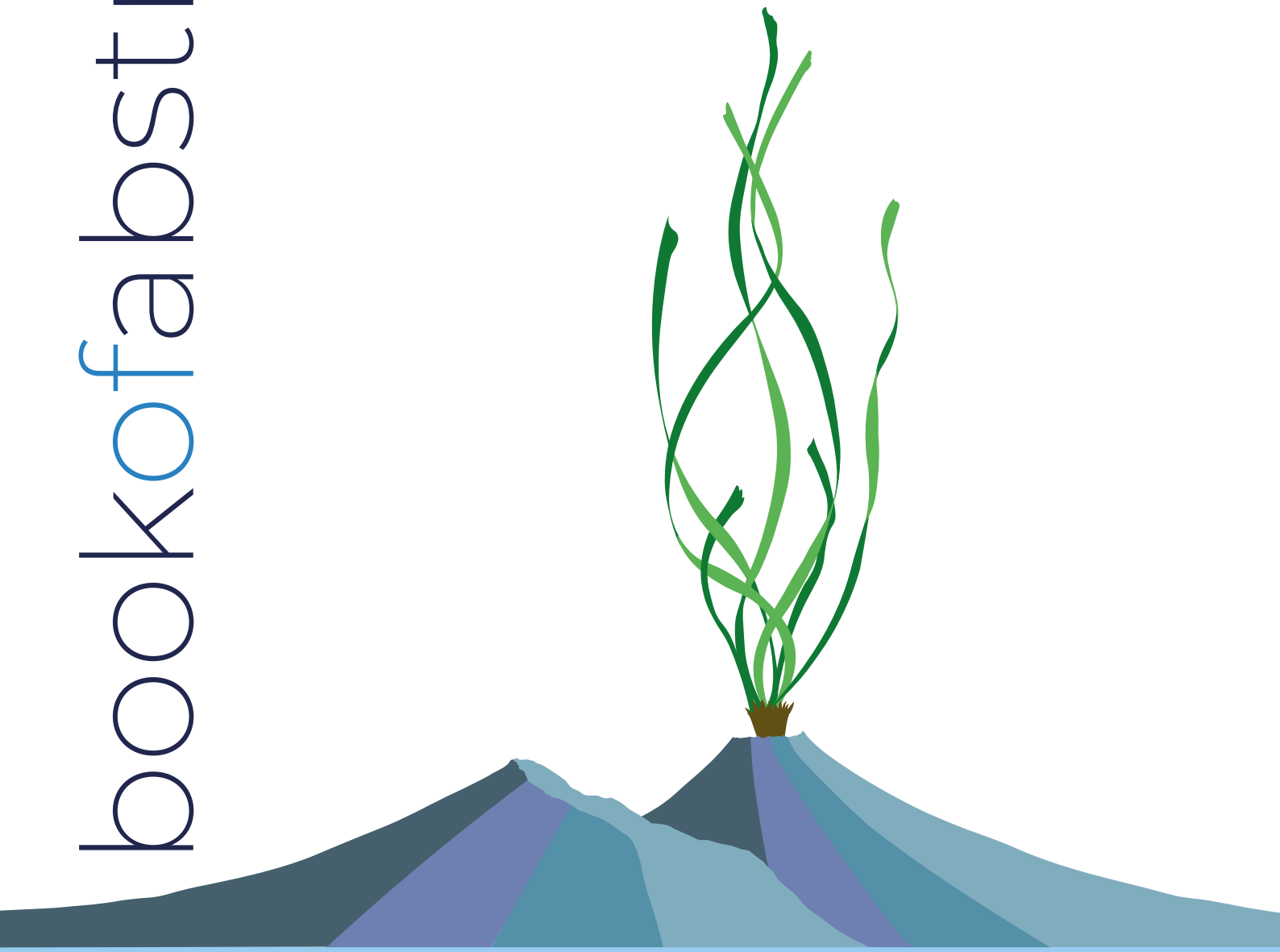
bookofabstract

ISBW15 & WSC2024

NAPOLI, ITALY, JUNE 17TH TO JUNE 21ST, 2024



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2024 World Seagrass Conference &
15th International Seagrass Biology Workshop
Seagrasses in the Anthropocene

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2024 World Seagrass Conference &
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Seagrasses in the Anthropocene

The 2024 World Seagrass Conference (WSC2024) & 15th International Seagrass Biology Workshop (ISBW15) will take place in Napoli, Italy, from June 17th to June 21st, 2024.

The theme of WSC2024 and ISBW15, Seagrasses in the Anthropocene, come from the knowledge that seagrass ecosystems are facing an accelerating human pressure at local and global scales. Environmental changes are transforming seagrass ecosystems into new configurations unlike anything observed before. Returning to past configurations is no longer an option.

The global challenge is to establish a new baseline, protect, restore, and rehabilitate the existing resource.

The key questions to address are:
To which extent species are resilient to environmental changes?
Which are the mechanisms behind that?
What can we do to ensure seagrass sustainability?
Which methodologies can we apply and/or further develop for keeping meadows functional?
How can we effectively combine socio-economic, cultural and management approaches with the basic science?

ISBW15 and WSC24 will strive to answer these questions with three themes:
– Theme 1 : Seagrass responses to environmental change
– Theme 2 : Seagrass community diversity and species interactions
– Theme 3 : Seagrass conservation, management and citizen science

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Plenary Speakers

Opening Plenary

Seagrass science in an international cooperation and policy context: A game-changer opportunity not to miss

Salvatore Aricò
PhD, CEO, International Science Council

Seagrass systems are increasingly referred to in the context of international policy processes as a promising response to inter alia climate change mitigation and adaptation. The science underpinning the contribution of seagrasses to globally agreed goals is also increasingly coordinated, and the ensuing knowledge actionable. Yet there is a disconnect between action on the needed conservation and sustainable use, and the sharing of benefits deriving from the maintenance of healthy seagrass systems, and the lack of integrated policies to ensure that seagrasses are capitalized upon as our best bet in the quest of sustainability. The 2024 World Seagrass Conference & 15th International Seagrass Biology Workshop offer an opportunity for the global voice of seagrass science to contribute to the vision of science as a global public good, in an era of global change, inequalities and polarization.

Theme Plenary

THEME 1

Thorsten Reusch
GEOMAR
Helmholtz-Centre for Ocean Research Kiel and Kiel University, Germany

A return to the sea – adaptations of seagrasses across scales

This keynote will give an overview on the breathtaking range of adaptations of seagrasses that were required to successfully return to the stressful ocean environment, but also to increasing levels of stress related to global change. Much can be learned from omic-guided approaches. For example, gene losses and gene family expansions facilitate light harvesting, hypoxic metabolism and salt tolerance across all three seagrass lineages. Population-genomic approaches permit an assessment of historical demography driven by glacial bottlenecks, allow the reconstruction of refugia, and permit the analysis genome-phenotype associations. Transcriptome profiling allows the detection of seagrass stress markers and priming effects. As clonal species, seagrasses are also ecellent examples as to how clones can diversify phenotypically through within-clone genetic and epigenetic evolution. Coupling these processes with purely ecological approaches is imperative as a basis for evolution-guided restoration measures in a rapidly changing ocean environment.

Theme Plenary

THEME 2

John J Stachowicz (Jay)
Professor, Department of Evolution and Ecology
University of California Davis (USA)

Darwin's Entangled Bank: interactions among seagrass, its associated animals, and the microbiome in a changing ocean.

Seagrasses are ecosystem engineers, but this engineering function depends on plant morphological and physiological traits, which vary among individuals and populations and with environmental change. In this talk, I will assess how genetically based and plastic variation in seagrass traits affect the diversity, composition and functioning of their associated communities. Global and local variation in seagrass form leads to predictable changes in epifaunal communities, but what are the consequences of this variation for seagrass ecosystems? Growing understanding of the role of the seagrass microbiome is revolutionizing our understanding of seagrass stress tolerance and disease ecology, but how much of plant adaptation and plasticity is microbially-based? How does the seagrass microbiome influence the better-known interactions between seagrasses and macrofauna? Integrating community and microbial ecology with our emerging understanding of seagrass trait, genetic and functional diversity can address these questions and enhance conservation and restoration of seagrass ecosystems in a changing world.

Theme Plenary

THEME 3

Jacqueline Uku
Kenya Marine and Fisheries Research Institute
Mombasa, KENYA

Seagrass conservation, management and citizen science

The degradation of seagrass meadows is prevalent in the Western Indian Ocean (WIO) region due to fishing impacts, anchor damage, sea urchin herbivory, extreme events such as cyclones and floods, and anthropogenic factors such as pollution and sediment inflows. In response to seagrass habitat degradation, there have been numerous efforts to advance the restoration of seagrass beds in several countries in the region. This presentation will focus on experimental restoration efforts in three countries of the WIO: Kenya, Tanzania and Mozambique. The conservation challenges and lessons learned will be elaborated as well as the integration of communities in citizen science initiatives.

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Scientific Sessions

SS01 – Global Change and Consumer Effects – Seagrass Resilience in the Anthropocene
Main-conveners: Marjolijn Christianen (Wageningen University, The Netherlands) – marjolijn.christianen@wur.nl

Co-conveners: Justin Cambell (Florida International University), Nicole Esteban (Swansea University), Fee Smulders (Wageningen University)

SS02 – Large scale approaches to seagrass ecology: integrating diverse approaches to produce a global view of seagrass ecosystems
Main-conveners: Jay Stachowicz (University of California Davis, USA) – jjstachowicz@ucdavis.edu

Co-conveners: Emmett Duffy (Smithsonian Institution)

SS03 – Seagrass trait-based ecology applied to seagrass responses to environmental change, biodiversity, ecosystem services, and conservation.
Main-conveners: Carmen B. de los Santos (Centre of Marine Sciences of Algarve, Portugal) – cbsantos@ualg.pt

Co-conveners: Camilla Gustafsson (Tvärminne Zoological Station, University of Helsinki) – Agustín Moreira-Saporiti (Marine Biological Laboratory)

SS04 – Seagrass genetics in the Anthropocene
Main-conveners: Patrick Larkin (Texas A&M University-Corpus Christi, USA) – patrick.larkin@tamucc.edu

Co-conveners: Paul Bologna (Montclair State University), Traci Erin Cox (University of New Orleans), Randall Hughes (Northeastern University), Ester Serrao (CCMAR), Jay Stachowicz (University of California Davis)

SS05 – Seagrasses in 'the real world': resisting and recovering from multiple stressors
Main-conveners: Hung Manh Nguyen (Ben-Gurion University of the Negev, ISR) – manhhung.hou@gmail.com; Chanelle Webster (Edith Cowan University, AU) – chanelle.webster@ecu.edu.au

Co-conveners: Kathryn McMahon (Edit Cowan University), Nicole Said (Edit Cowan University), Fiona Tomas Nash (IMEDEA), Gidon Winters (Dead Sea Arava Center)

SS06 – Ocean acidification research in seagrass ecosystems: From impacts to solutions
Main-conveners: Gema Hernan (Mediterranean Institute for Advanced Studies, Spain) – gemahernanm@gmail.com

Co-conveners: Iris Hendriks (Mediterranean Institute for Advances Studies), Aurora M Ricart (Institut de Ciències del Mar)

SS07 – Macro-micro interactions in seagrass ecosystems
Main-conveners: Ulisse Cardini (Stazione Zoologica Anton Dohrn, Italy) – ulisse.cardini@szn.it

Co-conveners: Fabio Bulleri (University of Pisa), Paul Gribben (University of New South Wales)

SS08 – Seagrass Microbe Interactions – Harnessing the Microbiome
Main-conveners: Aschwin Engelen (CCMar, Portugal) – aengelen@ualg.pt
Gina Chaput (University of California, Davis, United States) – gmchaput@ucdavis.edu

SS09 – Novel approaches to assist seagrasses in a changing environment
Main-conveners: Jessica Pazzaglia (Stazione Zoologica Anton Dohrn, Italy) – jessica.pazzaglia@szn.it

Co-conveners: Thorsten Reusch (GEOMAR, Kiel), Lázaro Marín-Guirao (CSIC-IEO, Murcia), Isabella Provera (Stazione Zoologica Anton Dohrn)

SS10 – Bird's Eye views of Seagrassscapes
Main-conveners: Dimitris Poursanidis (Foundation for Research and Technology Hellas, Greece) – dpoursanidis@iacm.forth.gr

Co-conveners: Vassilis Papathanasiou (Fisheries Research Institute, Greece) – vpapathanasiou@inale.gr

SS011 – Seagrass observing and monitoring for the future
Main-conveners: Marlene Jahnke (Gothenburg University, Sweden) – marlene.jahnke@gu.se; Lina Mtwana Nordlund (Uppsala University, Sweden) – lina.mtwana.nordlund@geo.uu.se

Co-conveners: Emmett Duffy (Smithsonian Institution), Eduardo Infantes (Gothenburg University), Per Moksnes (Gothenburg University)

SS012 – Securing resilient and just seagrass social-ecological systems
Main-conveners: Benjamin Jones (Project Seagrass) – ben@projectseagrass.org

Co-conveners: Lucy Coals (Deakin University & Project Seagrass), Leanne Cullen-Unsworth (Project Seagrass), Jennifer Rehage (Florida International University), Lina Mtwana Nordlund (Uppsala University)

SS13 – Toward better understandings and conservation of Tropical Asian Seagrasses: Succeeding the will of Prof. Miguel D. Fortes (1947-2023)
Main-conveners: Masahiro Nakaoka (Hokkaido University, Japan) – nakaoka@fsc.hokudai.ac.jp

Co-conveners: Maria Lourdes San Diego-McGlone (University of the Philippines), Wilfredo Campos (University of the Philippines)

SS14 – Seagrass restoration
Main-conveners: Agostino Tomasello (University of Palermo, IT) – agostino.tomasello@unipa.it

Co-conveners: Salvatrice Vizzini (University of Palermo), Geraldina Signa (University of Palermo), Francesco Rende (ISPRA), Leonardo Tunesi (ISPRA), Fabio Badalamenti (CNR-IAS), Monica Montefalcone (University of Genova)

SS15 – Recurring and emerging topics in the Anthropocene (open session)
Main-conveners: Irene Olivé (Stazione Zoologica Anton Dohrn, Italy) – irene.olive@szn.it

Co-conveners: Emanuela Dattolo (Stazione Zoologica Anton Dohrn), Gabriele Procaccini (Stazione Zoologica Anton Dohrn)

First insight into the circadian regulation of the Zostera marina transcriptome under experimentally controlled light conditions

Alessia Riccardi2, Luca Ambrosino1, Marco Miralto1, Miriam Ruocco4,5, Marlene Jahnke6, Gabriele Procaccini2,7, Maria Luisa Chiusano3, Emanuela Dattolo2,7

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4 Department of Biological, Geological and Environmental Sciences, University of Bologna, Bologna, Italy.
5 Fano Marine Center, Fano, Italy
6 Department of Marine Science, Tjärnö Marine Laboratory, University of Gothenburg, S-45296 Strömstad, Sweden
7 National Biodiversity Future Centre, Palermo, Italy

Life on our planet is punctuated by biological rhythms that are driven by the cyclic variation of abiotic factors, including the celestial movements and many other geophysical processes and biological interactions. Organisms can either respond directly to these periodic variations or, often, anticipate them, taking advantage of endogenous oscillatory systems, called "circadian clocks". Circadian clocks regulate a wide variety of metabolic, developmental and behavioral processes ultimately providing fitness advantages.
Global climate changes and light pollution are threatening the biological rhythms of many species, including marine angiosperms, leaving some important ecological questions such as: is the thermal-photic mismatch affecting the physiology and the distribution of seagrasses? How does this impact seagrass ecosystem functioning?
To answer these questions, we aim to characterize the molecular basis of the circadian clock and photoperiodism in Zostera marina. To assess the effect of light alterations on gene expression, we performed time-series experiments for 48h in light-dark and free-running continuous light and then, we evaluated the cyclic genes in our datasets by using JTK_Cycle algorithm. We observed that the oscillatory profile of genes being responsible for the regulation of rhythmic processes, such as GIGANTEA and LHY-CCA1, is lost or modified in continuous light.

Comparison of multi- and single-stressor event effects on Bahamian seagrass extent and health using Earth Observation

Alina Blume1, Marie-Helene Rio1

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The wide range of ecosystem services provided by seagrasses (e.g., biodiversity preservation and carbon sequestration) is under threat due to the impact of anthropogenic and climate related stressor events on habitat extent and health. The intensity and frequency of events like Marine Heatwaves and Tropical Cyclones is continuously increased by on-going climate change, causing a combination of multiple stressors to occur over relatively short periods of time. The combined effects of these multi-stressor events are difficult to predict compared to single-stressor events.

Satellite remote sensing offers consistent large-scale data of climate variables and is a powerful tool for mapping and monitoring seagrass ecosystems. To better understand the differences in effects between stressor events, we quantified and compared seagrass ecosystem extent changes within the Bahamian shallow water area after a single-stressor (Marine Heatwave) and a multi-stressor (Marine Heatwave + Tropical Cyclone) event.

For this, we created before and after event benthic habitat maps, utilising multi-temporal Sentinel-2 imagery at 10-m resolution and auxiliary bathymetry data within the cloud computing platform Google Earth Engine. Preliminary results indicate a strong correlation between seagrass density and vulnerability and a more severe decline of meadow extent after the multi-stressor event compared to the single-stressor event.

Marine heatwaves and light limitation independently alter the growth, productivity and leaf microbiome of the tropical seagrass Halophila ovalis

Alissa Victoria Bass1, Laura Jane Falkenberg1,2, Haiwei Luo1, Benoit Thibodeau1

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Seagrasses are threatened by anthropogenic change, both climate and non-climate related. Two stressors which can have negative impacts on seagrasses and seagrass ecosystems globally are marine heatwaves (MHWs) and light reduction, i.e. 'coastal darkening'.

In this experiment, we exposed the tropical seagrass Halophila ovalis to a 10-day MHW and three light intensities to examine the impacts of these two stressors on the growth, productivity, elemental cycling and leaf microbiome of the seagrass. We found that both MHW and decreased light negatively impacted the growth of the seagrass, particularly the rhizome elongation rate, and the leaf growth rate, as well as increasing the rate of leaf loss. Similarly, chlorophyll concentration was altered by both stressors, with the normal adaptational responses to reduced light (i.e., increasing chlorophyll concentration) being inhibited by the MHW. Nitrogen assimilation rate also decreased under both MHW temperature and reduced light availability.

From these results, we show that MHWs can drive decreased productivity of seagrass, particularly when combined with low light availability. Furthermore, MHWs can reduce the ability of H. ovalis to adapt to lower light levels. Poor water clarity and habitat health can therefore increase the susceptibility of seagrasses to extreme climatic events.

Assessing the effects of anthropogenic stressors on the health and biodiversity of seagrass beds in southeast Tasmania

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Seagrass beds provide a range of essential ecosystem services such as sediment stabilisation, nutrient cycling, and serving as critical breeding, feeding and nursey grounds for associated taxa. However the determinantal effects of anthropogenic activities on water quality degradation remains the leading cause of seagrass habitat loss. Here we examined the effects of stormwater drains, position in the estuary and leaf characteristics on the health and biodiversity of Heterozostera nigricaulis and Zostera mulleri beds, in sites across southeast Tasmania. Our results showed distance to stormwater outfalls had a negative effect seagrass leaf length, above-ground biomass, below-ground biomass, and a positive influence on filamentous brown epiphyte cover and the abundance of sulphur reducing bacteria. The carbon and nitrogen stable isotope values in the sediment and seagrass rhizome showed greater influences of terrestrial and anthropogenic nutrient inputs at sites in the upper than lower estuary. Lower macrofaunal diversity was observed at sites with increased epiphyte algal cover and reduced structural complexity of seagrass leaves. Overall, these findings contribute valuable insights into the intricate dynamics of seagrass ecosystems in southeast Tasmania, emphasizing the need for holistic management strategies that consider both anthropogenic and natural factors to ensure the long-term health and resilience of these essential habitats.

Spread and impacts of Non-indigenous benthic ecosystem engineers within intertidal seagrass meadows in the context of global change

Guillaume Bernard1, Marie Fouet2, Hugues Blanchet2, Olivier Maire2, Nathalie Cail-Mily1, Florence Sanchez1, Muriel Lissardy1, Xavier de Montaudouin 2, Florian Ganthy 1, Nicolas Lavesque2, Salomé Coignard 2, Cécile Massé 3

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Arcachon bay, a coastal lagoon located in southwestern France, used to shelter one of the largest intertidal Nanozsotera noltei seagrass meadow of Europe. The lagoon also hosts oyster farming activities which contributed to the introduction of numerous non-indigenous species during the last decades. Among them, benthic ecosystem engineers such as the Asian mussel Arcuatula senhousia, the sponge Celtodoryx ciocalyptoides and the macroalgae Gracilaria vermiculophylla have established durabily, colonizing N. noltei meadows. Here, we first present the results of a combination of extensive benthic monitoring surveys and aerial habitat mapping. We thereby document both spatial and temporal increases in the presence and abundances of these species, associated with pronounced impacts on benthic community structure, especially at high ecosystem engineers' density. Futhermore, through lab experiments carried out in controlled conditions, we show that increasing densities of ecosystem engineers such as A. senhousia significantly affect benthic metabolism (oxygen and nutrient fluxes) within seagrass meadows, and that these effects are mediated by the occurrence and the intensity of atmospheric and marine heatwaves we also manipulated. These highlight the importance of understanding the interactive effects of co-occurring environmental stressors and their dependencies for a better assessment of the impacts of global change on seagrass ecosystems.

Signatures of rapid acclimation to ocean warming of the seagrass Halophila stipulacea in the Gulf of Aqaba

Hung Manh Nguyen1,2, NetaLy Lipkin1,3,4, Moran Kaminer1, Beery Yaakov2, Simon Barak2 and Gidon Winters1,5

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2French Associates Institute for Agriculture and Biotechnology of Dryland, The Jacob Blaustein Institutes for Desert Research, Ben-Gurion University of the Negev, Sede Boqer Campus, 8499000, Israel
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The occurrence of extreme warming events in the Gulf of Aqaba (GoA) may prime the seagrass Halophila stipulacea to better survive future ocean changes. To verify this hypothesis, we gathered sea surface temperature (SST) data in the GoA over the last 16 years and conducted a mesocosm experiment examining single and combined effects of ocean warming (26° vs. 32°), eutrophication (2µM vs. 20µM of NO3-) and acidification (pH8.2 vs. pH7.6). The treatments were applied for 5 weeks on two GoA H. stipulacea populations experienced different anthropogenic levels using comprehensive measurements of plant stress response. Data showed clear rises in average SSTs and extreme warming days, especially over the last five years. For both populations, plants maintained their number of shoots, growth rates and effective quantum yield when subjected to temperature and nutrient increase (single or combined), whilst the lower pH was beneficial only under combined conditions. RNA-seq transcriptome analysis revealed similar gene expression profiles in response to single and combined stressors. The plants in this study appeared more tolerant to stresses than those from the same populations in 2017 and 2019, indicating a rapid acclimation to ocean warming, which might support the future existence of H. stipulacea in the GoA

Short-term effects of in situ nutrient enrichment and interactions between the seagrass Cymodocea nodosa and the filamentous green algae Chaetomorpha linum

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Although seagrasses and macroalgae often co-exist in shallow coastal waters, bloom-forming macroalgae can outcompete and dominate over seagrasses under eutrophic conditions. Understanding the circumstances in which the presence of macroalgae exerts an impact on seagrasses can help proactive management to prevent irreversible shifts. This study investigated the combined impact of shading induced by macroalgae Chaetomorpha linum and in situ sediment nutrient enrichment on C. nodosa's ecophysiology. The two-way factorial design included algae load addition treatments (Absence vs. 90%-100% cover by C. linum) and nutrient treatments (unfertilized vs. fertilized).

