ISBW14 ABSTRACT BOOKLET

<u>Session 1A:</u> Chesapeake Bay Partnership and Collaboration

Session Convener(s): Brooke Landry, Maryland Department of Natural Resources

The conservation, restoration, and management of Chesapeake Bay and its resources has been a 40+ year exercise in multi-jurisdictional partnership and collaboration. During this session, participants will hear from the agencies and organizations that have led the way and made progress possible. Leaders from the Chesapeake Bay Program, the Chesapeake Bay Trust, the Alliance for the Chesapeake Bay, the Chesapeake Research Consortium, and Waterkeepers Chesapeake will discuss their unique roles in the partnership - specifically how those roles have contributed to the recovery of SAV in Chesapeake Bay.

The following invited presentations are included in this session:
The CBP's SAV Workgroup: The benefits of multi-institutional collaboration in SAV restoration and management, Brooke Landry
Chesapeake Bay Program: Approaches for Setting, Overseeing, and Attaining Restoration Goals, Carin Bisland
Chesapeake Research Consortium: Translating Science to Management, Denice Wardrop
Chesapeake Bay Trust: Identifying and Funding Key Barriers to Meeting Goals, Jana Davis
Alliance for the Chesapeake Bay: Engaging a Watershed, Kate Fritz
Waterkeepers Chesapeake: The role of Riverkeepers in SAV Monitoring, Restoration, Outreach, and Advocacy, Betsy Nicholas

<u>Session 1B:</u> Successful tropical/subtropical seagrass restoration: Longevity, species for various impacts, services reassembled

Session Convener(s): Anitra Thorhaug, Greater Caribbean Energy and Environment Foundation and Yale University

This session will highlight the results of over 80 sets of trials, over 300 ha of seagrass in the Indo-Pacific and Atlantic tropical/subtropical basins. Speakers will demonstrate the methods, species, and planting designs creating the successful plantings in both the Indo-Pacific and Atlantic tropics/subtropics from multiple sets of restorations in key areas. These have been highlighted in our three recent seagrass reviews. The impacts overcome by means of restorative plantings will also be detailed as to species and techniques. This will emphasize data due to various types of impacts, and their successful solutions. The end result of successful longevity and sustainability will be emphasized with restoration sustaining as old as 47 years. The services measured from these restorations will be delineated such as animal recolonization studies,

biodiversity, blue carbon results in restorations, sediment/seagrass interactive resilience. The various restoration projects have had layers of preliminary tests creating better final larger-scale restorations, which will be discussed. Large scale restoration techniques from 12 ha to 50 ha will also be emphasized as to differing techniques to rapidly install large areas manually. Studies of differences and similarities of restoration species especially in co-generators (*Thalassia, Halodule, Syringodium, Halophila, Rup*pia) and mixed plantings across the major large tropical oceanic basins of Atlantic and Indo-Pacific will be emphasized.

Talks:

Tropical and subtropical Southeast Asian Seagrass restoration review and analysis

Anitra Thorhaug, GCEEF; Jennifer Verduin, Murdoch Univ. Perth, Australia; Wawan Kiswara, Indonesian Academy Science; Barry Gallagher, Univ. Malaysia, Sabah; Michael Yap, Univ. Malaysia, Sabah; Xiaoping Huang, Institute Oceanology, Chinese Academy of Sciences; Anchana Prathep, Seaweed and Seagrass Institute, Prince of Songla Univ., Phuket, Thailand; Arthur Schwarz, SWAU, Keene, TX

Southeast Asia contains the highest seagrass regional extent globally (5.5million ha), suffering the highest seagrass degradation. Seagrass areas are found in tropical/subtropical estuaries and shallow shelves. Solutions to seagrass destruction include restoration and preservation. *Objectives:* An analysis of "state of the restoration practice" of Southeast Asia seagrass. *Approach:* reviewing national and global seagrass data are analyzed in categories critical to restoration sustainability. Results: Twelve of the 26 Southeast Asian species are under cultivation including the dominant food-web producing &sediment stabilization, and high carbon-sequestering genera: *Enhalus, Thalassia, Halodule, Halophila, Syringodium, Cymadocea, Amphibolis, & Posidonia*. Analysis demonstrates 1.5 Million seagrass restoration planting units in 42 efforts 9 Southeast Asian nations provided technically sufficient information for large-scale initiation. Successful species, planting methods, anchoring,fertilizer, planting season, and physico-chemical constraints are analyzed. Large-scale efforts occurred in five nations; smaller efforts occurred in 4 others. The Western Australia example provides an excellent of large-scale successful restoration (*Posidonia australis*) (Verduin et al 2011, Paling et al 2001). The Philippines' inquisitiveness led seagrass restoration& preservation for four decades (Thorhaug& Cruz 1986, Campulong 1994, Fortes et al 2019). Multiple efforts were recorded in tropical China (dominant species, and preserving centers of population genetics) and in Vietnam. Conclusions: This analysis refines the regional restoration success following global seagrass restoration analysis of 1786 investigations (Van Katwijk, Thorhaug et al 2016) in which the Atlantic demonstrated the highest trial number of seagrass restoration. Seagrass restoration is poised for large scale, but political will for funding appears the obstacle for restoration.

Metrics of seagrass restoration – case of *Oceana serrulata* in the Western Indian Ocean

Maria Cuambe, Department of Biological Sciences, Eduardo Mondlane University; *Manuela Amone-Mabuto*, Department of Biological Sciences, Eduardo Mondlane University and Department of Botany Nelson Mandela University; Maria Américo, Department of Biological Sciences, Eduardo Mondlane University; Salomão Bandeira, Department of Biological Sciences, Eduardo Mondlane University

The seagrass *Oceana serrulata* (former *Cymodocea serrulata*) is a pioneer species in sand accretion areas of the western Indian Ocean region. In Maputo Bay (Mozambique), an area subjected to impact of currents is prone to both constant transportation and erosion leading to a constant denudation of the intertidal and immediate subtidal areas. This manuscript describes the ongoing seagrass restoration in the Western Indian Ocean that started in 2019. Several techniques were tested: sediment-free method (rod and finger/spring methods) and seagrass with sediment method (sod method). The rod method recorded the highest survival rate of over 60%. Around 2 hectares of restored seagrass, comprising nearly 150 000 modules of 3-6 shoots of *Oceana serrulata* were accomplished in February 2022. Restoration site in now visible over the Google Earth. Monitoring of the restoration have target mainly the metrics based on calculating seagrass percentage cover, shoot density, canopy height and biomass of both the restored and donor sites. Monitoring maps were also produced using drone.

The seagrass restoration success, out of Inhaca Island was assessed after 2,5 years through the calculation of a threshold value and quality ratio. While this is still an ongoing activity we determined that the restoration is being successful; having the quality ratio greater than the threshold value (0,52> 0,51). Inhaca island seagrassrestoration story continues to evolve with engagement of local communities who developed an association devoted to seagrass conservation.

Adaptive seagrass restoration - a habitat restoration experiment comparing stoic *Zostera marina* & opportunistic *Ruppia maritima* bed structure and function

Enie Hensel, Virginia Institute of Marine Science; Stephanie J. Wilson, Virginia Institute of Marine Science; Christopher J. Patrick, Virginia Institute of Marine Science; Bongkeun Song, Virginia Institute of Marine Science; Robert J. Orth, Virginia Institute of Marine Science