Both shading imposed by C. linum and nutrient enrichment, increased the photosynthetic pigment content of C. nodosa, with the latter's effect being accentuated in the presence of C. linum. Phenol foliar content also increased with C. linum presence. Algae load addition reduced foliar protein concentration independently of nutrient levels, while fertilization's impact was only observed in the absence of C. linum. Soluble sugar content in C. nodosa leaves significantly decreased with the interaction of high fertilization and algae load. Below-ground tissue exhibited an inverse pattern, unaffected by the two treatments' interaction.

These findings imply that combined stress from nutrient enrichment and C. linum shading triggered physiological adjustments in C. nodosa. Thus, incorporating physiological traits into the monitoring program can help prevent the decline and replacement of C. nodosa meadows in shallow coastal environments.

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Insights of seagrass recovery capacity following green turtle grazing: a critical slowing down approach

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Seagrass meadows are bi-stable systems; such a system does not change visibly when approaching a critical point, but recovery is then slower after a minor disturbance, known as "critical slowing down." In the Mexican Caribbean, we studied seagrass dynamics under rotational turtle grazing. We conducted burial disturbance-recovery field experiments, and hypothesized that sustained turtle grazing (beyond normal grazing levels) would impact seagrass recovery. Experimental disturbance (10 cm burial in xx cm2 areas) in treatment plots between xx and yy m2 were applied. The treatment plots, based on time of (simulated) grazing, were: short-term (4 months of cutting), medium-term (8 months of cutting), long-term (8 months of cutting in previously grazed areas =sustained grazing). We also observed natural-recovery (for 8 months) in previously grazed areas. Recovery was highest in the unburried areas, and it diminished slightly in the buried areas of the short and medium term grazing treatments. Long-term grazing decreased recovery notoriously, and led to a significant post-disturbance loss of belowground biomass (99%). Previously grazed plots were recently abandoned by the turtles, and showed recovery, if not further disturbed. Hereby, we provide evidence of "critical slowing down" under sustained turtle grazing, and aparently, the turtles "know" when to stop grazing.

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Identifying critical thresholds and effects of land-based pollution from nutrients and pharmaceuticals on seagrass habitats and fauna

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Seagrasses ecosystems are sensitive to multiple environmental stressors, including sedimentation and nutrient loading. Recent data shows that they are also vulnerable to emergent contaminants such as pharmaceuticals. Unknown is whether pharmaceuticals are present in the seagrass itself and may be a contributing factor to seagrass decline and to transfer to ecologically and economically-important seagrass fauna. Similarly, the degree to which nutrient and pharmaceutical pollution may be correlated and show similar thresholds as a function of distance from land-based pollution sources is not known. In this study, we focus on understanding the vulnerability of seagrass ecosystems to exposure to pharmaceuticals and to the combined exposure to pharmaceuticals and nutrient pollution. We tested seagrass fauna (both prey and higher order consumers), sediment and water for 95 pharmaceuticals. All samples contained pharmaceuticals, with a maximum of 16 pharmaceutials detected in a single fish and a total of 53 pharmaceuticals detected. Further, concentrations in fauna were detected at levels with a high risk to elicit pharmacological effects. Future sampling asks: is pharmaceutical exposure correlated with nutrient exposure in seagrasses? And are distance thresholds for land-based pollutant effects similar for nutrients and pharmaceuticals?

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Dominance of heat vs. hypoosmotic stress in the tropical seagrass Thalassia testudinum

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Tropical coastlines host the world's largest seagrass meadows and face intensifying threats from marine heat waves (MHW) like the 2023 Carribean MHW, combined with freshening after precipitation extremes. Understanding the ecophysiological responses of tropical seagrasses to these interacting stressors remains limited. Here, we studied four clones of Thalassia testudinum from Bocas del Toro, Panama, propagated at GEOMAR culturing facilities since 2017. We performed a fully factorial aquarium experiment with two temperatures (control 28°C vs. HW 34°C) and two salinities (control 32 psu vs. 27 psu), fully crossed with clone affiliation. A four-week stress period preceeded a six-week recovery phase. Heat stress significantly reduced leaf growth rates (>60%), reaching a minimum at the HW end, gradually recovering to near pre-stress rates after six weeks. Leaf production shoot mortality and photosynthetic activity showed delayed minima three weeks into recovery. After six weeks two clones exhibited net shoot increase, while two faced continued net mortality, photosynthesis values recovered. Hypoosmotic stress effects were significantly smaller but added to adverse warming effects. This study emphasizes the significance of recovery time post-HW, highlighting delayed onset effects, and an interaction with clone identity. Future studies should focus on identifying resilient clones for seagrass conservation and management.

SUBTIDAL EELGRASS CAN TOLERATE HIGH SALINITY FLUCTUATIONS

Katrin Rehlmeyer1, Dindi Hiddink-Verberne1, Ellis Weinberg1,2, Roos van Dorp1,2, Hans van Veen1, Tjisse van der Heide1,3, Oscar Franken1,3, Laura Govers1, 3

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Until the 1930s, subtidal eelgrass meadows (~150 km2) thrived in the Dutch Wadden Sea but went extinct due to a wasting disease outbreak coinciding with the construction of a >30 km long dam. The dam closed off over 1800 km2 of estuary, altering hydrodynamics, tidal range, and salinity. Instead of a gradual salinity increase from estuary to sea, freshwater now enters the Wadden Sea in pulses through sluices, causing high salinity fluctuations of ~12 PSU. Donor plants are required for restoration, but the impact of the system's light regime combined with salinity fluctuations on eelgrass is unclear. In a mesocosm study, we measured morphological and physiological responses of Danish eelgrass to five salinity levels (20; 20±6; 28; 28±6; 31 PSU) and two light levels (~70; ~200 µmol photons m-2 s-1). Salinity fluctuations showed no significant effect, but a 70% light reduction resulted in a -43% decrease in shoot numbers, -44% in leaf numbers, and -42% in aboveground biomass. Our findings suggest that the targeted donor material can tolerate high salinity fluctuations in situ but may struggle with low light conditions. We thus show that controlled experiments may help identify bottlenecks for the reintroduction of seagrass in heavily altered coastal systems.

Is tropical species Halodule wrightii persistence in temperate latitudes limited by seasonal alterations in water clarity and water temperature?

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Climate change and anthropogenic impacts are resulting in increasing water temperatures and impaired water quality, resulting in shifts in seagrasses range distributions and declines. Increasing water temperatures in the northwest Atlantic Ocean, a temperate-tropical seagrass biogeographic transition zone, are contributing to declines of temperate species Zostera marina. Currently Halodule wrightii, a tropical species found in this area, is not filling the gaps left by Z. marina. This pattern is particularly evident at the meadow's deep edge, indicating that light may be a limiting factor in the expansion of H. wrightii. To determine if H. wrightii persistence at temperate latitudes in the northwest Atlantic is limited by seasonal alterations in water clarity, water temperature or their interaction, monthly H. wrightii biomass and non-structural carbohydrate metrics were paired with continuous water temperature and light attenuation measurements for 2-years. While winter temperatures were physiologically stressful (<12°C), light limitation during warmer summer periods of maximum biomass and non-structural carbohydrate storage development also limited the ability of H. wrightii to expand into gaps left by declines in Z. marina. Therefore, expansion of tropical seagrasses into temperate locations may be limited by multiple stressors including sub-optimal water temperatures and seasonal declines in light availability.

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Effects of sunscreen exposure on Posidonia oceanica (L.) Delile under an increased seawater temperature scenario

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The environmental risk of coastal susnscreen pollution and ocean warming to seagrass meadows seems to be greatly intensified in the Mediterranean basin, due to its semi-enclosed nature that limits water renewal and the high influx of tourists it receives every year. Both of these stress factors could be interacting synergistically, thus, contributing to the current decline of Posidonia oceanica meadows. Our study aimed to determine the response of P. oceanica to the combined effects of elevated seawater temperature and sunscreen addition in a short-term laboratory experiment, testing an environmentally relevant sunscreen concentration in Mallorca, Spain (20 mg L-1) and a control (0 mg L-1) with the ambient temperature in spring (15 °C) and a worst case scenario of estimated temperature increase by 2100 (ambient + 5 °C). Sunscreen addition promoted net primary production rates in the seagrass under ambient temperature, while alkaline phosphatase activity (APA) in leaves was inhibited by the sunscreen treatment under increased temperature. Early-warning signs of the impacts of combined elevated temperature with sunscreen exposure in P. oceanica were the drastical decrease in leaf chlorophyll concentrations and nitrogen fixation associated with rhizomes (more than 50% and 100%, respectively), along with greater oxidative stress biomarkers in leaves (i.e., catalase activity and polyphenols content) and APA in roots (4-fold increase).

Light and hydrogen sulfides alter the fate of inorganic carbon in the seagrass Halophila ovalis

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Seagrasses are critical global carbon sinks, yet declining at rapid pace. Phytotoxic hydrogen sulfides (H2S) and light deprivation are known drivers of seagrass loss worldwide, however, the underlying physiological mechanisms are not well understood. To address this knowledge gap, we explored the fate of inorganic carbon (Ci) in Halophila ovalis which were exposed to either low light (88% shade), ii) sediment H2S stress, or iii) the combination of both factors in a mesocosm setting. A 13C tracer (NaH13CO3) was then used to investigate differences in Ci acquisition, translocation and metabolite incorporation. Ci acquisition into seagrass leaves was impacted by both H2S and low light stress with synergistic effects occuring when both stressors were combined. Below-ground data suggest that H2S interferes with carbon translocation from the leaf into the rhizome. Incorporation of 13C into leaf sugar pools was impacted under both H2S toxicity and light deprivation. In addition, low light affected critical intermediates of both glycolysis and the tricarboxylic acid cycle. Overall, this study suggests that it is likely a multi-level (acquisition, translocation, metabolism) disruption of the carbon budget that causes a decline in seagrass health and survival under both H2S and low light stress.

Eutrophication and Global Climate changes as drivers of Marine Ecosystem Regime Shifts: The Case of the Mar Menor Lagoon

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The eutrophicated Mar Menor coastal lagoon (Mediterranean, SE of Spain) suffered a intensive phytoplankton bloom in 2015-2016 inducing the collapse of dominant macrophyte communities (the seagrass Cymodcea nodosa and the macroalgae Caulerpa prolifera). We aimed to document the subsequent evolution of benthic macrophytes and to assess the potential implications of global climate change drivers in the lagoon dystrophic crisis. We assessed changes on the distribution of benthic macrophytes over time and factors potentially drove vegetation die-off (light limitation). One year of extreme turbidity was enough to promote abrupt decline of vegetation, and only the macroalgae was able to recolonize the entire lagoon bottom seven years later. To test the contribution of global climate factors, we statistically analyzed breakpoints of decadal time series of temperature, rainfall, salinity and irradiance. They revealed that increasing trends of marine heat waves and extreme rainfall events could have been involved in the sudden lagoonal regime shift and the environmental instability of the system, that experienced recurrent episodes of extreme turbidity, low salinity and anoxia. These results support the notion that the coupled loss of ecosystem services due to local pressures and global climate change could be one of the major causes of the accelerated collapse of coastal ecosystems.

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Predicting Seagrass Responses to Multiple Stressors: A Theoretical Approach using GrassLight 3.0

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Although environmental requirements of seagrasses have been studied for years, our ability to predict seagrass response to climate change remains elusive because it is extremely difficult to separate the confounding impacts of multiple stressors through direct field observations and manipulative experiments constrained by practical limitations on treatment assortment and replication. In contrast, mechanistic models can combine observational and experimental results into a theoretical framework for efficiently exploring the simultaneous effects of multiple stressors on seagrass performance at time scales ranging from seconds to years. The numerical model GrassLight 3.0 provides an interactive computational environment for exploring impacts of the biogeochemical and physical environment on metabolic performance of seagrasses at scales ranging from whole plants to seagrass meadows distributed across the submarine landscape. By quantifying metabolic performance, the model can also quantify the density-dependent ability of seagrasses to ameliorate the impacts of ocean acidification impacts on oysters, alter water quality and promote carbon sequestration in shallow marine sediments. In addition, the theoretical insights derived from GrassLight 3.0 can be used to guide field observations, experimental manipulations involving multiple stressors and restoration efforts as we march deeper into the Anthropocene.

Influence of warming and disease on carbon metabolism and dissolved organic carbon fluxes in eelgrass (Zostera marina) communities

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Climate change and disease are two major challenges faced by seagrass systems, which play a critical role in carbon cycling and provide key ecosystem services to humans, including their contribution to blue carbon. Zostera marina (eelgrass) is increasingly affected by warming, and is also regularly infected by Labyrinthula zosterae, the causative agent of wasting disease. However, the effects of these stressors on carbon metabolism and dissolved organic carbon (DOC) fluxes in eelgrass remain unexplored. In a mesocosm experiment involving a simulated marine heat wave (MHW) followed by pathogen challenge with L. zosterae, we observed that the MHW decreased net production rate (NPR) (but did not change respiration) and DOC fluxes, being the released DOC more recalcitrant. Yet, Z. marina appears to be resilient to the heatwave, since metabolic rates and patterns of DOC fluxes recovered to control levels once the disturbance ceased. On the other hand, plants undergoing the pathogen challenge, which caused a significant decrease in aboveground biomass, exhibited significant decreases in both NPR and DOC fluxes. Our research highlights the capacity of Z. marina to contribute to blue carbon by producing recalcitrant DOC, and highlights how different stressors can impact eelgrass metabolism and DOC release.

Expected beneficial effects of high CO2 on Posidonia oceanica are dampened by acute and chronic exposure to complex volcanic fluids in a shallow vent (Panarea Island, Aeolian Archipelago, Mediterranean Sea)

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Seagrasses are expected to thrive in future acidified oceans by overcoming low CO_2 diffusion into their tissues. Much information comes from studies of naturally acidified sites such as volcanic vents. However, at such sites CO_2 emissions are often associated with toxic gases (H2S) and metal-rich fluids, allowing us to assess the response of seagrasses to complex environmental conditions. Here, we summarise the results of studies conducted at a shallow Mediterranean vent (Panarea Island, Aeolian Archipelago, Sicily, Italy) to assess the response of the long-living and slow-growing seagrass Posidonia oceanica to both acute and chronic exposure to volcanic fluids. Using a retrospective approach (i.e., lepidochronological analysis), growth performance and $\delta^{13}C$ of sheaths and rhizomes revealed a sudden and intense physiological stress following an exceptional volcanic explosion, with a complete recovery occurring after 8 years. At the same time, while persisting when exposed to chronic complex volcanic fluids, P. oceanica showed reduced performance from the leaf to the meadow level. These findings indicate that the expected beneficial effects of high CO_2 levels may be dampened by other environmental factors, and at the same time suggest the resilience and acclimatisation ability of P. oceanica under future global change scenarios.

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Identification of benthic light thresholds of Zostera marina transplants and implications for depth limits and restoration

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Eutrophication has resulted in a state change from eelgrass dominance to bare sediment in coastal areas in Denmark. This alternate steady state of the marine environment is difficult to reverse due to multiple stressors. Epiphyte growth, opportunistic macroalgae blooms, anoxia, deteriorated sediment conditions with increased resuspension frequency and reduced anchoring capacity, but most importantly decreased benthic light penetration as a result of increased phytoplankton production. Our recent study in Denmark aimed to quantify the benthic light and depth threshold that limits restoration of eelgrass. The study was conducted in the esturary Vejle Fjord, and used a field based approach using transplantations along depth gradients combined with benthic PAR-loggers. The depth gradients were placed at sites with varying eutrophication. Results suggest that the prevalence of stressors directly affect the benthic light requirements for eelgrass growth, resulting in different light thresholds depending on local stressor levels. This effect combined with the reduced light penetration have greatly reduced the depth limits of eelgrass, especially in esturaries close to point sources with high nutrient inputs. Furthermore, the study demonstrated that eelgrass transplantation is possible deeper than the current depth limits of natural populations (according to the Danish EPA), suggesting that natural recovery is lacking.

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Mapping temperate seagrass distribution by using lidar bathymetry and optical satellite imagery: furneaux island in tasmania, australia

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Mapping seagrass meadows in temperate forests has been challenged by limitations of traditional optical imagery. Light absorption in the water column and the spectral overlap between seagrass and macroalgae make accurate identification difficult. This study addresses these challenges by combining high-resolution LiDAR bathymetry with public available (e.g. Landsat 8, Sentinel-2) and commercial (e.g. Planet SuperDove) satellite optical imagery to map seagrass presence and distribution in the western Furneaux Islands, Tasmania (2082 km^2). Expert knowledge and local observations gathered through interviews were used to create training and test datasets. These datasets were integrated into Google Earth Engine and analyzed using a Random Forest classifier. The results demonstrate that combining LiDAR and optical data significantly improves seagrass mapping accuracy compared to using either data source alone. Bathymetric variables, particularly depth and rugosity, emerged as crucial factors for accurate seagrass delineation. Notably, rugosity information enabled effective differentiation between seagrass and macroalgae. This study highlights the potential of incorporating high-resolution LiDAR bathymetry to enhance seagrass mapping in temperate waters with co-occurring macroalgae. The combined approach offers a robust and scalable method for monitoring and managing these critical ecosystems.

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Temporal population dynamics of exotic macroalgae in posidonia oceanica meadows using a two decade time-series

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Seagrass meadows are threatened by global change, including the impacts of invasive species. We quantified the presence of exotic macroalgae in seagrass meadows of Posidonia oceanica (16 sites; 23 stations) around four islands of the Balearic Sea (Cabrera, Formentera, Mallorca and Menorca) for nearly two decades (2006-2023). Five species of exotic macroalgae (Acrothamnion preissii, Asparagopsis taxiformis, Caulerpa cylindracea, Halimeda incrassata, and Lophocadia lallemandii/trichoclados) were identified in the meadows during the study period. Two of these species, Lophocadia lallemandii/trichoclados and Caulerpa cylindracea were sufficiently abundant in the meadows through space and time to run site-occupancy probability models. The population of Lophocadia lallemandii/trichoclados presented a polynomial curve shape: the population growth rate increased from 2008 to 2012 and then decreased steadily until 2022. On the other hand, the population of Caulerpa cylindracea increased from 2008 to 2022 indicating it is in an initial growing phase. Understanding the population dynamics of marine invasive species is fundamental to assess their impacts and for informing management strategies to control them.

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Investigating the use of environmental dna for biomonitoring on scottish seagrass beds

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Environmental DNA (eDNA) metabarcoding is an emerging tool for the rapid detection of species using traces of DNA left by organisms in their environment and can be used to characterize the species composition and richness of habitats. As such, eDNA has been proposed as a low-cost alternative to traditional taxonomic surveys for routine biomonitoring.

This project employs eDNA metabarcoding to improve our understanding of macroinvertebrate diversity in three Scottish Zostera marina beds and compares species detected from sampling two common eDNA sources: sediment, and seawater. Additionally, the species detected using metabarcoding are benchmarked against 130 macroinvertebrate taxa collected from the same sites alongside the eDNA, enabling a direct comparison between traditional and eDNA methods for estimating species richness.

The outcomes of the project will inform best practices for future studies aiming to use eDNA metabarcoding on seagrass beds and highlight the advantages and limitations of using this method in place of traditional surveys. Furthermore, this work will support the establishment of biodiversity baselines for Scottish seagrass habitats.

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Evaluating the ecological status of posidonia oceanica meadows in calabria (south italy): a critical analysis of the prei index overestimation

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Posidonia oceanica meadows play a crucial role in supporting coastal nutrient cycles, preserving water quality, and safeguarding the region's natural heritage. As a bioindicator for coastal marine waters, P. oceanica serves as outlined in the Water Framework Directive (2000). Italy and France have adopted the Posidonia oceanica Rapid Easy Index (PREI; Gobert et al., 2009) to monitor coastal marine environments under the Marine Strategy. A study conducted in six Special Conservation Areas (SACs) along Calabria's Tyrrhenian and Ionian coasts revealed a concerning decline of up to 50% in shoot coverage and density compared to previous decades. Various stressors have been linked to this decline. Despite the observed decline, the analysis using PREI consistently indicated a "good ecological status," regardless of the density classification. This emphasizes the need to incorporate diverse descriptors and indices for the effective monitoring of Posidonia oceanica. Notably, the PREI index tends to overestimate the quality of the meadows. Additionally, this study allowed for the evaluation of phenological data and epiphytic cover across different seasons. To enhance monitoring and conservation efforts, future research should prioritize updating and integrating parameters utilized by national and regional environmental agencies.

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Paleo-records and growth performance of three Posidonia oceanica barrier reefs in the central Mediterranean Sea

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Posidonia oceanica is an endemic Mediterranean seagrass forming dense meadows from the surface to about 40 m depth. This species can develop biogenic structures called matte - terraced formations of intertwined rhizomes, roots and sediment, which allow shoots to reach the sea surface forming barrier reefs. In this work, we report paleo-records of three barrier reefs along the south and north coasts of the island of Sicily (Italy) and estimate their age and accretion rates. We complement this information with lepidochronological reconstructions of the meadows growing at their top of the reefs, aided by reference growth charts. Our goal was to gain insights into the development and growth performance of P. oceanica barrier reefs in Sicily. The reefs dated back as far as ~1200 years, presenting differences in accretion rates as estimated by radiocarbon dating at different bathymetric depths. Growth performance was variable across years and sites, but consistent with data from other meadows in the Mediterranean Sea. We found substantial differences in primary productivity and speed of growth among the meadows, a possible proxy for different environmental conditions at the three locations. This information may help future research on P. oceanica reefs and contribute to their conservation.

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The Significance of Seagrass in the Girringun Traditional Use Marine Resource Agreement Area (TUMRA): Exploring Aboriginal Custodianship, Blue Carbon, and Collaborative Research Partnerships

JADE PRYOR

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Aboriginal people in the Girringun Traditional Use Marine Resource Agreement Area have deep cultural aspirations that drive their sustainable management of turtles and dugongs. Our research strengthens the connection between seagrass habitats and the cultural heritage in the Girringun TUMRA.

Through an innovative lens, we explore new approaches to monitoring seagrass and dugong health and the emerging value of seagrasses in carbon sequestration, emphasising the potential for blue carbon initiatives to provide additional incentives for sustainable resource management. Our research has catalysed knowledge exchange, resource management innovation, and enhancing Indigenous custodianship practices by fostering inclusive approaches and new technology.

We emphasise the importance of embracing holistic perspectives that intertwine seagrass ecosystems' ecological, cultural, and economic aspects. Our research partnership has delivered an Indigenous-led framework for the many clans in the Girringun TUMRA recognises Aboriginal custodianship as integral to protecting these ecosystems. We advocate for collaborative research partnerships that empower Aboriginal people and enable healing and connection to Country.