Habitat restoration is a powerful tool to help mitigate seagrass loss. Yet, many efforts focus on revegetating declining or lost species opposed to planting alternative species more conducive to current and future conditions. In the Chesapeake Bay, seagrass meadows are declining and there has been a dominant species shift from *Zostera marina* to *Ruppia maritima*– a more tolerant species to the observed increase in heatwave spikes and frequencies. Here, we conducted a field experiment to test the effectiveness of seed-broadcasting for R. maritima and how seagrass identity, *Z. marina* and *R. maritima*, alters bed structure and function. Our study showed broadcast seeding is successful for planting *R. maritima* – the first field test to our knowledge. Comparing the first growing season of these species*, Z. marina* plots produced on average, five times more biomass than *R. maritima* with grass shoots being four times higher and denser than *R. maritima*. For epifaunal responses, *R. maritima* plots had higher guild richness and animal abundance on average. Lastly, preliminary findings suggest seagrass species identity influences sediment nitrogen removal verse recycling rates. In conclusion, we show *R. maritima* is a promising species for seagrass restoration efforts in warming nearshore systems like the Chesapeake Bay. Importantly though, we found species identity can alter seagrass bed structure and function, and therefore if local conditions are conducive for either lost or opportunistic species like *Z. marina* and *R. maritima*, respectively, choice of species could potentially depend on targeted restoration goals (carbon sequestration vs. faunal habitat quality).

A collated evidence review to identify the gaps in the restoration ecology of the seagrass *Posidonia oceanica*

A. Pansini, Dipartimento di Architettura, Design, Urbanistica, Università di Sassari; Mar Bosch-Belmar, Dipartimento di Scienze della Terra e del Mare (DISTEM), Università di Palermo; Manuel Berlino, Dipartimento di Scienze della Terra e del Mare (DISTEM), Università di Palermo; Gianluca Sarà, Dipartimento di Scienze della Terra e del Mare (DISTEM), Università di Palermo; Giulia Ceccherelli, Dipartimento di Chimica e Farmacia, Università di Sassari

Active restoration actions are now considered reliable strategies to return seagrass ecosystems to their original state in a reasonable time frame. Decision making for correct seagrass restoration management requires valuable information on the effectiveness of past restoration actions. At this aim, evidence regarding restoration actions of the slow-growing seagrass *Posidonia oceanica*, endemic to the Mediterranean Sea, have been here collated. Combined information from a literature systematic review and specific questionnaire consulting seagrass ecology experts were synthesized, providing evidence on any human mediated active restoration, transplanting or rehabilitation outcomes on *P. oceanica*. Results identified the geographical distribution of *P. oceanica* interventions across countries, as well as the key relationship between environmental variables (such as depth and type of substrate), different techniques and plant portions used on transplanting trials and the final outcome of the restoration action (success vs failure). The current study identified an overall poor consistency of the available information on *P. oceanica* restoration, probably due to the wide portfolio of practices and methodologies used in different conditions. It may support the urgent need of testing different anchoring techniques, type of substrates and transplanted plant materials in field crossed experiments and in various environmental contexts to fill the identified gaps. Overall, the current situation clamours for an international effort from scientists and stakeholders to jointly design the strategy forward in identifying the best practices that lead to efficient restorations of *P. oceanica* habitat and functioning.

Assessing the role of seagrasses as a socio-ecological system: A case study from Cape Verde (Gamboa Bay)

S. Soumah, University Technical of Atlantic, Institute of Engineering and Marine Sciences

The marine ecosystems are extremely productive and valuable, with importance for the health of marine and terrestrial environments. However, climate change and intensive exploitation of natural resources have significant impacts on ocean ecosystems, including seagrasses. Globally, important areas of seagrass have been lost, with no certainty for recovery. In West Africa, their knowledge is still rudimentary, and their presence is confirmed in only seven countries. In Cape Verde, seagrass was reported in 2016 at Gamboa bay, the only documented site of a seagrass meadow. However, the site is exposed to human activities, with no study exploring the impacts on seagrass health and status. This study aims to assess and compare the present to the previous state of seagrass meadows in Gamboa and evaluate fishers' perception of seagrass. Field assessments and questionnaires were used. The results show that parameters such as total cover, biomass, rhizome, and canopy height of *Halodule wrightii* species identified have increased, while the shoot density has decreased. The actual shoot density is 5-fold less than that reported in 2016, and the total biomass is 1-fold more than that reported in 2016. The 10 patches of 20 m2 recorded then have extended to 6243 m2. Fishers understand the importance of the sea and are conscious about its cleanliness, but not fully aware of seagrasses, their ecosystem services, and not sure about protection. To further enhance conservation and management of seagrasses, socio-economic adjustment is required to provide guidance and information that can positively impact conservation and management activities.

Sexual Reproductive Ecology of *Thalassia testudinum* in Tampa Bay, Florida

Sheila Scolaro, Tampa Bay Estuary Program

Successful sexual reproduction and recolonization are critical in maintaining genetic diversity within seagrass meadows. *Thalassia testudium* flower, fruit, and seedling production were monitored visually at 10 sites in Tampa Bay, Florida approximately every 4 weeks from May to July 2017 to determine if there is spatial and temporal variation in sexual reproductive effort and success. Results from this study revealed strong temporal variability throughout the reproductive season. Additionally, results suggest that site location, water quality, seagrass density and localized reproductive variability affect sexual reproductive effort and success. Only 7 seedlings were observed throughout the monitoring period suggesting that asexual reproduction is the dominant form of meadow growth and expansion in Tampa Bay, Florida.

Posters:

Study of Sea grass beds in Sangomar AMP and Saloum Delta National Park: ecology, diversity and role for marine turtles

G.D. Diouf, University Institute of Fisheries and Aquaculture IUPA

Underwater plants or angiosperms are of terrestrial origin adapted to marine environments. They are distributed in all seas except Antarctica and the western African fringe remains the least known part. Their growth and distribution depend on physical, chemical, and biological environmental factors (light, nutrients, substrate, temperature, and nutrients).
The main objective of this work is to study seagrass ecology
in Sangomar MPA and Diombos estuary through surveys, data collection and sampling. Results show the presence of *Cymodocea nodosa* and *Halodule wrightii* constituting a
mixed subtidal seagrass bed in Sangomar MPA with sparse to medium coverage.
In Diombos estuary, these two are associated with *Zostera noltii* on a dense intertidal bed. Their associated fauna is diverse and composed of crustaceans (shrimps), mollusks, gastropods (cuttlefish) and fish (Mugilidae, Clupeidae). These sea grasses also prevent erosion by fixing sediments as observed in a part of Sangomar MPA. Their leaves provide habitat
for epibionts (micro-organisms, algae and epiphytic sponges).

Local natural and anthropogenic factors limiting their distribution are more apparent
in Sangomar MPA such as: sandbank siltation, micro-cyclone and seasonal swell, turbid water with strong hydrodynamics and presence of algae, motorized pirogues anchoring, pollution, dredging by trawling gear. These threats lead to a progressive decline of seagrass meadows, disappearance of both associated biodiversity and its goods and services provided. However, the lack of knowledge of this habitat by the young active inhabitants constitutes the first source of threat.

An examination of cold tolerance in *Halodule wrightii*: Is there a latitudinal gradient from Florida to North Carolina, USA?

Lindsey Stevenson, University of North Carolina Wilmington; Bradley Furman, Florida Fish and Wildlife Conservation Commission; Kelly Darnell, University of Southern Mississippi; Jessie Jarvis, University of North Carolina Wilmington