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Caribbean carbon accounting in seagrass (caricas) – a regional network for the assessment of seagrass carbon stocks

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The capability of some coastal vegetated ecosystems to sequester CO2 and store large organic carbon stocks is drawing increasing attention as a potential means of conservation-based climate change mitigation. Despite the fact that the Caribbean region supports large expanses of seagrass meadows, information on their status, trends, and carbon density is surprising sparse. Further, evidence of widespread declines of seagrasses across the region suggest that Caribbean seagrass blue carbon stocks are at risk to add to global warming. To address these uncertainties, the CariCAS project aims to 1) build a collaborative network of Caribbean seagrass scientists interested in blue carbon and to 2) outfit local experts from the new network to collect the data needed to construct inventories of seagrass blue carbon to a depth of 1m from 72 sites across 22 Caribbean nations to understand the range, variation, and environmental correlates of seagrass C stocks. These data are combined with seagrass mapping to generate first-order estimates of the amount of C stored in seagrasses across the region.

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Long-term monitoring reveals a caribbean seagrass meadow on the verge of collapse

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Seagrasses on the Caribbean coast of Costa Rica have been monitored as part of the CARICOMP program since 1999. Over 24 years, seagrasses had periods of stability and seasonal variability. However, a marked decline in canopy complexity, biomass, and species composition has recently occurred. In 1999, seagrass canopy was dominated by the large and climax species Thalassia testudinum with mean leaf lengths of 18 cm and 10 mm widths. However, by March 2023 the canopy was instead dominated by the opportunistic species Syringodium filiforme with a length of 3 cm and width of 1 mm. Furthermore, by October 2023 the canopy was instead dominated by the pioneer species Halodule wrightii with leaf lengths of 2 cm and widths of 1 mm. Shoot density of Thalassia in 1999 was estimaated to be 1350 shoots/m2 however by 2003 it decreased to 53 shoots/m2. Biomass of Thalassia also declined from 1100 g/m2 in 1999 to only 17 g/m2 in 2023. The cause for decline at this site has been linked to excessive sea turtle grazing as opposed to a decline in water quality. This meadow is considered to be on the verge of collapse and urgent conservation and restoration efforts are needed.

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Diverging trends of coastal ecosystem extent and condition: global seagrass monitoring highlights the need for coordinated data collection at multiple scales

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Vegetated coastal ecosystems are recognized for the services they provide but are declining globally. As a result, actions to monitor, assess, and manage these systems have been taken to ensure their continued benefit to nature and people. A variety of monitoring programs have been deployed at multiple scales of observation, from estimations of areal extent to in-situ observations of local condition (e.g., cover). However, it is rare that monitoring programs observe both scales simultaneously, and it is unclear to what extent observations from both scales can be compared, integrated, or even used interchangeably in regional and global syntheses of status and trends. Here, we analyzed data from five independent seagrass monitoring programs to test for correlation and causation between observations of areal extent and local condition. We found that, generally, trends in local condition were decoupled from changes in regional extent through time, and local condition data rarely detected changes before they manifested in areal extent observations. Our findings from seagrasses suggest that a comprehensive assessment of the status and trends of coastal ecosystems necessitates observations of both habitat extent and condition, and further highlights the need for coordinated efforts and open data sharing to support future monitoring efforts globally

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As efforts to monitor seagrass health have been increasing over the past few decades, practitioners have faced challenges with acquiring substantial seagrass health data. Many of the health indices are not comparable and too numerous to choose from when monitoring a seagrass habitat. Due to these challenges, seagrass health monitoring practices lack standardization. To work towards a consensus in health monitoring methods, we examined 500 papers from the available literature (peer-reviewed journals, dissertations, reports and presentations) to quantify the most used metrics for measuring seagrass health. Using these results and data that was collected from a workshop held at the 2023 UK Seagrass Symposium, a questionnaire was compiled and distributed globally to seagrass experts. The results were compared with those from the published literature to develop a proposed list of essential methods that provide the most robust, time-sensitive, and effective data for seagrass monitoring. From these results, the lack of reproductive data was highlighted, prompting the creation of SEAFLORA (SEAgrass FLowering Observation Recording Archive), a global database for seagrass practitioners to upload observations, data and photos on sexual reproductive events which will be used to inform restoration activities and seagrass research in a changing climate.

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Keeping Our Eyes on Seagrass: A Two Prong Approach to Addressing Seagrass Loss in Florida, USA

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Florida is home to two of the largest contiguous seagrass meadows in the United States (Florida Bay, and the Nature Coast). However, the state is not immue to global trends of seagrass loss. High nutrient and sediment inputs from land run off, heat stress, and algal blooms are driving delcines in coverage statewide, including collapse of some seagrass meadows on the East coast. Regular monitoring is necessary to provide up-to-date assessments, but high costs of long-term monitoring regularly prevents seagrass conservation and restoration projects from reaching their full potential. Eyes on Seagrass proposes using citizen scientists to close data gaps, increase sampling capacity, and foster a sense of stewardship in participants. Methods executed by volunteers were designed with agency collection in mind, allowing integration with regulatory datasets. Since 2019, more than 70 sites have been surveyed annually across Florida outside of agency monitoring, a service valued nearly $100,000 USD. In addition, every participant gained knowledge of seagrass ecology and threats, with 90% implementing at least one behavior to help improve environmental conditions for seagrass meadows as a direct result of participating in surveys

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Two decades of seagrass monitoring data show global decline with warming and regionally specific drivers

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Long-term monitoring of seagrass ecosystems over large spatial scales provides insights into drivers of environmental change. We compiled twenty years of Posidonia sinuosa seagrass monitoring data (2003-2022) from 61 sites over 3° latitude from south-western Australia, a global heatwave hotspot. As sites were in marine protected areas as well as urban and highly industrialised regions, and sampling overlapped a significant heatwave event, the relative importance of global and local processes were investigated. Spatial and temporal patterns in shoot density and key environmental drivers were assessed using Hierarchical Generalised Additive Models (HGAMs). We predicted that regions with warmer temperatures and more industrialisation would have greater declines over time. Considering all data, water depth, turbidity and ocean temperature were strong predictors of seagrass condition and there was a fluctuating downward trajectory from 2002-2017 associated with ocean temperature. However, the trajectory and important environmental drivers varied regionally. Cooler regions were stable and increased temperatures in summer were a strong driver of declines in more industrialised regions. This study reinforces that responses to future climate will vary regionally and safeguarding healthy meadows as potential climate refuge sites is a valuable strategy, as well as tailoring regionally specific management and conservation actions.

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Mapping the variability in seagrass carbon stocks across the Caribbean

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Seagrasses are widely understood to provide considerable climate mitigation benefits through carbon sequestration and storage, notably in belowground biomass and sediments. However, critical science gaps remain in our understanding of seagrass carbon, and particularly around scaling up from field-data to large-scale quantification. To facilitate conservation of these ecosystems and their inclusion in policy and financial frameworks for climate mitigation, we need robust estimates of both seagrass extent and their carbon storage at national to regional scales. We attempt to address this need by mapping the variability in seagrass carbon stocks across the wider Caribbean, combining field data, high-resolution earth observation data, and machine learning. We leveraged existing high-resolution seagrass extent maps for the Caribbean by Schill et al. (2021) and training data from the Caribbean Carbon Accounting in Seagrass (CariCAS) project, supplemented by data from Smithsonian Environmental Research Center's Coastal Carbon Network. Combining the field data and expert input from the partners within the network, we identified spatially explicit environmental drivers for inclusion in our modeling. Initial predictions highlight the variability in the climate mitigation potential of seagrass ecosystems across the Caribbean, improving upon existing estimates and providing useful outputs for prioritizing conservation and natural climate solutions.

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The \kwa\, an “indicator fish sound” for ecosystem health in the seagrass meadows of the Mediterranean

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In the Mediterranean Sea, the seagrass Posidonia oceanica plays a key ecological role, and is protected by a range of legislation. Standard monitoring programmes generally focus on the plant at different spatial and short temporal scales, barely considering the organisms dependent on the ecosystem. Passive acoustics allows to non-intrusively monitor habitat condition and organism-environment relationships, particularly in dense habitats such as meadows or forests, hosting numerous cryptic species. Despite this, no studies have investigated the relationship between soundscapes of Posidonia meadows and habitat condition. This study focuses on one specific sound ubiquitous to Posidonia meadows, the /kwa/. This call is produced by Scorpaena spp. across Mediterranean Posidonia meadows. Our objective is to use recordings from 28 Western Mediterranean meadows to explore its potential as an ecosystem health indicator. We developed an acoustic index based on soundscape features of the \kwa\ and quantified its relations with environmental variables as well as established ecological health metrics. The kwa-index positively correlated with meadow density and area as well as with health metrics. This suggest that sound production is high in lush, large meadows and that the \kwa\ sound can potentially act as a health indicator in complement to standard P. oceanica monitoring metics.

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Seagrass methods videos as a path towards development of standardized protocols for seagrass essential ocean variables

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In order to bring together priority data on seagrass globally, EOVs (Essential Ocean Variables) have been developed to ensure a core set of variables are prioritized for data collection around the world. However, seagrass methodologies to collect these EOVs (seagrass occurrence, areal extent, percent cover, shoot density, canopy height) vary regionally by environmental context and objectives, and can be limited by capacity (e.g. personnel, funding). In order to build consensus around common methodologies, units of measurement and data schemas, we illustrate how the creation of training videos for seagrass methodologies can be used to co-develop generalizeable methodological approaches for data collection. Working with the Nanwakolas Council, who oversees seagrass data collection by Indigenous Guardians in British Columbia, we co-developed a process for creating training videos that are openly available for pre-field training and in-field consultation purposes. Video creation includes co-development and review of video scripts and drafts with seagrass experts and managers, and working with Guardians in the field to film videos. Video finalization includes user feedback after using them in the field. Building on this case study, we outline a framework to co-develop best practice SOP videos for seagrass methodologies nationally and globally.

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Seagrass monitoring from space: on-going activities at the European Space Agency

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Remote sensing has emerged as a powerful tool for mapping and monitoring Seagrass ecosystems, as it allows for the repeated collection of large-scale and consistent data on their extent and health. In addition to primary measurements (e.g., spatial coverage, species composition, biomass estimation), remote sensing can be used to acquire information of environmental variables influencing those ecosystems (e.g. temperature, salinity, sea-level, currents, waves, wind, etc). The objective of this presentation is to give an overview of the main results of the current projects relevant to seagrass monitoring funded within the EO4Society programme element of the European Space Agency (ESA). In particular, in the frame of the BiCOME (Biodiversity of the Coastal Ocean: Monitoring with Earth Observation) project, Sentinel-2 data have been combined with in situ observations to map seagrass taxa extent in five coastal intertidal environments in France and Portugal, and two coastal subtidal environments in Mozambique and Indonesia. Other projects focus on developing improved satellite products of the pressures threatening these precious ecosystems, as marine heatwaves (CAREHeat), acidification (Ocean-Health-Acidification), or extreme winds (MAXSS). These products, all freely and openly available to the community, are an unique dataset allowing to further monitor seagrass ecosystems in a changing environment.

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A flexible multiscale framework for mapping seagrass extent, cover and species across multiple spatial and temporal scales

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Accurate and up-to-date mapping products often form an essential part of management, conservation and restoration activities in marine and coastal ecosystems. Increasingly, more detailed seagrass mapping products are being sought, particularly for the key variables of percentage cover and species composition. However, producing detailed, fit-for-purpose mapping products for seagrass ecosystems can be a challenging and time-consuming task, particularly when end users of each application might require a different combination of the wide range of satellite image data sources, environmental data layers and training/validation data. To address this challenge, we developed a flexible mapping workflow that can be customised to provide a bottom-up mapping solution in a range of coastal environments. The framework can map different seagrass properties using various machine learning models and can incorporate any commonly available satellite imagery and environmental data. A range of common field data types can be used for training and validation. We demonstrate the method on Landsat 8 (30 m), Sentinel-2 (10 m) and Planet (3 m) satellite image data. We also demonstrate how seagrass extent can be simultaneously mapped alongside other coastal ecosystem types (mangroves, saltmarsh, tidal flats, and coral reefs) within the same framework. Examples are demonstrated for several ongoing projects globally relating to environmental ecosystem accounting, restoration, conservation planning and environmental monitoring.

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Using deep learning and aerial imagery to identify ecosystem resilience indicators from temporal and spatial patterns of seagrass meadows

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Multiple stressors have led to many tropical seagrass meadows switching from late-successional to dynamic early-successional states exhibiting widescale patchiness. Disentangling the natural seasonal dynamics to those imposed by different stressors is vital for understanding the ecosystem processes related to the patchiness and identifying indicators for when a seagrass meadow is at risk of collapsing – ecosystem resilience indicators. Integrating deep learning technologies with drone and satellite imagery has enabled us to examine both the spatial and temporal dynamics of remote Indonesian seagrass meadows over 10 years and build upon an existing mechanistic knowledge of the seagrass ecosystem. Previous experimentation displayed how a substantial turtle population intensively grazing on the seagrass meadows of the Derawan Archipelago in Indonesia stimulates meadow patchiness, which becomes further exacerbated by wave action in exposed areas. By quantifying how the spatial characteristics of meadows across Derawan have changed and the main drivers of this change, we showcase the efficacy of patchiness as an ecosystem resilience indicator for seagrass meadows. Combining a mechanistic understanding with aerial and satellite imagery, we detail how ecosystem dynamics within seagrass meadows can be disentangled to identify ecosystem resilience indicators that will aid us in protecting seagrass meadows.

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Spatially Explicit Uncertainty in Marine Remote Sensing and how to use it for model optimization

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Cloud-computing aid scientists to push the boundaries of accurate and robust Machine Learning (ML) models, processing vast spatial and temporal scales of data, and measuring Essential Ocean Variables (EOVs). However, these approaches lack spatially explicit accuracy information on their products.
By utilizing Google Earth Engine (GEE), we estimate the per pixel uncertainty (PUNC) of two ML procedures and use it for a data-driven selection of training points via bootstrapping, in an attempt to minimize the introduction of noise in the model. The ML procedures are benthic habitat classification and satellite-derived bathymetry (SDB). ESA's Sentinel-2 and Planet's PlanetScope data compose the remote sensing data of this research while the case studies are the whole optical-shallow coastal extent of Bahamas and Wakatobi (Indonesia) for the classification, and Belize for the SDB. Results indicate that the proposed method is able to slightly boost the accuracy of the procedures. In addition, User's and Producer's accuracy of seagrass class increased by at least 20%. Moreover, the insights of these produced uncertainty maps can help researchers and policy-makers in planning more effective field expeditions and decision-making, respectively.

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Establishing genetic monitoring of seagrass - an example from Sweden

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Monitoring is an essential tool for assessing biological diversity over contemporary time frames. Genetic diversity provides the foundation for biodiversity and is important for adaptation, resilience, and long-term survival. Genetic indicators that evaluate genetic diversity were recently developed and applied nationally in Sweden. Here, we present a baseline and framework for future temporal genetic monitoring of Swedish eelgrass. We investigated 15 eelgrass meadows along a steep salinity gradient along the Swedish coast with 2b-RAD sequencing as a cost-effective and reliable method for genotyping. We observed genetic differentiation with increasing spatial distance and a genetic separation between the east and west coasts. Eelgrass on the west coast had less clonality, higher genetic variation, and showed stronger population differentiation. In contrast, there was little genetic differentiation along the east coast, and clonal reproduction was frequent. The dominance of clones implies lower genetic variation, which likely negatively affects eelgrass meadows' long-term persistence in a changing climate. The genetic assessment can be used for prioritizing meadows for conservation and restoration and, most importantly, serve as an example for establishing temporal genetic monitoring for seagrass.

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Seagrass species richness and identity influence annual seagrass cover, but changes in species composition drive meadow stability

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Understanding drivers of seagrass meadow stability–or constancy of seagrass cover over time–is key to sustaining these ecosystems and the services they provide. Biodiversity-ecosystem function theory predicts that diversity promotes ecosystem functioning and stability, and previous work has shown that genetic diversity enhances resistance and resilience to disturbance in single-species meadows. However, the role of species diversity in promoting meadow stability is less clear. We investigated the effects of seagrass meadow species composition on meadow stability over time in Florida's Big Bend, a relatively undeveloped and unimpacted region that hosts extensive mixed-species meadows. We analyzed long-term (16-year) monitoring datasets that recorded annual seagrass cover at 25 sites at each of four locations. We assessed how species composition and richness affected annual cover and stability in cover over the entire monitoring period. We found that species richness and dominance by a climax species positively affected annual cover, but that changes in seagrass composition negatively impacted stability. We also found that species composition mediated changes in seagrass cover in response to disturbance events, though responses varied by site. Our findings highlight how species' tolerances to different conditions can complement one another to sustain seagrass meadow cover over time.

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The Ecological Beach model: towards a Mediterranean network for combining a more sustainable tourism with Posidonia banquette conservation

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The increasing tourism along Mediterranean seashores is often difficult to reconcile with the preservation of the coastal landscape. A case in point are Posidonia oceanica deposits (banquettes), representing a typical feature of Mediterranean beaches, nowadays perceived as an “obstacle” to tourist activities and thus removed as a waste with relevant environmental impacts. To support eco-sustainable practices, we implemented the ECOLOGICAL BEACH model encouraging the preservation of Posidonia banquettes and beach-dune ecosystems, together with education and communication activities to improve knowledge and acceptance.
Since 2020, guidelines for the application of the model have been published and several ecological beaches have been realized (e.g. Torre Flavia, San Felice Circeo, Favignana island, Marina di Ascea in Italy, Kerkennah and Madhia in Tunisia). Moreover, monitoring activities have been carried out to investigate banquettes. Meanwhile, through education and communication activities, we can engage the public and foster a sense of ownership and responsibility towards the conservation of these fragile ecosystems.
The creation of a Mediterranean Network of the Ecological Beaches is the next important step for this process to: i) facilitate the acceptance of Posidonia banquettes across the Mediterranean Sea ii) transfer sustainable management to Mediterranean beaches.

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Developing the potential of thalassia testudinum in the health sector in cuba following the nagoya protocol and the biodiversity conservation

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Seagrasses are highly valued for the goods and services they provide. Thalassia testudinum is the most important seagrass species in the Caribbean and Cuba. A potential for medicinal /pharmaceutical use of T. testudinum, while the lack of a proper legal and institutional framework and sustainable harvesting/management protocols could threaten this genetic resource. So the aims of this project are 1. To complete and implement the legal framework following the Nagoya Protocol and the ongoing introduction of a new economic model in the country; 2. Strengthening the national capacity to conclude the research-development phase of the pharmaceutical product from the species; 3. Gathering and analyzing essential information on seagrass conservation with an emphasis on the habitat and the associated biodiversity in the intervention sites; 4. To contribute to strengthening the local communities' capacity to manage and harvest genetic resources from marine biodiversity using environmentally sustainable practices. 5. To raise awareness in Cuban society about the importance of the conservation and sustainable use of genetic resources on a legal basis to foster an enabling environment to implement the Nagoya Protocol. Some of the main results about the biological aspects of the project will be presented.

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Estimating the presence and diversity of microplastics in south african seagrass meadows

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Microplastics, plastic particles <5 mm in size, are a widespread phenomenon in marine ecosystems that threaten biota and human wellbeing. Seagrasses have been hypothesised to act as natural filters of microplastics due to their particle trapping abilities, yet little is known about the extent of microplastics within the sediment of seagrass beds. The aim of this study was to evaluate and compare microplastic accumulation in the sediments of Zostera capensis meadows with adjacent bare sediments in four South African estuaries. Sediment samples were collected from two locations containing Zostera capensis meadows in the middle reaches of each estuary. Density flotation was used to separate microplastics from sediments. Microplastics were identified using a stereomicroscope and microplastic identification guidelines. Polymer analysis was conducted using Fourier Transform Infrared (FTIR) Spectroscopy. In three of the four estuaries, significantly more microplastics were found in areas of dense seagrass coverage compared to areas of bare sediment. Fibres and fragments were found to be the dominant microplastic type while blue was revealed to be the dominant microplastic colour throughout the estuaries. This study confirms the trapping ability of seagrass meadows for microplastics and highlights the need for research into the negative effects of microplastics on seagrass health.

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Developing A Seagrass Blue Carbon Project While Supporting Shellfish Aquaculture Stakeholders

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In addition to being the location of the world's largest seagrass restoration project, the Virginia Coast Reserve also supports a thriving hard clam (Mercenaria mercenaria) aquaculture industry. This industry relieves harvest pressure on wild shellfish populations and is an important part of the local economy, with landings valued at $31.9M USD in 2021. However, there is overlap in regions of subaqueous bottom that are suitable for raising clams and areas that are suitable for seagrass restoration. This talk will outline how potential use conflicts between aquaculture stakeholders and restoration projects were taken into account and managed throughout the process of developing and registering the Virginia Coast Reserve Seagrass Blue Carbon Project. Communication with the shellfish aquaculture industry has been essential in: understanding the industry's needs in the development of regulations to permit the sale of seagrass-based carbon credits, the process of defining a carbon project area, soliciting public feedback, and following the requirements of Verra's Verified Carbon Standard. Going forward, expanding our knowledge of the interactions between shellfish aquaculture and seagrass restoration may be necessary to ensure community support for the project.

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A new approach for spatio-temporal seagrass predictions at regional scales: coupling and adapting a probabilistic model of seagrass resilience and a regional ocean model

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Across scales, seagrass meadows interact with their environment and anthropogenic pressures. In a context of climate change and increasing pressures on coastal ecosystems, tools for seagrass prediction and management should be adjustable to include various pressures, capture feedbacks between seagrass and its environment, and provide uncertainty information.
To meet these objectives, we developp a new modelling approach that couples a probabilistic seagrass model with a regional ocean model on a shared spatial grid. The coupling of the two models allows us to represent bio-physical interactions, such as the seagrass-hydrodynamics-sediment-light feedback loop, and predict seagrass dynamics on multi-year scales with a reasonable computation time. Moreover, the probabilistic model, based on a Dynamic Bayesian Network, allows the implementation of new pressures and processes by mixing information from data and expert knowledge, and gives indication on the uncertainty associated to the predictions.
Our case study is the Arcachon Bay where the total area of Zostera noltei has declined by 44% between 1989 and 2019. We ran alternative model simulations to investigate the relative influence of environmental factors (light, temperature, hydrodynamics, ...) and ecological processes on seagrass dynamics (distribution, density and physiological status of plants) throughout the bay on seasonal and multi-year scales.

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Are macroalgal mats a threath to seagrass meadows? A field survey in a complex archipelago seascape

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Seagrasses are facing multiple local and global pressures. A common consequence of eutrophication is blooms of ephemeral macroalgae with mostly negative impacts on perennial seagrasses. However, it is often challenging to predict the variability in algal cover in space and time. Using dive transects we quantified the presence, coverage, thickness, biomass and species composition of benthic drifting macroalgal mats at 35 sites in the Archipelago of SW Finland. The sites differed in exposure, littoral slope, seagrass (Zostera marina) coverage, and water clarity. To assess the temporal variation in biomass and coverage, we monitored 7 sites 4-6 times throughout the season (June-October 2023). Preliminary results suggest that with the exception of the innermost archipelago sites, algal mats covered most sites visited. The mats consisted mostly of Ulva, Ectocarpus, Pylaiella and Cladophora. At 15 sites seagrass meadows was present. Using this data, we present an analysis of variables predicting the occurrence of algal mats, thus pinpointing environments where seagrass meadows may be particularly vulnerable. To conclude, a regional (250 km2) estimate of the total biomass (tonnes/km2) of algal mats in the photic zone (0-10 m), and a conceptual model of seagrass-algal mat interactions will be presented.