North Carolina is located in a unique biogeographic transition zone where climate change is altering the relative abundance of temperate (*Zostera marina*) and tropical (*Halodule wrightii*) seagrass species. North Carolina seagrass meadows change seasonally, where *Z. marina* dominates during the colder winter to early summer and *H. wrightii* dominates during the warmer late summer to early fall. Currently, warmer water temperatures are driving the loss in *Z. marina* biomass, which may competitively advantage the heat-tolerant *H. wrightii* for longer periods throughout the year. However, *H. wrightii* becomes thermally stressed during colder periods where *Z. marina* dominates, and little is known about *H. wrightii* cold tolerance. Previous studies suggest that *H. wrightii* cold tolerance may vary across regions. Based on these findings, this study aimed to investigate *H. wrightii* cold tolerance across a latitudinal gradient from Florida to North Carolina. The effects of cold stress on *H. wrightii* were quantified during a 3-week laboratory experiment. Shoots were collected and planted from North Carolina, Florida Bay, and the Northern Gulf of Mexico. *H. wrightii* shoots from each location were exposed to optimal (20-23^{o}C), stressful (10^{o}C), and extreme (5^{o}C) temperatures. The resilience of *H. wrightii* to cold temperatures was quantified structurally (shoot height, number of leaves, mortality) and physiologically (pulse-amplitude modulation-fluorometry, C:N ratios). This study helps to fill the knowledge gaps on *H. wrightii* cold tolerance and provide a better understanding of how *H. wrightii* may persist at the leading edge of its geographic distribution.

Marine coastal restoration: an animal eye's view

Michael Sievers; Elisa Bayraktarov; Christopher Brown; Christina Buelow; Ellen Ditria; Kimberly Finlayson; Rob Hale; Michaela Kitchingman; Andria Ostrowski; Ryan Pearson; Megan Saunders; Brian Silliman; Stephen Swearer; Mischa Turschwell; Rod Connolly

Ecosystem restoration is a key challenge of the 21st century. Coastal restoration efforts are accelerating, and billions of dollars are already being invested globally in restoration each year. Yet, despite some notable exceptions and promising novel techniques, restoration outcomes are highly variable in terms of 'success'. Seagrass restoration initiatives could be suffering in part to animals being overlooked in restoration planning, efforts, and evaluations of success. Significant effort and investment in restoration are currently being directed towards seagrass plants, but greater integration of animals in restoration approaches will likely enhance success. To encourage scientists, managers, practitioners, and funding bodies to better incorporate animals into coastal restoration planning, action and monitoring, we outline key animal interactions and functions that are important for influencing restoration outcomes, and highlight ideas and strategies to better account for animals.

Changes in sediment carbon stock following seagrass restoration in Shark Bay, Western Australia

Yusmiana P. Rahayu, School of Biological Sciences, the University of Western Australia, Marine Research Centre, Ministry of Marine Affairs and Fisheries Republic of Indonesia;

Gary A. Kendrick, School of Biological Sciences, the University of Western Australia; Mathew A. Vanderklift, CSIRO Oceans and Atmosphere; Matthew W. Fraser, the University of Western Australia

Seagrass restoration can contribute substantially to climate change mitigation efforts by enhancing carbon sequestration capacity. However, there have been few empirical investigations into changes in sediment organic carbon stock following seagrass restoration. This study aims to compare patterns of sediment organic carbon stock in early ages of seagrassPosidonia australis restoration (6 month, 2 year, 2.5 year and 5 year) to adjacent unvegetated sand and continuously vegetated seagrass in Shark Bay, Western Australia. Our study shows that seagrass restoration in Shark Bay experiences a lag period in accumulating carbon in the sediment. Furthermore, carbon stock in restored seagrass sediment in the study sites indicate that carbon storage in early ages of restoration (up to 5 years) is still not showing differences from that of unvegetated areas. We highlighted the importance of designing location for seagrass restoration, adequate restoration project duration and long-term monitoring to justify seagrass restoration better success/failure. This study contributes to the growing body of literature on seagrass restoration and blue carbon by adding information on sedimentary carbon stocks in the early ages of restoration.