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Allelopathic metabolites, caulerpin and caulerpenyne: their impact on posidonia oceanica

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Lessepsian species of green algae as Caulerpa taxifolia (M. Vahl) C. Agardh, 1817, and Caulerpa cylindracea Sonder, 1845, pose potential competition against native Posidonia oceanica (L) Delile (Bouderesque and Verlaque, 2002). The aim was to evaluate the allelopathic interaction between these species, utilizing the alkaloid caulerpin and the sesquiterpene caulerpenyne purified from algae (Carbone et al, 2008). Changes in leaf growth, chlorophyll content, and leaf protein expression of P. oceanica cuttings were evaluated over a 28-day cultivation period in mesocosm (Oliva et al, 2023). Caulerpenyne demonstrated a significant inhibition of the growth of adult leaves and the formation of new leaves, while inducing the elongation of intermediate ones and increasing the total chlorophyll content. Caulerpin did not significantly influence leaf growth and the formation of new leaves. Pathways such as stress response, nitrogen (N) metabolism, lipid metabolism and antioxidation were identified among the differentially accumulated proteins common to the two treatments. Findings suggest that the competitive interaction between algae of the Caulerpa genus and P. oceanica, observed in nature, may be influenced by the allelopathic action of these two molecules, albeit with diverse mechanisms and effects.

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Threats of poor water quality to seagrass are widespread across the British Iles

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With a growing interest in seagrass restoration its important that we protect existing seagrass first and understand the threats that these systems face so that conservation action can be taken. One everlasting and recurring threat to seagrass ecosystems is poor water quality, coastal development, and poor land use. The nutrient environment of seagrasses around the British Isles has now been assessed (during 2022 and 2023) at over 60 locations by examining the nutrient content and the stable isotope signature of the leaves. Alongside a small-scale assessment in 2015 this data conforms a widescale problem of low light availability brought about by high turbidity alongside extremely elevated nutrient levels relative to global averages. Offshore and island associated seagrasses are largely healthy, however estuarine and lagoon seagrasses are subjected to very high nutrient levels that place many of these meadows close to an ecological tipping point. We found a bright spot in West and North Scotland where nutrient content and stable isotope signatures indicate refuge with low nutrient impact, but expanding aquaculture threatens these sanctuaries. Excess nitrogen is largely of an organic origin highlighting the role of agriculture and poor sewage management in the degradation of coastal water quality in this region.

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Unprecedented extended reproductive behaviour of seagrass (Posidonia oceanica) after a major heatwave

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Warming can have dramatic effects on plant phenology and reproduction, with important consequences for reproductive output, plant survivorship, or species dispersal. In seagrasses, "vegetative reproduction" through clones is generally the dominant strategy for meadow maintenance and expansion, with sexual reproduction strongly differing amongst species, being rare for some, and often associated with disturbance. Even rarer is the occurrence of pseudovivipary, an uncommon phenomenon in the plant realm, which has only been reported twice before in the marine environment as highly localized phenomena associated with environmental stress. Pseudovivipary is an asexual reproduction strategy whereby plantlets replace sexual reproductive structures, leading to the maintenance of the maternal clones. In summer of 2022 the Mediterranean Sea underwent unprecedented warming, and, associated with it, we observed pseudovivipary across numerous (>85 % of 38 sampled sites) Posidonia oceanica meadows along the Balearic Islands. This is the first time pseudovivipary is reported across so many locations in a marine angiosperm, and the fate of these plantlets is being monitored by assessing development, survivorship and dispersal through time. Considering the negative impacts that warming can have on seagrass ecosystems, the discovery of widespread pseudovivipary is a critical aspect to consider for understanding mechanisms of resilience in seagrasses.

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Can posidonia oceanica meadows change the propagation of antropogenic noise and protect animals from this emergent pollutant?

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In seagrass meadows, oxygen release in the water column (air bubbles) during photosynthesis and habitat complexity (e.g. size and shape of the meadow, shoot density, canopy height) can influence sound speed and thus the properties of sound propagation in seawater. It is unknown if seagrass meadows attenuate anthropogenic noise and act as a natural shield/protection. We investigate the potential role of Posidonia oceanica meadows in noise attenuation, the role of oxygen production and shoot density. In autumn 2020 and summer 2021, we sampled 2 meadows and nearby bare sediment in Cote d'Azur, France. We placed recorders equipped with oxygen sensors (in seagrass only) during daytime and run standardized, linear boat transects at constant speed. Using acoustic inversion of the boat passages, we estimated linear relationships between sound pressure level of boat passages and range (boat position) for 100Hz bands between 200Hz and 1500Hz. The slope of this linear relation was used as attenuation estimate. Noise propagation was reduced in meadows between 800 and 1100Hz and this was partly related to seawater oxygen concentration. We discuss how our preliminary results could open research avenues towards the consideration of seagrass meadows as refuges against anthropogenic noise pollution.

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Unexplored carbon pools and fluxes in posidonia oceanica: from primary production to necromass

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Posidonia oceanica seagrass beds are among the most complex and productive marine ecosystems. The fate their production may endure is highly variable, especially considering that most of it plays a role as necromass. Ineed, the balance between primary production and remineralization governs the cycle of these ecosystems. Once being shed from the original bed, the destination of dead biomass depends on the major driving forces acting on the bed (e.g. current regime and storms). The exported necromass leads to the formation of deposits both offshore, the neglected "maceration sites", and onshore, the "banquettes". They constitute an important carbon stock and a source for detrital food webs.
In this study, we investigated the fate of the primary production in a P. oceanica bed off the Ischia Island (Southern Italy, Tyrrhenian Sea). Three different compartments were considered: (i) the living bed, (ii) the maceration site, and (iii) the banquette.
The aim was to assess and quantify the associated carbon pools ad fluxes, using ecosystem accounting. Beside the well-known importance of the living seagrass beds, results shed light on the key role of their overlooked necromass in the blue carbon cycle.

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Human-nature relations as pathways for connecting people and seagrasses

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Worldwide, coastal areas are facing several pressures associated to human actions, which seriously compromises the functioning of these systems and the variety of ecosystem services and other nature's contributions to people they provide.
To understand the different social-ecological contexts and to drive sustainability transformations in coastal habitats, interdisciplinary cross-sectoral approaches are required together with effective communication strategies.
Here we present an initiative, started from the EuroMarine foresight workshop Pathgrass, aimed at developing and implementing social-ecological approaches in seagrass-dominated coastal systems. The Pathgrass workshop gathered a multidisciplinary research community of experts on seagrass, social-ecological systems, and social sciences to promote a collective reflection on human-seagrass connections/interactions. The Pathgrass initiative aims to i) identify (dis)connection points between human and seagrasses; ii) understand the causes of the (dis)connection; and iii) foster people-seagrasses connectedness. Further steps of this initiative will develop common conceptual frameworks and social-ecological sustainability models to be implemented in seagrass-dominated coastal systems.

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Zostera capensis: Nature based solution or band aid for chemical pollution in the Anthropocene?

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The advent of the Anthropocene is associated with many chemical pollutants entering water bodies. These include emerging contaminants (ECs) of concern such as organophosphate pesticides (OPP's) and heavy metals. Conventional treatment technology have proven ineffective for the complete elimination and removal of ECs, while half-life stability of metals allows for prolonged exposure in the environment. The aim of this research was to investigate the potential of the seagrass, Zostera capensis, as a nature based solution for chemical pollution. Zostera capensis was collected from the intertidal zone of Swartkops Estuary which is subject to industrial, agricultural and residential activities as well as the recipient of waste water effluent.
Extraction of OPP's followed by the QuEChERS method and were detected via GC-MS. Metal determinations followed acid digestion and detection with TXRF spectrometry. Bioaccumulation was found for most OPP's and metals analysed. Biota sediment accumulation (BSAF) of organophosphate pesticides and heavy metals occurred from sediment to roots and translocation of contaminants from roots to leaves was evident. The results highlight the potential for Z. capensis to be used in remediation as a nature base solution for contaminated estuaries however, it does not solve the ongoing pollution of the Swartkops Estuary.

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Oil spill effects on seagrass ecosystems: a systematic review

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Oil spills have significant impacts on seagrass ecosystems worldwide, with the extent of damage influenced by factors such as duration of exposure, oil characteristics, response time, and clean-up methods that can cause significant and lasting damage to these environments, and there is a lack of consensus on how oil spills affect seagrass habitats. This systematic review focused on identifying patterns in the response of seagrass ecosystems to oil spills. After applying the eligibility criteria, 63 studies were selected that specifically focused on the effects of oil on various aspects, such as morphophysiology, population data, fauna and microbiome associated, and plants used for bioremediation. The results indicate that petrochemical contamination indirectly affects seagrasses in subtidal meadows. In contrast, intertidal meadows suffer direct effects as the plants are exposed to direct contact with the oil and indirect effects due to the cleaning methods used. In addition, oil spills disrupt the functioning of the ecosystem, causing the mortality of organisms and cascading adverse effects. In any case, seagrasses can also be considered an alternative for the bioremediation of Polycyclic Aromatic Hydrocarbons. As a general recommendation, monitoring should begin immediately after oil spills to assess the recovery rate of seagrasses and associated communities.

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Carbon variability in UK seagrass meadows: protecting meadows for carbon benefits

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Seagrass meadows can store large quantities of organic carbon (OC) in their sediments, however, there are numerous uncertainties regarding the capacity of most seagrass beds to act as carbon sinks. These include a lack of carbon estimates from adjacent bare sediments, and a lack of replication of carbon measurements across individual beds. This study investigates the distribution of carbon across a ~4.4Ha seagrass bed in Drake's Island (UK) with the aim of informing meadow protection practices. Ten 70 cm cores were collected using a fractal design within the seagrass bed, whilst five 70 cm cores were collected from adjacent bare sediment, with increasing distance from bed edge (20-80m). Overall, seagrass cores had significantly higher OC content than adjacent bare sediment. However, high OC variability was found across the seagrass bed, with variability highest in the centre. Highest OC values were found at the edge of the bed with minimal variation between replicates. Importantly, these high OC values extended to cores from outside of the meadow, with OC% dropping below that observed within seagrass cores only after 40 m. These findings highlight the importance of considering surrounding bare sediment and spatial variability in quantifying and protecting valuable coastal carbon stores, respectively.

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Seascape configuration and connectivity shapes blue carbon stock dynamics in coastal seagrass landscapes

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Coastal seascapes comprise intricate mosaics of productive key habitats, such as seagrass meadows and other shallow-water habitats. Coastal habitat are, however, highly constrained by cumulative environmental stressors and human-induced competion for space, which affect important ecosystem services such as natural carbon sinks. To safeguard sustainable climate governance, coastal managers therefore call for appropriate spatial conservation prioritization of seagrass meadows and other coastal vegetated habitats contributing to long-term blue carbon storage. Using a multiscale seascape ecology approach, we synthesized lessons learned from studies assessing the influence of seascape configuration and connectivity on coastal blue carbon stock dynamics in seagrass meadows within the western Indian Ocean. Our research identified large continuous seagrass meadows as blue carbon hotspots. Pronounced gradients from land to sea generated distinct patterns of seagrass carbon stock dynamics and source composition. Notably, land-use changes due to urban development, deforestation, and habitat degradation in coastal seascapes were shown to alter the supply and movement patterns of carbon stored in seagrass meadows. Our research clearly demonstrates the benefits of using a seascape approach to understand blue carbon dynamics in tropical seagrass meadows, and thereby contribute to climate change mitigation.

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Accumulation of sunscreen components and the state of conservation of Posidonia oceanica seagrass meadows in a major coastal tourist destination in the Mediterranean Sea

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Coastal pollution in the anthropocence presents a challenge for seagrasses. The concern over emerging pollutants, such as organic and inorganic UV filters (UVFs) from sunscreen cosmetic products, has risen due to their potential impact on the over-all state of marine ecosystems. Their accumulation is particularly relevant in Mediterranean coasts, which are subject to a high tourism pressure during summer and can impact the health of the seagrass Posidonia oceanica, a key species in these coasts. Here, we report the accumulation of different organic and inorganic (TiO2, ZnO) UVFs in P. oceanica meadows (water column, sediment and tissues) in Formentera (Balearic Islands, Spain) and their potential impact on P. oceanica through a correlational study of their state of conservation. Ti, Zn and organic UVFs (such as ODPABA, 2OHBP, 4MBC, BP3, EHMC, EHS, HMS and Octocrylene) were found in the water column, sediment and P. oceanica tissues. Octocrylene, BP3, HMS and ODPABA in the sediments is negatively correlated with density (at 100% cover) of P. oceanica while 4-MBC in the sediments, negatively correlated with leaf length and surface area. These results, albeit preliminary, prompt for considering management schemes to protect seagrass meadows in coasts receiving significant amounts of these emerging pollutants.

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Economic valuation of restored eelgrass at the virginia coast reserve

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The eelgrass restoration project at the Virginia Coast Reserve is the largest and most successful seagrass restoration project on the planet. The planting of 240 hectares of eelgrass has expanded into over 3,600 hectares of restored meadows, which now provide significant benefits to people and nature. This works builds upon previous valuations by Abt Associates (2014) and Kerns et al. (forthcoming) by presenting an estimate for the total economic value of the restored seagrasses based on six ecosystem service flows: commercial fisheries, biodiversity, water purification, erosion control, recreational fisheries and carbon sequestration. We estimate that the seagrass restored by this project provided benefits of $82.84 per hectare per year in 2018, and that the total economic value of the seagrass beds over 50 years could reach $22.89 million with continued expansion until the maximum available ecological niche of 10,700 hectares is filled. Although carbon sequestration has the highest monetary value, over 40% of the total value comes from non-carbon benefits, with the biggest contribution being seagrass' support to recreational fishing. These results highlight the importance of blue carbon projects beyond their carbon sequestration potential, which will be critical as we face increasingly complex resource allocation decisions in environmental conservation.

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Carbon storage potential of intertidal seagrass beds in the northern Wadden Sea – grain size matters

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The Wadden Sea comprises the largest tidal flats of the world and extensive intertidal seagrass beds occur in its northern part. However, their carbon storage potential is largely unknown. Belowground burial of carbon was assessed from different locations in 4 seagrass beds. All beds are large (76 – 441 ha), with a similar cover density (60 – 80 %), species composition (dominated by Zostera noltei) and comparable age (> 90 years). The major difference is the sediment: 3 beds have established on sandy tidal flats and 1 on mud flats. Sediment cores were taken down to 45 - 65 cm depth and organic matter was measured along vertical profiles. In the sandy sediments, the permanent carbon storage was really low, with an organic carbon content below 0.4 % (average 0.22 – 0,38 %). The low content is primarily due to Zostera noltei being the dominant species which is relatively small and input to carbon storage originates mainly from internal biomass production. However, in muddy sediment the carbon content was also low but with 1.1 % about 3 times higher. Even though all tidal flat sediments are anoxic, the sandy substrates obviously allows more microbial degradation of biomass and thus more release of carbon.

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The green macroalga caulerpa prolifera constrains the natural recovery of seagrass meadows after eutrophication-induced coastal lagoon collapse

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Degradation of seagrass-based ecosystems is often associated with changes in environmental conditions that may impact on their natural recovery. Here we examine biotic and abiotic factors that may limit the natural recolonisation of Cymodocea nodosa meadows after a dramatic eutrophication-induced decline in the Mar Menor coastal lagoon. For this, we selected three meadows under different lagoon environmental conditions and used a comparative sampling approach within the surviving beds and outside them, in adjacent previously colonised bottoms. Seawater and sediment physico-chemical conditions outside the meadows are suitable for the species' growth, and surviving meadows showed full capacity to recolonise adjacent bottoms through vegetative growth and sexual reproduction. However, several years after the collapse, recolonisation is either non-existent or much slower than expected for this relatively fast-growing seagrass. The cause of this restriction is related to the large biomass the macroalga Caulerpa prolifera develops outside the meadows, as evidenced by experimental transplants with adult plants and seeds of C. nodosa. These findings are useful to inform a future restoration programme for the lagoon, currently dominated by the algae. Reducing nutrient loading and enhancing seagrass tolerance to C. prolifera canopy stress would be useful for assisted seagrass restoration in the lagoon.

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Diverse approaches to produce an integrated large scale view of seagrass ecosystems

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Detailed spatial data on marine ecosystems is critical for effective conservation and management. The urgency for this is particularly pronounced in northern Australia, a region encompassing World Heritage and Indigenous Protected Areas, urban centres, remote pristine coastlines, and developed and undeveloped catchments. The area boasts globally significant seagrass habitats, crucial for their economic (fisheries, tourism), conservation and cultural values (dugong, green turtle). While spatial data on northern Australian seagrass has been collected since the early 1980s in some areas, much of the early data was poorly curated, not publicly available, or lost. To remedy this, we undertook the monumental task of compiling and making publicly accessible 40 years of historical survey data on 14 seagrass species. This extensive dataset includes >130,000 geolocated survey sites and >1700 seagrass meadows. It provides the foundation for incorporating large-scale environmental data to model species-specific habitat suitability, identify and address knowledge gaps, and emphasizes the necessity for novel approaches and technology to map and monitor seagrass in remote areas. Our efforts force a rethink of spatial management and planning for these dynamic marine systems, laying the groundwork for informed conservation and sustainable resource management.

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Spatial Dynamics of Seagrass between 2004-2023 in Moreton Bay Australia, Provide Consideration For Global Scale Mapping of Seagrass

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Seagrasses have natural fluctuations and have seen decline through floods, coastal developments, and climate change at local to global scale. Local scale assessment over time and space under various environmental conditions will provide the basis to develop global mapping approaches. Here we provide an assessment of seagrass spatial dynamics from 2004-2023 14x at site and local scale and 4x regional scale to provide considerations for global mapping. Biannually (14x) seagrass species and cover maps were created for Eastern Banks (local scale). This by integrating +3000 photoquadrates collected biannually with coinciding high spatial resolution satellite imagery. Seagrass extended was mapped 4x for the Moreton Bay (regional scale) combining field data, expert knowledge and satellite image stacks. Annalysis at site, and local scale has shown change in species composition and reduction of seagrass cover over time partly related to flooding and highlighting presensce of persistent meadows. At regional scale seagrass extent were more challenged in mapping due to variation in water depth and clarity. The consistent repeated almost daily collection of satellite imagery globally in combination with field data, provide potential to map seagrass globally when considering the various conditions and temporal characteristics.

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Identification and characterization of flowering genes in Zostera marina

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Eelgrass (Zostera marina) is a foundation species in coastal ecosystems and is threatened by natural and anthropogenic pressures related to climate change. Eelgrass has two methods of propagation: clonal branching and sexual reproduction via flowering. Flowering and seed production in eelgrass is considered important for resilience and contributes broadly to genetic diversity. However, the molecular mechanism of flowering in eelgrass and the environmental factors contributing to flowering are so far unknown. Flowering and seed production in the model plant Arabidopsis is achieved by the expression of a specific flowering gene (florigen) which is highly conserved in flowering plants. We have identified several candidate florigen genes in Z. marina. In field studies, we observed differing expression levels of these florigen genes in flowering and vegetative tissues collected from populations in Willapa Bay, WA.

We hypothesize that one or more of these genes can serve as a molecular marker for flowering, which may enable us to predict how climate change will affect sexual reproduction. Improving our understanding of flowering in eelgrass will give insights into how populations will respond toclimate change and help inform restoration and management strategy

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Integrating Local Biotic and Continental Scale Environmental Drivers of Eelgrass Health and Resilience

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Eelgrass (Zostera marina) forms foundational habitats with new ecosystem values such as pathogen filtration, but is at-risk from environmental stressors, including climate warming and disease. Disease outbreaks of L. zosterae on the Pacific west coast are associated with both widescale environmental and local biotic factors. Recent, big declines in eelgrass meadows throughout the San Juan Islands, Washington in the Salish Sea are accompanied by continental scale outbreaks of warming-associated disease. Machine language learning, drone surveys and molecular diagnostics reveal climate impacts on disease levels from San Diego to Alaska and local scale work shows how biotic influences of both microbiome and herbivores may increase risk of disease. While long term surveys are valuable, we suggest one-time surveys of meadow health offer an additional metric for wider scale assessment of priority for future, widescale conservation efforts. Sites with the lowest disease levels provide an integrative proxy for sustainability and resilience to multiple stressors. Our approach of using disease as a measure of resilience to multiple stressors can be applied to other systems to guide conservation and management decisions.

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“Diving” into the macroecology of seagrasses: testing some rules

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While seagrasses have long been studied using a range of physiological, genetic, population-level and ecological metrics, classic biogeographical approaches, implemented for terrestrial plants, have been largely passed over for their marine counterparts. This has limited our macro-ecological and macro-evolutionary understanding of marine plants. Here, I first demonstrate that strong phylogenetic signal (the propensity of closely related species to resemble each other), and models of trait evolution, evidence Phylogenetic Niche Conservatism (PNC) for seagrasses, so close relatives live in comparable niches. This highlights the relevance of evolution from common ancestors and shared history underpinning large seagrass phylogenetic structuring. Secondly, I demonstrate that seagrasses have larger distribution ranges close to the equator in both hemispheres, supporting the inverse of the Rapoport’s biogeographical pattern. This may be attributed to their origins during warm geologic periods, and the subsequent longer climatic stability in tropical areas leading to climate niche conservatism constraining seagrass evolution.

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Exploring the resilience of Zostera noltei meadows in Cul de Loup cove Normandy, France): a multidisciplinary investigation to grasp their ecological preferences amid a changing or declining context

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Cul-de-Loup cove , located in Normandy (Manche , France is shelter ing a Zostera noltei meadow divided into few moderate area s . Since 2008, the large st Zostera noltei is declin ing thus downgrading its water framework directive report (WFD). Since 2022, several Zostera noltei areas were discovered in the cove. Seagrass meadows face numerous threats, putting at risk the multitude of benefits they offer to both humanity and biodiversity. B etter understand interactions between anthropic activities and seagrass habitats is a key to investigate coastal resilience and recovery

To study this evolution, a pluridisciplinary project (ZAPER) was recently set up in 2023 focusing on 1) spatial distribution of Zostera noltei using drones , 2) water quality from cit ies and agriculture outlet s on a bi monthly basis and from the Channel signal using a multiparameter buoy and hourly data acquisition , 3) biogeochemistry , sedimentology and meio macrofauna analysis into Z. noltei sediments using O 2 , pH and H 2 S microelectrodes followed by meiofaunal sieving , core incubation followed by macrofaunal identification and in situ sampling for the measurement of a set of biomarkers including oxidative stress responses First year results show a major faunal and biogeochemical difference s between old natural meadow and newly colonized areas. A large range of analysis and data treatment are still running to better understand th ose interactions.

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Mapping and assessing the national carbon stocks and seagrass habitat in Seychelles

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Seagrass ecosystems contribute towards climate change mitigation by sequestering carbon dioxide (CO2) from the atmosphere into long-term carbon stores. Destruction or disturbance of seagrass habitat therefore risks significant CO2 emissions. We present results from detailed satellite-based mapping of Seychelles' trained and verified usingmore than 40,000 underwater quadrats and videos. Remote sensed maps were integrated with assessments from 90 sediment cores up to 1.2m, and vegetation samples analysed using a combination of loss on ignition (LOI), elemental, and radioactive isotope techniques. Seychelles is estimated to have over 1,400 km2 of seagrass habitat comprising up to ~12 seagrass species. Meadows typically store ~118 tonnes C ha-1, yielding an estimated total stock of ~17 million tonnes COrg (~61 million tonnes CO2e). This stock is estimated as between 60 and 300 years of net carbon accumulation. Yet, the diversity and composition of seagrass meadows and their capacity of meadows to sequester and store carbon varied across anumber of environmental gradients. The work presents a pathway to include seagrass 'blue carbon' into National Greenhouse Gas Inventories (NGHGI), while emphasising the need for effective conservation and management to deliver climate mitigation and adaptation benefits and safeguarding a range of critical ecosystem services.

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Inferring seagrass meadows Blue Carbon stocks from space

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Due to their high carbon storage capacity and the risk of CO2 emissions associated to their loss, the conservation and restoration of seagrass meadows are enhanced as a way to contribute to climate change mitigation while protecting all other ecosystem services. The implementation of these (Blue Carbon) strategies is usually constrained by the lack of data on carbon stocks in seagrass meadows, added to the difficulty of monitoring the spatial and temporal trends with the accuracy needed. In this sense, remote sensing techniques could significantly increase our capacity to produce carbon inventories, report spatial and temporal variability and assess the impact of conservation and restoration projects in terms of carbon benefits. Yet, whereas remote sensing techniques have been broadly applied for terrestrial ecosystems' carbon inventories, their application for seagrass meadows is still limited. This work aimed to explore the relationship between in situ data on biomass carbon stocks from intertidal seagrass (Zostera noltti) meadows and spectral vegetation indexes derived from satellite (e.g. SENTINEL-2). This led to the development of a predictive model of seagrass biomass carbon stock that was applied to reconstruct the spatial and temporal (1985-2021) evolution of seagrass Blue Carbon in estuaries of northern Spain.

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A process-based modelling approach to assessing live above and below ground biomass: A non-intrusive way to compliment coverage monitoring.

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Seagrass meadows are important coastal habitats providing various ecosystem functions such as carbon storage, for which belowground biomass is a key indicator. Manual assessments of biomass are both laborious and time-consuming, while areal monitoring (drones, planes, satellite) can generally only provide accurate coverage for aboveground biomass estimations. Here, we explore the use of process-based mechanistic models in evaluating above- and belowground biomass distribution in eelgrass meadows. We conducted a feasibility study modelling eelgrass above- and belowground biomass in two modelling areas that cover a range of physical and environmental conditions – one in the Chesapeake Bay (USA) and a second in Danish waters (Denmark) using MIKE ECO Lab. This study demonstrates the capability of processed-based models in supporting traditional monitoring of eelgrass beds. The scalability and versatility of process-based models paves the way for using biogeochemical models as a faster and cost-effective approach to understanding and improving monitoring of eelgrass meadows. This is an important component that contributes towards understanding and managing eelgrass meadows.

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Quantifying intertidal eelgrass exposure to thermal stress along a latitudinal gradient

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In a warming ocean, seagrass meadows are increasingly vulnerable to marine heatwaves that cause physiological stress and, in some cases, large-scale diebacks. Intertidal meadows are also vulnerable to extreme atmospheric warming events that can cause mass mortality and loss of meadow area. Thermal stress can further influence seagrass resilience to other stressors, such as disease. Yet quantifying thermal stress in intertidal meadows remains challenging; temperature records from remote sensing and long-term monitoring stations do not capture exposure to peak temperatures in intertidal flats. Additionally, seagrass populations can be adapted to temperature regimes at local and regional scales, altering responses to thermal stress exposure between meadows. Here, we integrated three years of temperature records from satellites and in situ loggers to quantify exposure to thermal stress in intertidal eelgrass meadows along 23 degrees of latitude of the northeastern Pacific coast. We compared thermal stress and relief (cooling) across spatial and temporal scales to determine the localized impact of regional heating events. Results showed sustained declines in eelgrass densities at many sites and large-scale losses of meadow area following an extreme atmospheric heatwave. These results will inform our understanding of seagrass resilience to thermal stress under climate change.

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Monitoring the Seagrass Queen of the Mediterranean: Sentinel-2 for Cloud-Based Image Processing and Blue Carbon Assessment

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Seagrass ecosystems stand out as crucial organic carbon reservoirs of our planet. The endemic Mediterranean seagrass species Posidonia oceanica has the highest C sequestration (Cseq) rate among all seagrasses, being key in climate change mitigation. The Balearic Islands' coastal waters (Spain) host expansive P. oceanica meadows that have had a 40% decline over the past six decades. Thus, spatially explicit continuous monitoring is crucial for an optimized management, both for seagrass extension and blue carbon accounting. To assess them, bathymetric data is crucial, so we first developed an interpolated 10 m bathymetry snapped to the Sentinel-2 A/B (S2) grids. Using the Google Earth Engine cloud computing platform, we generated a 7-year S2 multi-temporal composite (2016-2022), and then applied a Random Forest scalable machine learning algorithm to map benthic habitats, estimating 505,6 km2 of seagrass extent, up to 30 m depth. Integrating Tier 3 in situ measurements of P. oceanica soils Cstock, we estimated 12.27 million Mg Corg. Moreover, applying derived in situ curve trends, we mapped the annual C fixation (Cfix) and Cseq rate across depth. This information can enable the development of blue carbon strategies by providing efficient, timely, and cost-effective monitoring solutions tailored to a Tier 2 scale.

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Go large or go small? Testing the predictive importance of environmental variables for genotypic richness in eelgrass meadows

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A key goal of global conservation is to preserve biodiversity, including genetic diversity as it has been shown to maintain adaptive potential and ecosystem resilience. Sexual reproduction is an important source of genetic diversity. However, some seagrass meadows may have high levels of clonality and our understanding of the factors that promote or limit sexual reproduction is still limited. One way to study patterns of sexual reproduction is to use genotypic richness, a measure of clonality. We compiled genotypic richness data from 26 published studies on 278 meadows across the Northern hemisphere to describe patterns of genotypic richness along the distributional range of Zostera marina. Across meadows, genotypic richness was, on average, high (i.e. many different genotypes were found among the sampled individuals). However, we also found meadows where only one genotype was identified. We then examined the predictive relative importance of a range of environmental variables on genotypic richness at global and regional scales. We found that light availability and temperature were the most important predictors of genotypic richness at the global scale but not necessarily within different regions. These findings emphasize the importance of considering multi-scale approaches for a better understanding of the drivers of genetic diversity.

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The role of seagrass meadows as carbon and pollutants sinks and sediment biodiversity hotspots: a metanalysis of studies that presented paired control data

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Seagrasses are amongst the most productive marine ecosystems on Earth, providing a unique habitat opportunity for many species and key ecosystem services (ES). ES, such as carbon accumulation, water purification and biodiversity support, are widely assumed, but many biological and environmental variables can determine the degree of their provision. Furthermore, studies of seagrass ES do not always provide a comparison with unvegetated areas, making it difficult to assess the difference in service provision. Here, we aimed to estimate the effect of seagrass presence on the provision of services compared to adjacent areas of bare sediment. We conducted a systematic review of three main ES related to seagrass substrate: carbon accumulation, water purification (pollutant burial) and biodiversity support, including exclusively studies that provided paired control data. We collated 5191 comparisons

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(234 publications). Most observations were concentrated on Zostera meadows and the services of carbon accumulation and biodiversity support. The meta-analysis showed that seagrass meadows play a clear role in enhancing substrate biodiversity and water purification. However, their role as organic carbon sinks depended more on local factors and meadow species composition. Our results strengthen the need of including unvegetated areas as control samples to assess the provision of ES by seagrasses.

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Social-environmental drivers of change in Indo-Pacific seagrass meadows

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Seagrass meadows provide essential services for both nature and society. Following historic declines in seagrass distribution, conservation, protection and restoration efforts are becoming increasingly critical to enable the continued supply of essential ecosystem services. While in-situ data collection on seagrasses and threats is crucial, a full-spectrum analysis of threats can be both costly and time-consuming. Alternatively, open-access data for known drivers of change in seagrass ecosystems could provide a valuable resource. However, such a dataset is not readily available, especially across the Indo-Pacific. We argue that a curated dataset that acknowledges social and ecological dimensions is required to facilitate a social-ecological system perspective in seagrass research and management. This dataset would necessitate information on diverse variables, from water temperature and salinity, to human population density and marine protection. In this study, we have compiled a social-ecological dataset, with variables that describe or act as proxies for processes that drive change in Indo-Pacific meadows. By mapping variables onto the Social-Ecological Systems framework, we structure our understanding of what data is currently openly available and highlight essential gaps for future development.

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Overcoming barriers to seagrass restoration

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In South Australia, human activities have caused large losses of seagrass meadows between 1949 and 2002, mostly in the shallow waters of Adelaide (up to 7m depth). However, over the last two decades, more than 11,000ha of Posidonia meadows are believed to have naturally recolonised these metropolitan waters – a temporal and spatial scale never witnessed before. To date, no in-water measurements have explored the mechanisms for this unprecedented recovery, which are highly relevant information for application to restoration. In this study, a multidisciplinary approach combining genomic tools and numerical simulations, was used to investigate the role of clonal and vegetative reproduction in the recovery, and the mechanisms that enabled it. Initial field surveys indicated that areas that hadn't suffered any losses appeared to be composed of dense Posidonia spp. and Amphibolis antartica meadows; while recovery sites were characterised by monospecific meadows ranging from 20 to 90% cover, of which Posidonia sinuosa was the main representative. This initial analysis also suggests no significant differences in cover among regions but possible differences associated with depth, where particularly dense and well-established P.sinuosa meadows were found in >10m depth. The findings from the genomics and modelling outputs will facilitate insights into the modes of recovery and the potential sources of the recruits.

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The interrelationship between seagrass ecosystem services

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There exists increasing interest in the use of credit systems to sell seagrass ecosystem services. Much of this interest relies on the assumption that these ecosystem services inter-relate in a positive and generally linear manner, however what we know from other ecosystem is that they don't commonly have such simplistic and positive inter-relationships. There exists only a limited understanding of these concepts in seagrass, and most studies actually quantify only one or two services at once. Here we use a unique dataset from the Zostera Experimental Network to examine the inter-relationships between multiple seagrass ecosystem services across 50 sites of Zostera marina in the Northern Hemisphere. This includes data on carbon storage, nitrogen cycling and biodiversity. Our analysis shows that some linear relationships do exist between such services but these are limited. This analysis illustrates that investments in individual seagrass ecosystem services has the ability to create unintended consequences for other parts of the system function.

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An overview of Project SeaStore in South Africa: trans-disciplinary approaches to seagrass conservation and restoration

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In South Africa, as elsewhere globally, seagrasses face continuing anthropogenic threats, with reported declines. However, seagrasses remain poorly protected and vulnerable to changing conditions and in general there are significant gaps in knowledge around seagrass biology and management. The Cape dwarf eelgrass, Zostera capensis, is the most abundant seagrass in South Africa, where it occurs in sheltered bays and estuaries. Populations are highly fragmented and occur across a strong environmental gradient straddling two diverse ocean systems. In 2019, an inter-disciplinary team initiated Project SeaStore, with the aim of filling research gaps on the ecology, evolutionary diversity and physiology of Z. capensis in southern Africa. Since then, we have made significant leaps in detailing genomic and evolutionary patterns of population structure and diversity, as well as understanding seagrass responses to thermal stress using measures of photosynthetic efficiency, that has allowed for the identification of markers for biomonitoring and assessing in situ plant performance. In addition, we have developed novel protocols for the micropropagation and tissue culture of Z. capensis, explored transplanting as a potential tool for seagrass restoration, initiated research on the impact of glyphosates and heavy metals on seagrass fitness and extended research into estimating blue carbon stores in regional meadows. This talk provides an overview of the main aims and findings of Project SeaStore, particularly towards the aim of restoring, maintaining and conserving Z. capensis in South African estuaries and discusses future research priorities essential to the long-term persistence of seagrasses in Africa.

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15 years changes of eight seagrass beds of Japan: loss of southern limit of eelgrass, earthquake, typhoon impact, decline in shallow water

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Seagrass bed surveys conducted through the long-term monitoring government project known as “Monitoring Site 1000” have been ongoing since 2008 at eight seagrass sites across six regions in Japan, spanning from sub-arctic to sub-tropical zones. We recorded seagrass coverage at sampling points, extending from the coastline to the deepest areas in each site.
This study presents a synthesis of trends in seagrass coverage over the assessment period, identifying correlated factors. A more detailed analysis explores associations between characteristic factors, including the influence of typhoons and earthquakes. Results revealed that, one study site average and 15 sampling points experienced a decrease in coverage (negative slope and $R2 < 0.2$). Conversely, one study site and 12 sampling points exhibited increased coverages over the 15-year trend. Points with decreased coverage were predominantly situated in shallower bathymetric zones, particularly in southern regions. At the presentation we will delve into specific site details, such as the disappearance of the southern limit of Zostera marina, the impact of heat through remote sensing comparisons using deep learning, and recovery post-Great East Japan Earthquake, comparison with herbivore distribution using species distribution modelling using eDNA data.

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A call for nimble approaches to address inevitable surprises in seagrass ecosystems

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Global warming has seen an increase in the frequency of pulse disturbances in seagrass meadows including storms, coastal fires and floods that by their nature are unpredictable. These events may leave strong signatures on nearshore seagrass meadows, yet, typical monitoring programs, geared to track more gradual change are not designed to measure the full extent of their impact. Based on the successes and failures of attempting to evaluate two such pulse events – storm Gloria and coastal fires – I discuss strategies for research communities to collectively address these events. Critical to any effective evaluation of their impact is the ability to quickly quantify the disturbance at appropriate ecological scales, before noticeable effects dissipate. Regional networks of collaborating research and our ability to mobilise efforts is essential to respond rapidly to these events. We need to evolve nimble approaches that adapt rapidly to region-specific impacts to collectively focus energies where they are most required. These nimble approaches need to find ways to quickly develop uniform protocols, find rapid-response funding, effectively share and analyse data, and capitalize on citizen science initiatives. Nimbleness in research and action is going to be increasingly essential to respond to the inevitable surprises of our climate change reality.

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A comprehensive assessment of flowering in Zostera marina: linking environment, phenology, and gene expression

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Sexual reproduction in Zostera marina happens seasonally. However, there is a lack of studies about its phenology, environmental drivers, and gene expression responses of populations in contrasting conditions. We took an integrative approach to address these knowledge gaps in Z. marina. We established five permanent stations in eight seagrass populations in Cape Cod between March and September 2023 (before, during and after flowering). We measured the density of reproductive shoots, environmental conditions, and sampled seagrass to study gene expression linked to flowering. Reproductive shoots started to develop in mid-to-late April when the water temperature reached 10° C, suggesting a temperature signal for the triggering of flowering. The appearance of reproductive shoots was uniform at the meadow scale. The percentage of reproductive shoots increased until mid-May, reaching a maximum of 9% of the total shoot density. Sequencing data from vegetative seagrass samples showed expression of genes leading towards flowering, and the comparison between vegetative and reproductive samples showed differential gene expression. This work sheds light on the sexual reproduction of Z. marina using a comprehensive and integrative approach, from phenology to environmental drivers to genetic apparatus, which will help to understand how flowering will be affected in a changing environment.

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The sex life of seagrasses: A global synthesis of patterns in clonality and population genetic diversity in seagrasses

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Population genetic diversity, the allelic variation among individuals in a population, can contribute to more resilient ecosystems. A better understanding of the global patterns in genetic diversity provides context for diversity found in local populations, thereby informing conservation, restoration, and management actions. We assessed global patterns in the genetic diversity of seagrasses through a systematic literature review, using commonly reported clonal and genetic diversity metrics. We assessed how these diversity metrics varied across key biological attributes: family, life history strategy and reproductive mode, and across bioregions and latitude. A total of 154 articles were found with genetic diversity data from 1622 populations, of which the majority (1483 populations) used microsatellite markers. Overall, there was a range in variability across populations with weak spatial patterns, indicating that local conditions appear to strongly influence genetic diversity. There were some significant effects of biological attributes on clonal and genetic diversity metrics. This comprehensive review is the first of its kind and questions theoretical predictions for genetic patterns in seagrasses. Our findings indicate that when incorporating genetic diversity into restoration and management actions, there is a need to collect site-specific genetic data and to understand the local conditions.

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Modes of Evolution in the Annual and Perennial Life Histories of Zostera marina (Eelgrass)

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Variation in annual and perennial life history strategies in the seagrass Zostera marina (eelgrass) is regarded as facultative and largely driven by the environment. However, we used a combination of field reciprocal transplants and population genetics analyses among annual and perennial eelgrass concurring within a single bay and found evidence for local adaptation and genetic differentiation between spatially proximate annual and perennial meadows. Because of the geographically restricted connectivity between regions where annual and perennial eelgrass coexist, it is possible that multiple evolutionary divergences have occurred between these life histories through independent and repeated selection. Here, we assessed whether parallel evolution has occurred among pairs of geographically proximate annual and perennial populations across the distribution of eelgrass using a phylogenetic framework. We aim to describe the extent to which independent lineages have arisen across the species range. Our work emphasizes the adaptive potential of life cycle variation in Z. marina, its evolutionary repeatability, and their implications for the long-term resilience of populations. These findings ultimately contribute insights into the feasibility of employing trait-based strategies (e.g. using short-lived seed-producing annuals) from locally derived populations to enhance eelgrass recovery and maintain ecosystem services in seagrass habitats.

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Forecasting Maladaptation of the Seagrass Zostera marina to Future Climates in the Baltic Sea

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Genetic diversity forms the foundation of healthy global ecosystems, but as climate change threatens these ecosystems, the ability to predict how this diversity will be impacted is crucial. To fill this gap, recently methods known as genomic offsets (GOs) have been developed, which use predictions of allele frequency variation along environmental gradients to quantify the disruption of genotype-environment associations under environmental change and thus to determine the degree of future maladaptation. This study uses GOs to characterize the degree of maladaptation of the eelgrass Zostera marina to future climates across the North Sea/Baltic Sea salinity transition zone, with the goal of predicting this species' response to climate change. Using seascape genomic data from 38 sites distributed across the Baltic, we find that future maladaptation to salinity and temperature gradients is predicted to be strongest in the Eastern Baltic. We also find that these predictions are complicated by the semi-clonal population structure observed in this species, as different treatments of clones in the data lead to large differences in the magnitude of predicted offset. Despite these differences in magnitude, these results indicate that Eastern Baltic populations of Z. marina may be at particularly high risk from the effects of climate change

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Extreme variation in the reproductive strategy of Enhalus acoroides across islands in Southeast Asia and the Western Pacific.

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Enhalus acoroides is a dioecious, large-sized seagrass species that is widely distributed across the Indo-Pacific region. Based on its strong fruit dispersal capacity and slow rhizome growth rate, it is assumed that sexual reproduction is favoured over clonal reproduction in E. acoroides. However, significant variation in reproductive strategy has recently been detected with the occurrence of large clones in eutrophied lagoons (Dierick et al., 2021). The contribution of sexual vs. asexual reproduction plays a vital role in the resilience of seagrass beds. As a result, there is a pressing need to enhance our comprehension of the reproduction strategy and dispersal capacity of E. acoroides, and the environmental drivers that control this life history trait. Here, we investigated the clonal richness, genetic diversity, and genetic connectivity in 33 populations on contrasting island situations in the Andaman Sea (Phuket), the Gulf of Thailand (Koh Samui, Koh Phangan, Phu Quoc), the Camotes Sea (Leyte), and the Western Pacific Ocean (Guam). Our results highlight strong local and regional variability in the reproductive strategy of E. acoroides, which has major implications for conservation. Strikingly, unprecedentedly high levels of clonality are found in the Western Pacific Ocean, a phenomenon previously undocumented for E. acoroides.

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Eelgrass population genomics informs meadow and epifaunal community response to rapid warming in the gulf of maine

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For seagrasses, accurate estimation of population connectivity is critical for determining species resilience to disturbance as well as identifying donor populations for restoration. The Gulf of Maine is warming rapidly, and recent marine heatwaves coincided with up to 50% loss of local eelgrass (Zostera marina) meadows. Here we pair population genomics analyses with field surveys and a lab-based temperature stress experiment to reveal how genetic and phenotypic differentiation in eelgrass populations might determine ecosystem response to rapid warming in the Gulf of Maine. Using 310,345 SNPs shared across 15 eelgrass populations ranging from Boston to northern Maine, ADMIXTURE analyse indicates strong regional differences in population ancestry although complex coastlines and currents contribute to both within-region inbreeding as well as surprising cross-region connectivity. Monthly field surveys conducted at six eelgrass populations captured varying meadow response to marine heatwave conditions in northern versus southern Maine, where southern Maine meadows failed to recover and epifaunal community identity shifted. Despite the persistence of northern eelgrass meadows in the field, in laboratory settings these meadows demonstrate a much greater sensitivity to high temperatures compared to southern populations. Genomic data, field monitoring, and population phenotyping can empower mangers with vital information for optimizing restoration success.

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Transcriptomic and photophysiological responses to thermal stress in environmentally diverse seagrass populations

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Gaining insights into the transcriptional and photophysiological responses of climatic extremes, such as marine heatwaves (MHWs), is crucial to understanding the responses of foundational species. Species distributed along an environmental cline, such as the ecologically important seagrass Zostera capensis, provide an opportunity to assess key functional gene expression and photophysiological responses to temperature effects between populations. Here we exposed two genomically divergent Z. capensis populations from contrasting thermal niches within the same system, to a simulated MHW (34 °C for three days) in a common-stress garden approach. The population locally adapted to greater thermal stress showed pre-adapted phenotypic variation in response to acute warming through activation of heat-responsive genes and molecular chaperones. Both populations showed the activation of genes involved in thermal resilience including higher photosynthetic stability and respiratory acclimation. We conclude that the different intraspecific adaptive responses exhibited in gene-expression patterns during recovery provides critical information on thermal adaptation in aquatic habitats under climatic stress. In this study we identify transcriptomic mechanisms that may facilitate intrapopulation differential resilience of Z. capensis to anomalous warming events, and propose transcriptomics as an important tool to predict the tolerance of local populations to thermal stress in the face of global climatic change.

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Temporal mating system variation and its effects on seed size in the eelgrass, Zostera marina: Implications for population maintenance and resilience

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Sexual recruitment is a driving force of genetic diversity in seagrass meadows, determining evolutionary potential and playing a critical role in ecological function. North Carolina hosts eelgrass (Zostera marina) at its southern range edge; warming temperatures have resulted in shifts to an annual life-history strategy in these populations, with increased sexual reproduction and decreased seed size. Because mating systems are correlated with genetic variation and subsequent phenotypic traits, understanding patterns of sexual recruitment is necessary to understand processes that shape genetic diversity and ecosystem function. To that end, we genotyped and measured developing seeds across the entirely of flowering eelgrass shoots in Topsail, NC. Using microsatellites, we examined individual-level mating system dynamics and their influence on seed size. Reliance on sexual recruitment was evident among shoots, and we detected temporal increases in self-pollination resulting in decreased seed size. Our findings reflect shifts in reproductive strategy, potentially due to heat stress and pollen limitation, and genetic influences on seed size. Given the key roles that genetic diversity and seed size play in enhancing meadow maintenance and resilience, disentangling the links between life-history, sexual reproduction, genetic structure, and phenotype will ultimately aid in informing the management and conservation of this valuable species.

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Assessing the relationship between sulfide intrusion, genetic diversity, and clone size in Halodule wrightii

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Genetic diversity is positively associated with a number of traits important for the maintenance of seagrass populations, while clonal reproduction has been shown to be correlated with an increased probability of survival, especially in stressful environments. We performed a study to investigate the relationship between the intrusion of hydrogen sulfide, an environmental phytotoxin, and genotypic identity, heterozygosity, and clone size in Halodule wrightii. Isotope ratio mass spectrometry (IRMS) was used to collect sulfur isotopic ($\delta^{34}S$) data, a measure of H_2S intrusion, from 143 root, rhizome, and leaf tissue samples from three locations in the western Gulf of Mexico. A series of microsatellite markers and gridded coordinates were used for genotyping, heterozygosity (Ho), and clone size estimation. While individual genotypes varied widely for tissue $\delta^{34}S$ values, and larger clones tended to show less intrusion (root $r = 0.54$, $p < 0.01$), multivariate ANOVA confirmed location to be a more important factor. Environmental factors appear to have a more significant role than genotype, clonal size, or heterozygosity in H_2S uptake and distribution.

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Exploring genetic diversity and connectivity of eastern mediterannean seagrass (Posidonia oceanica) meadows

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In times of global change, undertanding seagrass population dynamics provides insights into their adaptive potential and resilience. Here, we studied the genetic diversity, population structure, and connectivity of Posidonia oceanica meadows across the Eastern Mediterranean Sea (Aegean, Ionian and Cretan Seas, Greece) using 12 microsatellites and Lagrangian particle drift modelling. The strong genetic differentiation observed between the Ionian Sea populations and those in the Aegean and Cretan Seas suggests limited genetic exchange between them. Conversely, populations from the Aegean and Cretan Seas were characterized by high gene flow, indicative of a robust interconnected network. Notably, North Aegean Sea populations displayed the lowest genetic diversity and the highest clonality, differentiating from the rest of the populations. The genetic differentiation between the Ionian and Aegean/Cretan Seas aligns with the limited oceanographic connectivity based on seed dispersal probabilities. In the Aegean Sea, while Lagrangian simulations partially supported gene flow patterns, especially in the South Aegean, the distinctiveness of the North Aegean Sea populations can be attributed to historical events such as the Last Glacial Maximum. These genetic insights hold practical significance for management strategies, aiding the identification of management units and pinpointing potential donor sites in transplantation initiatives.

There may be more seagrass species than we think: the case of the Zostera japonica species complex

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The distribution range of the seagrass Zostera japonica covers a broad ecological amplitude from tropical to temperate, which is highly unusual for any plant.The tropical-subtropical and temperate populations showed different life history strategies and we have found a deep divergence and secondary contact between them based on sanger sequencing and microsatellite data. Here, we tested whether or not divergent ecotypes of Z. japonica represent different cryptic species. By mapping to a newly assembled chromosome-level reference genome, we obtained 2,743,659 nuclear SNPs along with chloroplast genomes for 304 ramets from 18 populations. We identified two deeply divergent genetic clades in the north and south of the distribution range (hereafter ZJ_N and ZJ_S), with hybridization at a few intermediate locations. Hybrids were either diploid F1-crosses or were triploid, while no higher-order hydrids or backcrosses were detectable. Reproductive isolation between both cryptic Z. japonica species is likely maintained by fusion of diploid and haploid gametes leading to triploidy, which is supposed to be a dead ending for any further sexual reproduction. Using Z. marina as outgroup, a time-calibrated phylogeny including the sister species Z. noltii, revealed that ZJ_N split from the clade comprising ZJ_S and Z. noltii at 6.91 MYA, while ZJ_S and Z. noltii shared the last common ancestor at 4.41 MYA. To our knowledge, this is the first time that population genomics has revealed the existence of cryptic species in a seagrass, thus seagrasses may not be so species poor as previously assumed.

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Are macrozoobenthic communities associated with Zostera noltei meadows resistant to environmental changes ?

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Seagrasses form important coastal habitats characterised by numerous ecological functions. Arcachon Bay, a lagoon located on the Atlantic coast (France), shelters Europe's largest Zostera noltei meadows (~40 km² in 2019). This habitat underwent a strong decline over the past 20 years, with -44% of its surface lost (~70 km² in 1989). Concomittantly, changes in water nutrients concentrations, primary production and biogeochemistry fluxes were also reported.
In this context, this study aims to characterise the meadows' macrozoobenthic communities responses to seagreass decline and investigates their degree of resistance and resilience. A total of 49 stations were sampled using a hand-corer (0.045 m²) in 2002 and were revisited in 2023. Macrofauna was identified at species level, sediment was characterised and Z. noltei leaves and root biomass were measured.
In our stations, leaves and root biomass decreased from 2002 to 2023, which is consistent with the global decline of Z. noltei meadows' surface in the lagoon. Diversity estimates remained stable although changes in species composition were observed. Preliminary results suggest that the benthic community facing Z. noltei meadows decline in the bay are resistant and resilient at this timescale and question the impact of habitat fragmentation on ecosystem functioning.

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Microbial driven CO2/CH4 gas flux of the intertidal seagrass Zostera noltei

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Seagrass offers great potential towards global blue carbon; sediment retention and sequestration capabilities, as well as the degradation of plant material, aid the long-term carbon storage in coastal sediments. The release of labile organic material (dead plant matter) also fuels the microbial production and oxidation of methane. Both methanogenic and methanotrophic microbes are fundamental to carbon cycling, yet are overlooked in seagrass carbon budget research. The study addresses this key knowledge gap by analysing greenhouse gas flux of the intertidal seagrass Zostera noltei, in relation to the sedimentary microbiome, across a seasonal cycle in the southern North Sea, UK. Here, CO2/CH4 flux of Z. noltei meadows and adjacent unvegetated mudflats were measured using in-situ flow-through incubation chambers and the sediment microbial communities were quantified by qPCR analysis of both taxonomic (16S rRNA) and functional (mcrA/pmoA) genes.

Preliminary data from the autumn sampling showed significantly higher uptake of CO2 from seagrass habitats compared to unvegetated mudflats. Moreover, whilst net CH4 emissions were evident from both habitat types, CH4 flux did not differ significantly between them. Further analysis is underway to link these findings to the functional microbiome. This pioneering research is of national importance to//has national implications for UK blue carbon science and natural capital markets.

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Exchange of benthic components across a diverse Zostera noltei meadow within a deteriorating or evolving ecosystem

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Seagrasses meadow s provide valuable ecosystem services play ing a key role on benthic biogeochemistry and plant sediment interactions through several biogeochemical processe s Due to large losses of seagrass meadow worldwide, studies are conducted to investigate key strateg ies for increasing coastal resilience and recovery such as restoration or natural colonization studies . In Normandy (France), Cul de Loup cove is colonized by Zostera noltei meadows , allowing us to investigate benthic biogeochemistry in two contrasted ecosystems : old and declining meadow and newly discovered The present s tudy aimed to assess how changes in seagrasses within heterogeneous Z. noltei meadow influence the spatiotemporal changes in benthic metabolism . The total benthic metabolism of the seagrass community was estimated through the total oxygen uptake (TOU) and t he effect of the presence of seagrasses on the diffusive oxygen uptake (DOU) was also assessed Cores were collected during two season s (i.e. summer and spring) and four different sites Moreover, m acro and meiofaunal analysis were conducted in the same cores allowing us to assess benthic diversity parameters. Important differences were observed based on colonization steps

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Using mutualistic interactions as a non-invasive management strategy of green turtle feeding sites

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The conservation success of the green turtle has highlighted the potentially disruptive impact of intensive grazing on seagrass-meadows. A ~5 ha meadow in Akumal Bay, Mexico has supported, for several decades, an increasing population of juvenile and sub-adult turtles that maintained feeding-ground fidelity through modification of feeding strategies, thereby bringing the meadow to the brink of collapse. An unexpected population explosion of calcareous algae (rhodoliths) discouraged turtles from feeding in areas of dense rhodoliths aggregations, allowing recovery of the climax species Thalassia testudinum, and thereby establishing a mutualistic and dynamic equilibrium among rhodoliths and turtles. In 2022, we tested whether rhodoliths can be used to control turtle feeding grounds for management purposes. Quadrants (25 & 49m2), established at sites with evidence of recent herbivory, were filled with rhodoliths that were removed from reciprocally sized plots in a mixed bed with dense rhodoliths and seagrasses. Additionally, seagrasses were clipped in another area without browsing. After five months, turtles were grazing in the rhodoliths removal and clipped plots. The turtles had stopped visiting the plots with added rhodoliths and T. testudinum was recovering. Given the expected global increase in turtles, this non-invasive method deserves attention as a conservation measure for overgrazed meadows.

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Experimental manipulation of host-associated microbes to understand their effect on seagrass performance

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There is substantial evidence from a wide variety of systems, ranging from plants to humans, that microbes play crucial roles in the performance of eukaryotic hosts. Current approaches to understanding microbial effects on hosts are mostly descriptive or focus on model hosts in unrealistic conditions. To determine effects of microbes on host performance, we need experimental approaches that (i) manipulate host-associated microbiota, (ii) disentangle microbially-mediated effects on hosts from direct effects on hosts associated with the methods employed to manipulate host-microbiota and (iii) can be implemented in the field. We examined the effectiveness of different types and/or concentrations of antimicrobials (and relevant procedural controls) on disrupting bacteria associated with roots/leaves of several Australian (e.g. Zostera muelleri, Posidonia australis) and Mediterranean (Cymodocea nodosa, P. oceanica) seagrasses. We used molecular tools to determine effects of antimicrobials on bacterial assemblage structure and abundance and assessed short-term responses of hosts to treatments via measures of photosynthetic efficiency, respiration and tissue condition. Short-term exposure to iodine (few minutes) significantly disrupted seagrass-associated bacteria, with no immediate significant effects on hosts. Thus, this method may be broadly applicable and can be used to determine microbial effects on seagrass performance in laboratory and field experiments.

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Deciphering the habitat of shallow chemosynthetic fauna in seagrass sediments: biogeochemical changes across short spatial gradients

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Seagrasses play a pivotal role as habitats for a diverse array of marine life, including sediment macro and meiofauna engaged in chemosynthetic symbiosis with bacteria capable of driving energy from reduced compounds generated during anoxic organic matter (OM) remineralization. Despite extensive studies exploring these symbiotic relationships for insights into genetic and metabolic interactions, there remains a critical knowledge gap concerning the ecology and distribution of these associations. This study addresses this gap by investigating the habitat preferences of shallow chemosynthetic fauna within seagrass sediments, with a specific focus on biogeochemical changes across short spatial gradients. Field surveys were conducted at five sites in Calabria (Italy), spanning both the Tyrrhenian and Ionian Seas. Three Posidonia oceanica and two Cymodocea nodosa meadows were examined along horizontal (meadow, edge, and outside sites) and vertical (0, 10 and 30 cm belowground) gradients.
The study assessed the diversity and distribution patterns of chemosynthetic fauna, along with other macro- and meiofauna, at each site. In situ porewater samples were collected using MacroRhizon samplers, enabling the analysis of porewater environmental chemistry, including concentrations of dissolved inorganic and organic nutrients, as well as dissolved gases. Concurrently, sediment grain size and composition were examined. To further elucidate the contribution of various OM sources to sedimentary OM, stable isotopes analyses ($\delta^{13}C$, $\delta^{15}N$, and $\delta^{34}S$) were employed. This research identifies specific biotic and abiotic factors that shape habitat suitability of chemosynthetic organisms in seagrass sediments, enhancing our understanding of their ecological preferences.

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Protective ecosystem services of seagrass meadows – supporting One Health through Nature-based Solutions

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Seagrass meadows safeguard ocean health through their protective ecosystem services. Several years ago, we described that seagrass meadows remove pathogenic bacteria from seawater and thereby prevent disease on nearby coral reefs. Such a service can potentially be used to improve seawater quality, reduce risks of disease outbreaks and protect biodiversity. Here, we will provide an overview of recent progress we made in this field and the directions we are taking for future research. And we will specifically address how seagrass meadows affect the microbiome of and effectively reduce bacterial pathogen loads in nearby and associated organisms. Understanding how seagrass meadows protect organismal and ecosystem health will allow the implementation of this ecosystem service as a Nature-based Solution to protect biodiversity and valuable marine ecosystems, to support the sustainable production of safe seafood for coastal communities, and to reduce human disease risks in coastal zones. Restoring seagrass ecosystems will thus contribute to the One Health approach to find a sustainable balance between the wellbeing of people and the health of natural ecosystems.

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Quantifying blue carbon storage in Plymouth Sound seagrass beds to support development of a Carbon Code

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This study aimed to assess sediment carbon stocks and accumulation rates of UK Zostera marina seagrass beds to support the development of a UK Seagrass Carbon Code. For the first time, this study assessed seagrass sediment carbon stocks to great depth at high resolution, to gain detailed understanding of variability with depth and insight into historical patterns. Nine 3 metre cores were collected from 3 sites across Plymouth Sound, UK, using a vibrocorer in August 2022. High resolution analysis, every 1cm, was carried out for Organic Carbon content using Elemental Analysis. A subset of samples were analysed using Loss on Ignition to compare methodologies. 210Pb dating was used to estimate sediment accumulation rates. Initial results for the Drakes Island site displayed high variability in OC content between cores and with depth (average = 4.07% OC, range = 0.25-28% OC). 2 cores displayed distinct peaks in carbon, related to the presence of coal. 210Pb results provided an estimated sedimentation rate range of 0.23-0.33 cm/yr, indicating a 3 m core to date ~1200 years. This study has demonstrated the value of high resolution analysis and highlighted methodologies important for improving our understanding of seagrass carbon stocks and their role in carbon storage.

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Plants and animals share sulfur-oxidizing symbionts in seagrass meadows

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Host-microbe associations are essential for the health of seagrass meadows. While the seagrasses themselves host specific and benefical 'microbiomes', also symbionts of co-occurring animals can benefit the seagrass ecosystem, such as the sulfur-oxidizing Thiodiazotropha endosymbionts of lucinid clams that 'detoxify' seagrass sediments. Molecular surveys are revealing members of the genus Thiodiazotropha in root and rhizome microbiomes of seagrasses, however, their relationships to clam symbionts are unknown. We used a combination of sequencing techniques to reveal the diversity of Thiodiazotropha symbionts in co-occurring lucinids and seagrass Cymodocea nodosa. In >100 clams, within-host symbiont diversity was greater than previously observed, with multiple symbiont types co-occurring regularly. These symbionts were also identified on seagrass roots in the surrounding environment along with many other Thiodiazotropha sequence variants. The environment may therefore have a greater influence on symbiont diversity than previously thought by offering a secondary niche. Using a metacommunity model, we show that the presence of a second co-occurring host type (seagrass) can increase symbiont diversity within clams. Intimate symbionts are usually highly specialized to associate with a particular host species. Thiodiaoztropha would be the first symbiont capable of intimate associations with both a plant and an animal host.

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Microbiome dynamics in restored seagrass meadows: implications for ecosystem recovery

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Seagrass meadows harbour a unique biodiversity, with many ecosystem benefits. Global attempts to restore lost meadows in order to halt the ongoing decline in seagrass area have had variable results. Root- and sediment microbiomes and their interactions may be critical for initial restoration success and the return of ecosystem services, yet their role is largely unresolved. In the SeaStore project, we used 16S- and 18S rRNA gene amplicon sequencing to track shifts in Zostera marina meadow microbiomes, one, three, and 12 months after transplanting shoots at two newly restored- and unvegetated control sites in the German Baltic Sea. Seagrass establishment was successful at both sites; shoot densities increased 25-fold after 12 months at one site. However, we found that prokaryotic communities in restored meadow sediments still resembled those of the unvegetated sediments rather than those of natural meadows, with higher abundances of anaerobic taxa in the latter. Additonally, data from a Swedish site after 6 years of restoration showed a similar pattern. This suggests that below ground recovery in restored meadows happens on longer timescales, but that prokaryotes could serve as proxies for defining long term restoration success criteria, such as return to natural meadow sediment state.

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Diatoms shape the Zostera marina leaf surface microbiome during early microbial colonization

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Seagrass leaves are rapidly colonized by microbial cells during formation and growth, similar to other submerged surfaces in marine environments. The resulting microbial biofilms are sites of intense microbial interactions, including seagrass-microbe interactions, which can have both positive and negative effects on the seagrass host. We investigated microbial colonization of leaves of Zostera marina using microscopy during a period of rapid leaf expansion. In combination, we analyzed leaf surface biofilms using amplicon sequencing, metagenomics and metaproteomics. Contrary to our expectations, electron microscopy revealed that diatoms (genus Cocconeis) were early colonizers, while bacterial colonization appeared delayed and concentrated around diatom cells. Network analysis identified bacterial taxa which distinctly cooccured with diatoms, leading to the hypothesis that these taxa are more closely associated to Cocconeis diatoms than to the seagrass itself. Analysis of metagenome-assembled genomes of these taxa indicated capacity for utilization of diatom-derived polysaccharides. Our findings suggest that other eukaryotes, such as epibiotic diatoms, strongly shape the seagrass microbiome in addition to the influence of the seagrass host. This has implications for our understanding of seagrass-microbe interactions, whose complexity may determine the outcome of fouling of seagrass leaves, a process leading to detrimental shading which threatens seagrass meadow ecosystems.

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Seagrass beds as a source of methane: a novel pathway and the effects of nutrient enrichment

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Seagrass ecosystems are recognised as potentially important carbon sinks in coastal areas, helping to mitigate climate change by absorbing carbon dioxide (CO2). However, the concurrent emission of methane (CH4), a more potent greenhouse gas, could impact their climate benefits. The factors influencing methane production in seagrass ecosystems remain unclear. Methanogenic archaea produce methane through methanogenesis and utilize three main pathways: hydrogenotrophic (using CO2), acetoclastic (using acetate), and methylotrophic (using methylated compounds). Here, we investigated these pathways in seagrass ecosystems with and without nutrient enrichment - a common stressor in coastal ecosystems. Following in situ nutrient enrichment over 75 days, seagrass cores were incubated with 13C-enriched CO2 in the dark, or over a light-dark cycle. Methane production was indicated by the transfer of the 13C tracer from 13C-CO2 to 13C-CH4. Contrary to prior findings, suggesting exclusive methylotrophic methanogenesis in seagrass, we found 13C-CH4 production in dark cores, indicating hydrogenotrophic or acetoclastic methanogenesis. Nutrient-enriched seagrass exhibited increased productivity (more O2 production), and seagrass photosynthesis in the light/dark suppressed 13C-CH4 production. However, nutrient enrichment did not affect methane fluxes. Despite anthropogenic stressors potentially amplifying climate change-contributing processes like methanogenesis, our findings suggest seagrass may act as a mitigating buffer against these impacts.

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The effect of anaerobic remineralization of the seagrass Halophila stipulacea on porewater biogeochemistry in the Gulf of Aqaba

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Seagrass meadows play a pivotal role in mitigating climate change by storing over 15% of the accumulated global carbon in the ocean's sediments. Seagrasses secret oxygen from their roots, creating microenvironments with strong and complex redox gradients that greatly affect carbon mineralization rates. Threatened by local and global stressors, seagrasses are rapidly disappearing.

To examine the effects of Halophila stipulacea disappearance on key microbial processes in sediments, we conducted a series of incubation experiments. Two types of sediments from the Gulf of Aqaba were incubated with different H. stipulacea compartments (old and young leaves, rhizomes, or roots). The chemical changes in DIC, Fe2+, H2S, SO42- were measured with time and used to calculate the remineralization rate of each seagrass compartment.

Our results show that the rhizomes decomposed the fastest, followed by the young leaves, roots, and old leaves. The slow decomposition rates of the roots could indicate the preservation potential of belowground biomass. High hydrogen sulfide concentrations were observed only in the slurries containing rhizomes and young leaves. This could lead to seagrass mortality via a positive feedback loop which generates more hydrogen sulfide. Our results demonstrate the importance of understanding the biogeochemical effect on marine sediments following seagrass disappearance.

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The role of belowground microbes in mediating heat stress in seagrasses

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Emerging evidence shows that belowground microorganisms may play a role in the performance of seagrass under environmental stress. However, we still have limited understanding of when and where these microbes matter the most.

We determined the relative importance of root- and the bulk sediment microbes on the performance of Zostera muelleri in response to a marine heatwave, a major stressor for seagrasses. A manipulative mesocosm experiment was performed involving the separate sterilization of root and bulk sediment-associated microbial communities. We show that disruption of the root microbiome decreased leaf growth under all temperature and sediment treatments. Under a +6-degree marine heatwave scenario, leaf growth was reduced but only in the presence of an intact bulk sediment microbiome, whereas under lower temperatures seagrass growth was maintained regardless of the presence/absence of an intact bulk sediment microbial community. Importantly, even in the presence of an intact root microbiome, the growth of plants was not maintained under a +6-degree marine heatwave scenario. Analysis of root and bulk sediment microbes indicated that higher temperatures were associated with a shift in the bacterial assemblage.

These results highlight the importance of understanding the interaction between seagrasses and their belowground microbiome to predict how they will respond to future environmental changes.

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The cyanobacterial assemblages in Posidonia oceanica leaf stratum: a functional approach

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Associations between Posidonia oceanica L. Delile and cyanobacteria may appear unfeasible, because the plant -a foundational seagrass in coastal Mediterranean ecosystems- achieves high abundances at low concentrations of dissolved inorganic nitrogen, while cyanobacteria are well adapted in eutrophic and nutrient-rich environments. However, several microbial taxa were identified associated to the seagrass environments, and they are important to nutrient cycling, including microbes capable of nitrogen fixation, ammonification and sulfur oxidation. While the host-microbe interactions are still scarcely investigated, populations of many marine macrophytes are in decline and this topic could be important to characterize key chemical interactions. To this end, 12 cyanobacteria strains were isolated from leaves of Posidonia oceanica in the Bay of Naples and cultured in axenic conditions. The strains were identified by means of a polyphasic approach. The remarkable diversity of the cyanobacterial microbiome associated to P. oceanica, here described for the first time, was related to their well-known ability to produce allochemical compounds, released in the environment to increase their competition for space. Their toxigenic power was tested on sea urchin embryos and most strains demonstrated low toxicity. This characterization explains the success of cyanobacteria in a peculiar environment characterized by high competition for space and resources.

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Facilitation or competition between Thalassia testudinum and Caulerpa paspaloides in a seagrass meadow?

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Interactions between seagrasses and macroalgae have been defined as competitive relationships since they use similar nutrients, space, and sunlight. The objective was to analyze the interaction between T. testudinum and C. paspaloides using population models, as well as physicochemical and photosynthetic performance indicators. The monitoring was done at “Los Petenes” Biosphere reserve in three different meadows: monospecific of T. testudinum or C. paspaloides and mixed meadows having both species. Data was taken in the dry, rainy and “nortes” seasons from 2016 to 2019. Thalassia testudinum and C. paspaloides biomass (g/m2), photosynthetic efficiency (Fv/Fm), physicochemical parameters (sediment and column water nutrients, depth, light at bottom (%) temperature, pH, salinity, type of sediment and organic matter for each meadow type. The most important factors in the PCA were depth, bottom light (%), presence of macroalgae, biomass and Fv/Fm of both species and the second component with factors temperature, pore-water phosphorous, and dissolved inorganic nitrogen (DIN). Fitness was higher in monospecific meadows for both species than in mixed meadows, due the absence of other species. However, monospecific meadows of C. paspaloides had higher mortality in the norte season. Coexistence seems to have a detrimental effect on the performance of T. testudinum.

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Photorespiration in Zostera marina: Ecological Implications

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Photorespiration in plants is usually described as a wasteful process, resulting in CO2 being released back to the surroundings while O2 is consumed. Although most marine macrophytes repress photorespiration by possessing a well-developed CO2-concentrating mechanism (CCM), Zostera marina has been found to photorespire under conditions of high O2, combined with low dissolved inorganic carbon (Ci), concentrations. Such conditions can typically form in shallow bays where e.g. the widely distributed and prolific macroalga Ulva spp. can raise the seawater pH to ~10 during the day, thus lowering both CO2 and HCO3- concentrations significantly. Under such high-pH conditions, the photosynthetic (and, consequently, growth) rates of Zostera marina can be significantly inhibited. (On the other hand, photorespiration can be used as a “safety valve” for dissipating excess light energy.) In summary, there is a need to take photorespiratory losses into account when modeling the photosynthetic performance and productivity of (at least) temperate seagrasses, especially when growing interactively with highly productive macroalgae.

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Seagrass – lucinid clams interactions and their role in DMSP cycling

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The antistress compound dimethyl sulfoniopropionate (DMSP) and its gaseous metabolite dimethyl sulfide (DMS) are abundant marine nutrients, signalling molecules, and essential components of the global sulfur cycle with roles in climate regulation. Seagrasses produce exceptionally high intracellular DMSP levels which can serve to recruit and feed specific microbial communities resulting in further sulfur biotransformations, e.g., to dimethylsulfoxide (DMSO). These sediments are also home to lucinid clams, which host chemosynthetic sulfur-oxidising bacteria in their gills that can respire DMSO to DMS. This study investigates the role of the interaction between seagrasses (Cymodocea nodosa and Zostera noltii), their holobiome and lucinid clams (Loripes orbiculatus) in DMSP production and cycling in vegetated coastal sediments. Samples of L. orbiculatus, C. nodosa, Z. noltii, and sediments (with their microbial communities) will be collected in Piran, Slovenia. They will then be incubated in cores with different combinations of the three partners. We will quantify DMSP standing stocks in each partner – sediment microbiota, clams, and seagrass – and evaluate the contribution of each to DMS/P production. We will relate these fluxes to the diversity of the microbiota and to sediment porewater chemistry. This study will further our understanding of DMSP cycling and DMS emissions in vegetated coastal sediments.

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SS07 - Macro-micro interactions in seagrass ecosystems

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Diazotrophy in the seagrass rhizosphere - the potential role of rhizobia?

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Seagrasses can enhance nutrient mobilization in their rhizosphere via complex interactions with sediment redox conditions and microbial populations. Yet, limited knowledge exists on how rhizosphere dynamics affect nitrogen cycling. Using high-resolution chemical imaging, we show that radial O2 loss (ROL) from rhizomes and roots leads to formation of redox gradients around below-ground tissues of seagrass (Zostera marina), which are co-localised with regions of high ammonium concentrations in the rhizosphere. Utilizing chemical imaging in concert with fine-scale sampling for microbial community and gene expression analyses, we showed that multiple biogeochemical pathways and microbial players contribute to the high ammonium concentration within the oxidized regions of the seagrass rhizosphere. Bradyrhizobium (symbiotic N2-fixing bacteria) were particularly abundant and expressed the diazotroph functional marker gene nifH in rhizosphere areas with high ammonium concentrations. Such potential mutualistic association between Z. marina and Bradyrhizobium can facilitate ammonium accumulation, the preferred nitrogen source for seagrasses, enhancing seagrass productivity and performance within especially nitrogen-limited environments. ROL also caused strong gradients of sulphide at oxic/anoxic interfaces in rhizosphere areas, where we found enhanced nifH transcription by sulphate-reducing bacteria. ROL from below-ground tissues of seagrass thus seems crucial for ammonium production in the rhizosphere via stimulation of multiple diazotrophic associations

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Exploring the epiphytic bacterial and fungal communities associated with the Posidonia oceanica in a changing environment

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Seagrasses and associated microbial communities constitute a functional unit, called holobiont, which responds as a whole to environmental changes. Shifts in the seagrass associated microbial communities may occur as a response to both environmental changes and to specific morphological and biochemical adjustments occuring in seagrass in response to environmental gradients, and in parallel, the ease microbial shifts can contribute to host's health and capacity to withstand environmental changes. Integrated assessments of seagrass ecophysiology and microbial community structure can consequently help to understand the capacity of the 'holobiont' to persist and adapt, but also be used as an early warning indicator of seagrass stress. Posidonia oceanica is known to harbor diverse epiphytic bacterial communities, while its mycobiome still remains poorly understood.
In this study, we employed a multidisciplinary approach to investigate changes in the morphology, biochemistry and epiphytic microbial community structure (bacteria and fungi) of P. oceanica in Akrotiri bay (Cyprus, Eastern Mediterranean Sea), including: i) a coastal site close to Limassol Port, and ii) the underwater archaeological site at Amathous. The composition or structure of P. oceanica microbial communities reflected the specific biochemical or morphological condition of the meadows, providing a baseline for understanding the P. oceanica microbiome and supporting its potential use as a seagrass descriptor.

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Seed and sediment microbiomes influence the germination of seagrass seeds

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Seagrasses are the only flowering plants that produce seeds in the marine environment, forming vast meadows crucial for important ecosystem services. Over the past decades, seagrass cover has declined in many places, and re-colonization is slow. Despite clonal growth, the recruitment of seagrasses from seeds is essential for maintaining genetic diversity and facilitating dispersal. While the seed microbiome of several terrestrial plants has been shown to influence germination and seedling survival, the microbiome of seagrass seeds has received limited attention.
To investigate the effects of the microbiome on seagrass seed germination and seedling development, we manipulated the microbiome of Zostera marina seeds and sediments and conducted a germination experiment. We found three times higher germination rates for seeds with intact natural microbiomes incubated in sterilized sediments compared to sterilized seeds incubated in native sediments. By comparing microbial communities (assessed via 16S and 18S rRNA gene amplicons) in the treatments, as well as in field-sampled material, we conclude that seagrass seeds have a microbiome distinct from other plant parts, featuring several potentially plant growth-promoting taxa. This microbiome is likely critical in germination and establishment of healthy seedlings, a prerequisite for recovery and restoration of seagrass ecosystems worldwide

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The composition and functional potential of growth Promoting bacteria within the seagrass rhizosphere

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Globally, seagrass meadows are in decline due to the combined impacts of climate change and human activities. Although current restoration of seagrasses aim to mitigate meadow decline, success rates are often low. One promising approach towards enhancing seagrass growth is the application of plant growth promoting (PGP) bacteria.
Here, we aimed to explore the potential of seagrass-associated microbes to promote plant growth. Based on work from agriculture systems and seagrass biology, we anticipated to find bacteria associated with the seagrass that promote plant health and growth by providing them with essential nutrients, detoxifying sediments, and stimulating root growth. To this end, we isolated over 400 bacteria from the rhizosphere, rhizoplane and endosphere of the seagrass Zostera marina. Using a series of physiological assays, we found that a large portion of PGP bacteria produce phytohormones, fix nitrogen, oxidize sulfur and solubilize phosphorus. Our in-depth genomic analysis enabled us to further explore the functional potential of selected PGP bacteria, including the identification of novel isolates and unknown microbial traits that likely benefit seagrass health. By isolating and characterizing these putative PGP bacteria, we have the ability to develop new microbial approaches towards enhancing plant growth and impacting the success of seagrass restoration.

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Partners for Life - Understanding Microbiome Assembly and Function Throughout Eelgrass Development and Establishment

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The microbiome is a dynamic “organ”, shifting in its community composition and function as the host develops and responds to its environment. Here, we present the microbiome assembly of Zostera marina as it develops from seed to juvenile seedling and how that compares to microbiomes of established eelgrass meadows during seasonal shifts in northern CA, USA. Using 16S rRNA gene amplicon sequencing and metagenomics, we show microbial community composition and functional patterns - highlighting key microbes and their roles that are important in Z. marina development. We also present the results of laboratory experiments testing the role of bacterial volatiles in combating seagrass wasting disease and describe the usage of the EcoFAB 2.0 for lab controlled seagrass seedling microcosms. We discuss how our findings can develop microbes as indicators for eelgrass meadow health and potential tools for meadow restoration.

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Use of probiotics to stimulate the success of seagrass restoration

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Seagrass meadows are globally declining due to anthropogenic stressors. Therefore, urgent restoration efforts are required to recover and expand these crucial ecosystems. In the last decades, the role and importance of the seagrass microbiome has gained more attention. As soil bacteria have been leveraged to enhance crop productivity for many years, growth-promoting bacteria are now proposed as a tool for improving seagrass health and recovery. This project investigates the role of the microbiome in seagrass health, growth, and resilience. We aim to identify and characterize novel and known bacterial isolates to expand the list of putative beneficial microbes associated with seagrass roots. These can be used as probiotics to facilitate seed viability, stimulate the health and growth of transplanted seagrass shoots, and thus promote the success of seagrass restoration. We determined the microbial diversity on all vegetative parts of the seagrass Ruppia maritima and isolated bacteria from five marine macrophyte root systems. These bacteria were barcoded using the total 16S rRNA region. Subsequently, we performed whole genome sequencing on a selected set of isolates and tested their role in germination and early-stage development of R. maritima seeds in a laboratory experiment with Bacilli sp. increasing both germination and growth.

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Eelgrass resistance to a marine heat wave correlates with having flexible leaf microbiomes while maintaining root microbiome composition

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Microbiomes, fixed differences among individuals and plasticity all affect organism responses, but separating direct and indirect or interative effects among these factors remains a challenge. Here we examine the extent of genotype by environment interactions of Zostera's microbiome assembly to begin revealinig the potential role of a host's microbiome in mediating its response to environmental stress. We exposed paired eelgrass genotypes to either ambient temperatures or a 5-week marine heat wave for one growing season and measured eelgrass performance and characterized the root and leaf microbiome before, during and after the experimental heat wave. On the host level, marine heat wave exposure drive a shift in rank order of genotype performance indicating variation among genotypes in response to temperature. On the microbiome level, leaf and root microbial communities differ in the extent of genotype by environmental drivers of their community assembly over time. Regressing differences in host performance to changes in microbial composition across treatment reveals resilient genotypes have high leaf microbiome flexibility and constant root microbiomes while the opposite is present for low-ranking genotypes. These results suggest resilient plant genotypes may be assemblinig the appropriate microbial communities, relying on these shifts as means of coping during periods of stress.

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Carbon stocks and microbial communities from a Welsh Zostera Noltii meadow

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Studies on the microbial role in carbon cycling within seagrass sediments are still in their infancy. However, following important developments in molecular biology research, the importance of marine microbes to ocean processes has been gaining traction. This study aimed to analyse carbon sources and stocks from a Zostera noltii intertidal meadow in Porthdinllaen, on the north coast of the Llyn Peninsula in north Wales, examining stocks from seagrass sediments and leaf biomass, as well as sediment from points adjacent to the meadow. In addition, microbial communities have also been identified for all three groups, to provide a better understanding of the interaction between microbiome and carbon cycling. Seagrass seeds from this site have been harvested to be used in large seagrass restoration projects in the UK, highlighting the importance of fully understanding the mechanisms that enable these ecosystems to act as important carbon sinks.

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SS08 - Seagrass Microbe Interactions – Harnessing the Microbiome

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Role of rhizosphere microbiota in controlling seagrass response to environmental stressors

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Increasing the resilience of seagrass ecosystems and enhancing restoration outcomes requires knowledge of the processes that determine seagrass performance. Towards this end, resolving how below-ground microbial communities influence seagrass performance is acknowledged as a key knowledge gap. Molecular studies indicate the seagrass rhizosphere houses microbial taxa and functional groups that putatively benefit seagrass performance. We still, however, have little understanding of how plants control rhizosphere communities when under stress and when those microbial communities provide the most benefit to the host plant. Employing methods we developed for removing microbiota from the seagrass rhizosphere, our overall aim was to experimentally test how rhizosphere microbial communities respond to and control seagrass response to key environmental stressors. We used a combination of both field and lab experiments in which we exposed plants that had intact and disrupted microbial communities to different stressors. Overall, we showed that seagrass plants perform better with an intact microbial community, with the benefits increasing with increasing nutrient stress. We also showed that above-ground biomass removal (simulating processes such as herbivory or mechanical disturbances) can lead to changes to rhizosphere communities. Thus, seagrass rhizosphere microbial communities 1) respond to environmental stressors and 2) can control plant responses to environmental stress.

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Seagrass wanted dead or alive: A call for global collaboration in uncovering the diversity and pathogenic potential of phytomyxid parasites in seagrass meadows

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Phytomyxid parasites (Rhizaria: Endomyxa: Phytomyxea) are obligate intracellular biotrophic protists infamous for infecting various crops of great economic significance. They also represent one of the three groups of microorganisms generally recognized as parasites of seagrasses. Based on observations reported in the 20th century, three phytomyxid species were formerly thought to be responsible for morphological deformations in three different seagrass genera – Halophila, dwarf Zostera species and Halodule. However, our current research suggests that phytomyxid infections can be found in numerous other seagrass taxa and the diversity of these parasites is significantly greater than previously anticipated. Our molecular analyses of the rRNA phylogenetic markers show that seagrass-associated phytomyxids have likely co-evolved with their hosts and are highly host-specific. Furthermore, despite being historically perceived as extremely scarce in the marine environment, we recently revealed that phytomyxids parasitizing Zostera marina are in fact one of the most predominant eukaryotes in eelgrass beds on a global scale, and can be found in the roots of >99% of Z. marina plants. Given the clearly understudied ecological significance (and/or pathogenic potential) of Phytomyxea in seagrass meadows worldwide, we call for international collaboration aimed at uncovering the diversity of these protists – SEAGRASS WANTED!

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Study of the influence of microbiomes on seed germination and development in the seagrass Cymodocea nodosa

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Marine macrophyte ecosystems are considered as a fundamental habitat throughout the world. The continuous increase in anthropogenic activity and global change pressures that seriously threaten these habitats, has led to an increased interest in assessing different factors that may promote their resilience.
In seagrasses, firsts life stages can be critical when determining the natural recovery of the ecosystem. In this sense, identifying the factors that positively influence the development and establishment of these early stages is essential for ecosystem conservation and restoration.

The study of microbiome can be a determining factor to understand their functionality and resilience, so this study aims to evaluate the influence of microbiome on C. nodosa seeds germination and development.

To test the hypothesis that the presence of certain microorganisms influences the development of seagrass, a manipulative experiment was carried out in the laboratory. Six treatments from the interaction between two factors were examined: (1) sterilization (or not) of the seeds and (2) sediment type (sediment from vege tated and non-vegetated environments and artificial sediment).

Seed germination and development was strongly influenced by the presence of the seed microbiome and sediment type (and thus soil microbiome). Also, microbial community composition differs between treatments and developmental seed stages.

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SS09 - Novel approaches to assist seagrasses in a changing environment **278**

Can microclimates foster enhanced resilience to climate change in seagrass?

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Global climate change, particularly ocean warming, can impact coastal benthic ecosystems worldwide. In the marine realm, however, little is known about how existing microclimates prime (harden/pre-select) populations and genotypes for enhanced resilience to climate change.
This research exemplifies experimental efforts across geographical scales and environmental gradients to entangle the relevance of small-scale natural microclimatic variability for the resilience of seagrass Zostera marina to warming and extreme climatic events. We combined short-term and long-term micro- and mesocosm studies with high-resolution environmental monitoring to contrast seagrass inhabiting areas with variable and stable thermal microclimates.
Despite the pronounced differences in thermal variability and underlying partial genetic differentiation between nearby seagrass meadows, we find limited support for a priming of seagrass for enhanced relilliance to long-term (1.5 years) warming and short-term warming and freshening events.
This research underscores the magnitude of thermal microclimatic differences across very small spatial scales. We equally highlight the complexity of microclimatic variability to serve as selection beds for ecosystem resilience to future climate change and, in particular, changes in variability and the occurrence of climatic extremes.

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Non-invasive assisted evolution strategies on Posidonia oceanica seedlings

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Restoring and strengthening seagrass meadows is essential to maintain their processes, functions and ecosystem services in the context of global change. This requires a redoubling of efforts to promote the acclimatisation and adaptation of the meadows to the pace at which environmental change is occurring.
This presentation illustrates different non-invasive assisted evolution approaches applied to the Mediterranean endemic seagrass Posidonia oceanica, with the potential to improve the existing genetic basis of natural populations, enhancing their ability to tolerate stressful environments (i.e. marine heatwaves) and accelerating recovery after environmental disturbances. Specifically, two assisted evolution approaches were explored. The first one aimed at identifying best performing genotypes through phenotypic screening tests on seeds and subsequent manipulative selection experiments on seedlings. The second is based on seed priming by pre-exposing seeds to mild-stress to increase their responsiveness to a subsequent stressful event, in order to unravel key aspects the induction and persistence of the priming state. The findings of these works represent an advance in the knowledge of assisted evolution strategies in P. oceanica, and are of great value and utility for improving the resilience and restoration of this valuable species.

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Accelerated growth and low mortality of juvenile Zostera marina plants under an extreme Baltic heat wave

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Marine heat waves are increasingly threatening coastal ecosystems, including seagrass beds. Earlier ontogenetic stages may be more or less vulnerable. Here, we studied the impact of heat stress on 6-month-old Zostera marina plants to assess effects of months-long elevated temperatures (27 °C) on juvenile plants compared to controls maintained at 19 °C. Heat-exposed plants exhibited significant accelerated growth rates compared to the control group, while mortality started only after six weeks. These unexpected results contrast with prior findings where adult plants from the same region grew slower, showed decreased productivity, and revealed higher mortality at 27°C. Further research is needed to verify these differences with adult plants in the same experimental set-up, and to explore underlying physiological mechanisms driving thermal tolerance in juvenile Z. marina. This divergence underscores the complexity of temperature responses in different life stages in ecologically important species such as seagrasses. If early heat stress leads to a lasting priming effect, these plants could serve as heat-tolerant founders for new seagrass meadows. As one element of the “Assisted Evolution”-toolbox, such approaches may be promising for the sustainable restoration of seagrass ecosystems in the face of climate change.

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Molecular signs of priming imprint in Posidonia oceanica seedlings

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Seagrasses are continuously exposed to repenting environmental changes, and exploring novel approaches to enhance stress tolerance capacity could be crucial for their survival in the future. Starting from what was already demonstrated in land plants, a thermal-priming treatment was here applyied for the first time in Posidonia oceanica seedlings. At the base of this approach, there is the potential for plants to store stress-response mechanisms, to be reactivated in the face of further stressful exposures. These mechanisms can be regulated by stress-memory, which is epigenetically modulated. In particular, DNA methylation can modify gene expression, promoting phenotypic changes that could improve stress tolerance. DNA methylation and transcriptomics profiles of primed and not-primed seedlings were explored to investigate the role of DNA methylation in mediating priming and in the regulation of thermal stress responses. Primed seedlings performed better than not-primed ones, showing the largest transcriptomic regulation. The integration of transcriptomics with DNA methylation outlined central genes and key biological processes involved in the priming acquisition in P. oceanica seedlings.

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Evaluating and enhancing eelgrass resiliency and restoration potential in a changing climate

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In recent years, elevated water temperatures have resulted in large-scale Zostera marina diebacks of entire meadows in the lower Chesapeake Bay, Virginia, USA resulting in a conversion from historically stable, dense meadows to low-density ephemeral ones. In contrast, many Z. marina populations in Back Sound, North Carolina, USA appear to be more resilient to warming water temperatures. Structural, physiological, and genetic resiliency traits of Z. marina populations in NC and VA were compared before and after stressful summer temperatures to identify specific meadows in NC that could serve as seed donor beds for Chesapeake Bay. Reciprocal test restoration of NC and VA Z. marina seeds were used to further elucidate if greater resiliency to local stressful conditions will result in an increase in seedling survival and resilience to temperature stress outside of the local system. Z. marina restoration without considering the resiliency of the meadows to climate change no longer appears to be a viable option for long-term success. Therefore, state agencies and non-profits in both regions need species specific data to better enhance resiliency of Z. marina populations by advancing the development and implementation of ecosystem restoration strategies that mitigate current and anticipated stressors.

Bring on the HEAT: Helping Eelgrass Adapt to Temperature through Assisted Migration

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Eelgrass (Zostera marina) along the eastern seaboard of the United States faces multiple threats, from declining water clarity to rising sea water temperatures. Under continued warming, model predictions suggest future retraction of up to several 100 kms northward under continued warming. In 2022, The Nature Conservancy convened a group of scientists, managers, and practitioners from a range of disciplines, including terrestrial ecologists, agriculture, and industry, to propose innovative solutions to save and restore eelgrass in the face of climate change. The primary recommendation from this working group was to source thermotolerant genotypes from already heat-stressed areas and move them to areas where temperatures are expected to rise, a process known as assisted or population migration. The persistence of these transplanted genotypes should, ideally, confer climate resistance/resilience to seagrass beds and prevent further losses. A diverse team of researchers will soon embark on a preliminary implementation of assisted migration across five of the northeast US National Seashores. Here, we review our proposed design and identify regulatory and methodological hurdles still necessary to overcome, and welcome advice from those applying similar approaches.

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Navigating the changing seascape: Epigenetic and microbiome responses in eelgrass meadows

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As the climate is changing, species will have to move, acclimatise or adapt. Sessile species with low genetic diversity may be especially vulnerable. For such species, epigenetic modifications and microbiomes may instead play an important role, and it is important to explore if such information can be useful in restoration efforts. We sampled Zostera marina from four meadows along a 1,000 km steep salinity gradient (5-21psu) on the Swedish coast and exposed clones to current and future salinities and temperatures in a mesocosm experiment. We saw clear differences in both methylation and seagrass leaf-associated microbiomes from the same clones in the field, at the start of the experiment and at the end of the experiment. Individuals from the same meadow showed similar patterns of methylation and microbiome, but meadows differed at all time points. Survival was lower under a future scenario, and while methylation patterns and directions were highly site-dependent, we observed greater microbiome community divergence with increasing severity of treatment. This highlights the importance of studying eelgrass from several meadows with different environmental and genetic backgrounds when aiming to predict species response to a changing climate, and before such information can be used to facilitate adaptation during restoration efforts.

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Development of axenic cultures of Zostera marina from seeds and their potential use to propagate new plants through somatic embryogenesis

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Declines in seagrass ecosystems due to local and global stressors necessitate urgent conservation efforts. While mitigating local threats can prevent habitat losses, the challenge lies in restoring seagrass without overharvesting donor populations. We are testing a pioneering approach to develop cultures of seagrasses through seeds and propagating new plants through somatic embryogenesis using explants. The first step of our study focuses on developing a standard protocol for growing cultures of Zostera marina through seed sterilization and germination. We have observed a 63% germination rate of seeds grown in a two-layered culture medium comprising basal media rhizome layer (Murshige and Skoog, MS) and a 20 ppt seawater overlayer. Seedlings were cultivated until the development of the first true leaf. Clonal plants were tested using direct organogenesis media, both solid and liquid. Secondly, we are testing the use of MS medium with varied callus-triggering hormones to induce callus formation from cotyledon, young leaf, and apical shoot explants. Our aim is optimization of callus induction and proliferation, differentiation of somatic embryos from callus, and encapsulation of single embryos to produce artificial seeds. This methodology holds promise for the propagation and enhancement of Z. marina, offering potential applications in seagrass conservation and restoration efforts.

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Understanding seagrass temperature tolerance to aid in seagrass resilience and restoration efforts

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Ocean warming is having unprecedented ecological impacts on marine ecosystems, with immobile benthic habitats, such as plants, particularly vulnerable to stochastic events e.g. marine heatwaves (MHW). Understanding seagrass thermal tolerance across species provides valuable knowledge for focused restoration efforts, whilst assessing the thermal tolerance of multiple populations of a single species provide insights for thermal resilience building. We investigated thermal performance of six predominantly temperate seagrass species (Posidonia sinuosa, Posidonia australis, Amphibolis antarctica, Amphibolis griffithii, Zostera nigricaulis, and Halophila ovalis) and with four species (P. sinuosa, P. australis, A. antarctica and H. ovalis) how this varied by location along a thermal latitudinal gradient spanning 10°. We measured oxygen evolution in closed incubation chambers at temperatures ranging from 15-45°C for seagrass productivity (Pmax), optimum temperature (Topt) at which maximum photosynthesis occurred, and thermal maximum temperature (Tmax). Thermal optima (Topt) showed the greatest variation across species, differing by 10°C within the same location (e.g. 22.5°C for Z. nigricaulis to 32°C for H. ovalis). There was less variation with Tmax varying by up to 5°C across species (e.g. 35°C for Z. nigricaulis and 40°C for H.ovalis). Within each species there were differences among locations for the thermal photosynthetic performance, but this did not follow the predicted patterns along the latitudinal gradient. These findings can inform restoration approaches by identifying which species have a higher thermal tolerance and may be more resilient to ocean warming and heatwaves. There are also opportunities for resilience building within a species by transplanting populations with higher temperature tolerances.

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Thermo-priming vs acclimation: investigating the resistance of Posidonia oceanica seedlings to heat waves

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Marine heat waves (MHWs) have been increasing in frequency, duration, and intensity as a consequence of global warming. This phenomenon is exacerbated in Mediterranean Sea and information on adaptative strategy of key species such as Posidonia oceanica is now needed. A “priming” stimulus prepares an organism for an improved response to environmental changes by triggering a memory during a lag-phase. In this study we investigated how the development of thermo-primed P. oceanica seedlings is affected by a field simulated MHW depending on the duration of the lag-phase. Results did not show evidence of a memory triggered by the priming stimulus, but the importance of an acclimation phase before the highest temperature stress was highlighted: seedlings with a lower temperature lag-phase between two heat events developed a lower number of leaves and higher leaf necrosis than seedlings that experienced a gradual increase of temperature during the experimental time. Also, regardless the priming stimulus, MHWs slowed down the development of the leaf and root length. However, although an overall resistance of P. oceanica seedlings to heat was recorded, testing different intensities of priming and length of lag-phase is now necessary to provide information about its adaptive success.

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Trigolactone and gibberelic acid promote gemination of Zostera marina seeds

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Seagrass meadows are rapidly declining worldwide, with Zostera marina being one of the most impacted species. While successful restoration efforts are becoming more frequent, unfortunately, numerous attempts still experience low success rates and limited germination.
Seed priming has the potential to maximise the probability of germination, addressing issues related to low, slow, asynchronous germination, or dormancy. Advances in Zostera marina's genome have unveiled new insights into receptors that may modulate germination under suboptimal conditions.
In this study, we assessed the effect of priming treatments on Zostera marina seed germination. Three different phytohormones (GR24 - synthetic Strigolactone, smoke water - KAR, and GA3 - Gibberellic acid) were tested in ten different concentrations on two generations of Zostera marina seeds.
Germination rate significantly increased when seeds were exposed to GA3 and GR24. GA3 exhibited a wider efficacy at both high and low concentrations, while GR24 promoted germination at intermediate concentrations. Seed generations also influenced the outcomes, with younger generation seeds being more sensitive to the primers compared to older generation seeds. Our study suggests that hormone priming can enhance germination success and provides insights that may guide methods to increase the success of seed-based restoration projects

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Sustenance and more: the diverse role of intertidal gleaning in the livelihood of women in coastal communities

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Coastal resources play a vital role in the well-being and livelihoods of people in coastal communities globally, with diverse uses and values that vary among individuals and across different periods. Equitable management of these resources necessitates an understanding of how people value ecosystems under varying circumstances. Intertidal gleaning, a type of small-scale fishery in the seagrass meadows and mangroves of Perigi Acheh village in the Sungai Johor estuary is conventionally portrayed as primarily focused on food security. This study explored the values of gleaning, emphasizing its non-material significance, including aesthetic, recreational, cultural, and social dimensions. Through an ethnographic case study in the Perigi Acheh village, we uncovered functional and social values that women and other gleaners attribute to this practice. Contrary to the oversimplified notion of gleaning as solely a means for sustenance, our findings highlight the diverse priorities gleaners place on activities such as socializing and connecting with the intertidal gleaning habitats. This emphasizes the importance of moving beyond simplistic understandings, signifying the evaluation of intangible values when assessing coastal ecosystem services. By recognizing the non-material roles of gleaning, we can offer more accurate portrayals of coastal livelihoods, promoting equitable management in these areas.

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Securing a future for seagrass ecosystems in SE Asia – enhancing knowledge of seagrass ecosystem services (Blue Carbon) to incentivise conservation and community benefits

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Seagrasses provide many ecosystem services, including carbon sequestration, but are frequently neglected in decision-making. Seagrasses of the Indo-Pacific support up to one billion people through their provision of fisheries and provide critical habitat for many marine species. At the same time, seagrasses in the region are declining because of coastal development, unsustainable resource extraction, and environmental degradation. Limited data exists on seagrass status, their ecosystem services and value in the region, information that can incentivise seagrass conservation.

The Seagrass Ecosystem Services Project (SES project) was established to provide critical data on the state and condition of seagrass ecosystems and to promote the integration of SES into evidence-based decision-making and business models to ensure seagrass sustainability across the Indo-Pacific. The project focused on five priority sites in SE Asia and a range of SES, including carbon sequestration (Blue Carbon; BC), aiming to build capacity within NGOs to undertake BC Assessments and integrate the findings into policy, decision-making and management. Here we provide an overview of the project development and BC-related outcomes, highlighting the lessons learned to empower future similar projects and enhance their success. There is an urgent need for more projects that focus on the socialecological aspects of seagrass habitats.

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Seagrass security: assessing the role of fisheries supporting and provisioning services in UK's temperate seagrass (Zostera marina) meadows

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Seagrass meadows, provide vital coastal and ecological connectivity, ecosystem services and key provision habitats that support fisheries, particularly as a nursery habitat for commercially fished species. Seagrass presence and extent are in significant decline, being altered by human pressures and a changing climate, with consequential impacts to commercial fish stock biomass, economic losses, and a changing seascape. Associated ecosystem and fishery complexities and limited understanding within these habitats means commercial valuation and natural capital assessments are often overlooked during ecosystem service review as lack of meaningful data and methodologies makes it difficult to quantify and value. Using a Seagrass Residency Index (SRI) approach, the economic value of seagrass habitat and commercial fisheries value of supporting and provisioning services can be quantified. This study assesses the role of temperate seagrass meadows (Zostera marina) in supporting fisheries and quantifying its commercial value using SRI method approach in a UK context. Seven UK seagrass meadow case study sites were studied across varying environmental gradients, seagrass biotopes, spatial scales, and stages of restoration. This research presents a contemporary picture of the economic value of seagrass meadow provisioning services for commercial fish species in the largest assessment of its kind in the UK.

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Socio-ecological modelling on seagrass ecosystems in Sangihe Islands, Indonesia

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Seagrass meadows are highly productive ecosystems that support many species, including humans. Seagrasses provide habitat and food for fish, invertebrate assemblages, and charismatic species like Dugong dugon. Seagrass systems also support human livelihood, food security, and nutrition sources in many communities. However, seagrass meadows face high global decline rates due to changing environmental conditions. In 2017, community-based (CB)-MPAs in several villages in the Indonesian Sangihe Islands were established to protect marine habitats, vulnerable species, and improve local livelihoods. This research explores the interaction between fisheries activities, seagrass ecosystems, dugong populations, and community-based MPAs, aiming to support better marine management for coastal communities. We used semi-structured household surveys to interview fishers, open-ended interviews for key informants, and intertidal-fixed transect sites from the seagrass-watch method to study the seagrass coverage. We revealed a negative correlation between fisheries activities and seagrass health. We also found that locally positive perceptions of the benefits of CB-MPAs were positively correlated to seagrass habitat protection, dugong population conservation efforts, increased fish stocks and improved local livelihoods. The authors recommend that all stakeholders and governments integrate this socio-ecological model for future coastal management and policy.

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Overcoming seagrass blindness: seruan setu – secret gardens of the sea gamelan performance for greater seagrass recognition in malaysia

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Seagrass has been described as lacking in charisma, leading to limited societal recognition of the pressing need for its conservation. While significant progress has been made in the past five years, with the global seagrass community employing science documentaries, public talks, print media, and citizen science programs, conventional science communication methods may not resonate universally—especially among those disinterested in science. In contrast, the cultural arts possess the unique ability to evoke emotions and establish a personal connection with audiences, making them a potent tool for fostering appreciation and excitement, especially for subjects deemed less-charismatic, like seagrass. This presentation introduces a Malaysian cultural arts approach to public engagement, spotlighting Seruan Setu, a gamelan music performance dedicated to seagrass ecosystems, as a case study. Seruan Setu, staged at the Kuala Lumpur Performing Arts Centre in August 2023, featured a collaboration between marine scientists and the Rhythm in Bronze gamelan orchestra. The multidisciplinary performance, encompassing gamelan music, dance, animation, and documentaries, attracted a capacity crowd, including government leaders. Audience surveys and a post-performance conference provided insights on the performance impact, which will be shared, along with video excerpts. The essential elements that contributed to Seruan Setu's success in Malaysia, such as how collaborations were formed between artistes, scientists, and communities, will be discussed.

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Developing carbon emission factors to support seagrass Blue Carbon conservation and restoration projects

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Seagrass Blue Carbon (BC) is being introduced into national carbon inventories and fluxes to promote conservation and restoration actions as a natural climate solution. However, the lack of robust carbon emission factors associated with the loss or restoration of seagrass meadows is limiting BC projects and their implementation in national climate policy and strategies. Here we compiled published literature on soil carbon stock changes associated with seagrass loss and restoration to estimate carbon emission factors that could be used in policy development. The results showed that direct impacts (e.g., storms, dredging or achoring) resulted in average erosion and loss of 50 ± 29% of soil carbon stocks, whereas indirect disturbances (e.g., heatwaves and eutrophication) can cause the erosion and loss of 20 ± 22% within <1 to 55 years after disturbance. Assuming that 50% of the eroded soil carbon is remineralized, we estimated 17-202 Tg CO2eq yr-1 emissions from seagrass loss worldwide at 1.5% yr-1 loss in global extent. We modelled the exponential recovery of soil carbon stocks following seagrass restoration that can take up to 30 years. This information can facilitate the development of BC crediting schemes across multiple management activities to promote large-scale implimentation of seagrass BC projects.

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Simple Alterations to Traditional Mooring Configurations to create the Striling Advanced Mooring System

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The Ocean Conservation Trust & Marine Conservation Society have trialled alterations to traditional mooring configurations to relieve the destructive scour of the sinker chain within seagrass meadows, on the South Devon Coast in the U.K. The moorings were installed in 2019 in collaboration with a number of local mooring holders, with the aim of firstly demonstrating Advanced Mooring Systems engineering solutions are as safe as traditional configurations, and secondly Advanced Mooring Systems safeguard seagrass recovery within the halo of the scour caused by traditional mooring. Over the past 4 years the results have been mixed, however, 2023 evidenced a strong recovery within the area of damage caused by the moorings, recording a 212% increase in seagrass cover within the mooring area. The takeaway message of this recent trial is Advanced Mooring Systems work! They safeguard vital habitats! Which, after damage can take a while to recover, and taking measures to not only restore, but to also protect these fragile habitats is an essential part of Seagrass Protection.

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The cultural value of seagrass to humanity from historical to contemporary uses

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Seagrasses have been entwined with human culture for over 120,000 years, constituting a natural resource that has benefited humanity throughout this long history. Understanding the cultural value of seagrass from historical to contemporary uses can foster the valuation of these ecosystems to further encourage conservation and restoration actions. This study compiled evidence on the cultural values of seagrass around the world, showing that they have been used for spiritual and ceremonial purposes, as grounds for direct and indirect food resources, and in industrial activities including construction, clothing, fertiliser, livestock feed, and medicine. Although multiple applications of seagrass in industry have been suggested, seagrasses are a protected species and harvesting for industrial applications is prohibited, which renders seagrass farming a big challenge for the 21st century. Seagrasses are arising as a promising resource towards sustainable development goals and as a weapon against climate change despite extensive historic and current losses of seagrass ecosystems. This review can aid the development of markets around the cultural value of seagrasses to incentivize their conservation and restoration, shining light on the ancient relationships between seagrass and humanity

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Songlines and Seagrass: Cultural and biodiversity dimensions govern seagrass protection in the Gulf of Carpentaria, Australia

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We delve into the profound connection between the Yanyuwa and Marra Aboriginal people in the Gulf of Carpentaria, Australia, and seagrass ecosystems. Seagrass emerges as integral to their identity, intricately linked to their songlines and cultural heritage. The significance of protecting coastal resources becomes evident as it maintains ecosystem health and facilitates cultural connection and biodiversity protection.

Aboriginal knowledge holders reveal a deep interconnection between cultural practices, seagrass, and marine megafauna dynamics. Their Sea Country is more than an ecological reservoir, embodying living archives of lore and cultural practice across generations. This relationship reflects a profound understanding of ecology, emphasising the importance of species like turtles and dugongs and their seagrass habitats.

Recognising the importance of seagrass in cultural and ecological contexts is crucial for effective conservation strategies. We argue that a changing climate and anthropogenic threats have hastened the need for culturally sensitive and innovative approaches that equally value Indigenous and Western scientific knowledge. We emphasise the urgency for collaborative research to weave diverse knowledges, fostering conservation practices that honour the intricate web of knowing cultivated by Indigenous peoples. We present a blueprint for protecting these values as an inclusive and meaningful response to ensuring sustainability in Sea Country.

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Exploring the Nexus of Seagrass Ecosystems, Angler Dependency, and Conservation Concerns

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Incorporating local ecological knowledge into scientific inquiry enhances our understanding of complex ecosystems. Anglers, as avid observers of natural environments, hold valuable insight into temporal changes within coastal habitats. In particular, their experience extends into the significance of seagrass ecosystems in maintaining coastal biodiversity and providing essential ecological services to recreational fish populations. Everglades National Park (ENP), located in the southernmost region of mainland Florida, is a unique ecosystem comprised of shallow mud banks and vast seagrass meadows dominated by Thalassia testudinium, Syringodium filiforme, and Halodule writii. With high fish diversity and abundance, Florida Bay offers one of the most sought-after recreational fishing environments in the nation. It was estimated that the ENP recreational fishery generates over $1 billion annually. Of that, Florida Bay has been estimated to contribute roughly $439 million alone. In this study, we delve into the perspectives and preferences of 160 professional fishing guides, uncovering their profound concern for the loss of seagrass in Everglades National Park. As stewards of this unique ecosystem, the guides emphasize the urgency for ongoing habitat improvements, spotlighting seagrass preservation as essential for sustainable management practices to safeguard their livelihood and preserve this vital habitat for the enjoyment of future generations.

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Seagrass inclusion into climate policies

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Seagrass meadows provide a range of environmental, economic, and community benefits to our global society. They are also nature-based solutions to climate change, capable of locking away carbon into ocean sediments and providing numerous climate adaptation benefits including coastline stabilization, improving water quality, and reducing wave impacts. The management and conservation of this ecosystem can play a vital role in advancing multiple sustainable development goals, including meeting climate objectives. For example, countries can protect and restore seagrasses as part of the actions they take within the nationally determined contributions (NDC) they put forward under the Paris Agreement. There is growing momentum globally to include seagrass within NDCs, but when compared to mangroves, seagrasses are often left out of the climate dialogue. Come hear how the country of Seychelles and others in the Western Indian Ocean are overcoming research and policy barriers to include this critical ecosystem within climate policy and overall management.

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Drastic changes to the seagrass medows in Thailand

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The seagrass meadows in Thailand provide numerous ecosystem services, however, in the recent years their decline have been observed. In this study, the changes within the last several years were recorded by various organizations within Thailand and Australia using unmanned aerial vehicles (UAVs) across many seagrass meadows along Andaman coast of Thailand. The drone images were obtained through various projects by local universities, NGOs, government staff and more recent project in the collaboration with CSIRO, Australia. In total 7 sites were revisited and mapped from 2016 to 2023. Using the drone images, it was identified that the seagrass meadows in Trang provice, have been mostly affected and suffered dramatic loss. On the other hand, seagrass meadows in Krabi and Phuket province showed smaller changes in the seagrass area. The losses of the seagrass could potentially be attributed to various factors occuring at the same time, such as increased sedimentation and other anthropogenic acctivities, climate change and herbivory pressure. The effects of the seagrass loss along Andaman coast has national importance as these meadows were one of the largest and most diversed in Thailand, which consequently has enormous effects on the decline of the ecosystem services that these meadows provided.

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Building capacity key to filling gaps in our understanding of seagrass ecosystem services

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Seagrass ecosystems across Southeast Asia support a rich biodiversity, but are in decline. To address these declines, decision-makers need accurate assessments of the status of and pressures on seagrass ecosystems, but these are constrained by incomplete and uneven spatial coverage. To contribute to these assessments, the IKI Seagrass Ecosystem Services project sought to deliver site-specific assessments of seagrass health, and to evaluate the ecosystem services seagrass provides. A group of six local NGOs and community groups at project sites (Indonesia, Thailand, Malaysia, Philippines and Timor-Leste) have been empowered to assess seagrass with the provision of technical tools and capacity building. Focusing primarily on biodivserity assessments we highlight how we can reduce parachute science, build capacity and fill gaps in our knowledge of seagrass ecosystems. Using an iterative proccess to effectively build capacity, we worked with partners to identify monitoring questions and aims, the key biodiversity functions and processes to monitor and the most suitable monitoring methods to do this. We then delievered training to carry out monitoring activities, manage and interpret data. We call on the scientific community to share data, knowledge and tools to ensure the accessibility, interoperability, and reporting of seagrass ecosystem services data at a global scale.

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Advancing our understanding multi-species inter-tidal seagrass meadows in the Andaman and Nicobar archipelago, India

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Seagrasses occur in all coastal waters except Antarctica, but only a fraction of this area, typically inhabiting monospecific meadows in the temperate, has formed the basis of our knowledge of seagrass ecosystems. Tropical meadows that show both monospecific and multi-species assemblages have had poor research representation. These meadows tend to be diverse and highly dynamic and depending on the seagrass species, their canopy height, density and other spatial and temporal variations, the magnitude of services are likely to vary. The shallow coastal waters of the Andaman and Nicobar archipelago of India support several multi-species intertidal and subtidal seagrass meadows. Our research group has been focussing on understanding the drivers of species assemblages and meadow dynamics, and the sociological, ecological and geophysical functions of these meadows. In this talk, I will focus on our ongoing research and some of the key findings.

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Mapping and Characterization of seagrass meadows of Abu Dhabi Coastal Waters, United Arab Emirates

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The coastal waters of Abu Dhabi in the southern Arabian Gulf are subject to extreme environmental stresses that impact various marine habitats, including seagrass meadows that support a diverse ecosystem, hosting over 3000 dugongs and 4000 green sea turtles. The study utilized machine learning techniques on Landsat satellite images from 2002, 2015 and 2019, to map seagrass, quantify broad habitat changes, and assess trends over time. The integration of multiple spatial products (bathymetry, seagrass and change maps) was achieved from a single satellite image alongside concurrent field survey data. Given the environmental challenges in the Gulf such as eutrophication, hyper-salinity, and poor water transparency, field verification was carried out in 585 points using underwater cameras to enhance the accuracy of remote sensing data for mapping. The study revealed a seagrass extent of 2922 Km2. Along a depth gradient, selected seagrass meadows were characterized for species composition and biomass. Three species of seagrasses namely, Halodule uninervis (62%), Halophila stipulacea (23 %) and Halophila ovalis (15 %) were assessed. The paper explores the distribution of these species along a depth gradient, establishing correlations between species association, composition, sediment types, and climate parameters.

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Seagrass meadows as seabird's habitats in the southern Red Sea coasts of Saudi Arabia

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Studies of seabird communities along seagrass meadows, particularly in arid environments, have remained largely limited. We studied a pristine seagrass meadows in the southern Red Sea coasts of Saudi Arabia with aims (1) to determine the diversity and distribution of seabird communities between sampling stations (S1– is a seagrass meadows; S2 – is an open coast adjacent to seagrass meadows; and S3 – is an open coast with no seagrass) and seasons (March for spring, July for summer, and November for fall); and (2) to identify the most influential climatological variables influencing the seabird communities. Bird point count survey was the sampling method used. Twenty-nine (29) seabird species from 14 families were identified throughout the study. Site S1 showed significantly higher species richness, diversity, and dominance than S2 and S3. There was a consistent downward trend in these diversity indices from S1 to S3. The multidimensional scale (MDS) and the analysis of similarity (ANOSIM) showed that seasonality has a significant influence on the heterogeneity of seabird species richness. Distance-based linear model (DISTLM) showed that air temperature is the most influential factor affecting the variability of the seabird community.

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Variation of Seagrass Community Structure and Carbon Stock in the Berau Marine Protected Area with response to land-use change

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Seagrass ecosystems increasingly receive attention due to their capacity to store high carbon. Protecting this ecosystem is the key to increasing resilience to climate change. However, in some of the Marine Protected Areas (MPAs), seagrass ecosystems are still under threats, especially from land-use change. This study aims to investigate the current condition of seagrass ecosystems in Berau MPA with response to land-use change along the Berau Watershed. We used several methods like SeagrassWatch and remote sensing, and proxies like water quality and stable isotopes. Seagrass percent cover was categorized as poor (<29,9%) and not healthy (30-59,9%). Biomass carbon was measured the highest (435 g C m-2) in the island with turbid water and low seagrass cover of 25% (Rabu Rabu island) due to the existence of one individual of a larger species E. acoroides that is known to be more persistent in extreme conditions. Meanwhile, the lower biomass carbon was obtained from the smaller and pioneer species found in the islands with clear water and higher seagrass cover of 58% (Maratua island). This study indicated that seagrasses in Berau MPA were threatened with degradation. As the threats from anthropogenic increase, there must be an increase understanding on MPA functions in seagrass carbon sequestration to avoid further loss of carbon.

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Seagrass research and conservation in southeast Asia: sir mike's outstanding achievement and contribution

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Southeast Asia is a hotspot of global seagrass diversity. However, the research and conservation efforts have been far behind those in developed regions. Professor "Sir Mike" Fortes was the pioneer and was always at the center of seagrass research and conservation in SE Asia. Above all, his enthusiasm, mentorship, and friendly personality inspired and encouraged many succeeding researchers and practitioners, not only in Asia but all over the world. By reviewing his research career and outstanding achievements, we will discuss the challenges and opportunities of current seagrass research and conservation practices in this region, and how we can develop future research and collaborations based on his legacy.

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