<u>Session 2A:</u> Trajectories of recovery after degradation in seagrass ecosystem structure, function and services

Session Convener(s): Jessie Jarvis, University of North Carolina Wilmington

Seagrass ecosystems are inherently dynamic and respond to disturbance across a range of scales. Globally many seagrass ecosystems have been lost or declined but in the last decade the rate of decline has reduced and, in some places, there has been successful recovery of seagrass ecosystems, at times facilitated by restoration. Recovery is a concept with varied definitions and trajectories of recovery can differ depending on the nature of the pressure and the system. This session invites participants to share research and monitoring on the recovery of seagrass ecosystems, particularly on the trajectories of recovery and how the structure, function and ecosystem services of seagrass ecosystems change following degradation and during recovery. As restoration can also be used to initiate recovery or supplement natural recovery processes this is also of interest. We welcome presentations on recovery at the level of seagrass structure (e.g. area, biomass, cover), function (e.g. productivity, nutrient uptake) or ecosystem service (e.g. carbon storage, provision of fisheries). This could include submissions on definitions of recovery, metrics to measure recovery, timescales of recovery and factors that influence recovery. We want to uncover the latest news from practitioners, managers and researchers on seagrass recovery.

Talks:

Widgeongrass: The seagrass of the future in a warming Chesapeake Bay

Christopher J. Patrick, Virginia Institute of Marine Science; Marc Hensel, Virginia Institute of Marine Science; David Wilcox, Virginia Institute of Marine Science

Climate change and local stressors are not only causing loss of foundation habitats worldwide, these drivers are also causing changes to the identity of species forming foundation habitats. Changes to species identity can fundamentally change ecosystem dynamics, posing a unique managerial challenge. In the Chesapeake Bay, summer temperature extremes have caused widespread loss of the dominant foundation species eelgrass (*Zostera marina*). Using 36 years of data on SAV coverage and environmental drivers, we reveal that much of the previously eelgrass-dominated Bay is now occupied by a temperature-tolerant foundation species, widgeongrass (*Ruppia maritima*). The shift from a species with a resistant (eelgrass) to a more resilient life history (widgeongrass) has changed temporal dynamics of Chesapeake Bay SAV (submersed aquatic vegetation), driving both the much-lauded recent recovery and subsequent crash, the largest in the last 40 years, in total SAV across the Bay. While widgeongrass is heat tolerant, it is more sensitive than eelgrass to declines in water quality during the spring when new shoots are too short to exhibit ecosystem engineering capabilities. For the Chesapeake Bay, this indicates that nutrient management efforts to reduce inter-annual variation in water quality have greater importance than ever before. Worldwide, this case study suggests that climate change may select, at least initially, for opportunistic foundation species present in the system that grow and reproduce quickly (e.g. resilient), but lack resistance to punctuated disturbances that are typical of system dynamics. Given the many functions provided by foundation habitats, shifts toward instability may have far reaching consequences.

Return of multiple ecosystem services after eelgrass (*Zostera marina*) transplantations in Danish estuaries

Rune C. Steinfurth, Department of Biology University of Southern Denmark; Troels Lange, Department of Biology University of Southern Denmark; Timi L. Banke, Department of Biology University of Southern Denmark; Paula Canal-Verges, Department of Biology University of Southern Denmark; Mikkel Keller Lees, Department of Biology University of Southern Denmark; Niels Svane, Department of Biology University of Southern Denmark; Mogens R. Flindt, Department of Biology University of Southern Denmark

Eelgrass (*Zostera marina*) habitats have declined massively during the last century in Denmark because of anthropogenic disturbances, primarily eutrophication. Several important ecosystem services (ES) have disappeared along with it, contributing to a further deterioration of ecosystem functions. The United Nations has called for ecosystem restoration to be the primary strategy to counteract loss of important ecosystems. In Denmark, seagrass restoration has been implemented in the national water action plans, as a marine measure to negate the effects of land-based run-off. Researchers at the University of Southern Denmark have had the responsibility to develop this marine measure and to monitor the associated improvement of ES. Three large-scale (>5.000 shoots) eelgrass transplantations have been successful in Danish estuaries. The restored beds have developed shoot densities equivalent to natural eelgrass meadows. This presentation highlights the return of multiple associated ES such as blue carbon, nutrient sequestration and improvements in biodiversity.

Predicted warming intensifies the negative effects of eutrophication on tropical

Pedro Beca-Carretero, Department of Oceanography, Institute of Marine Research (IIM-CSIC), Vigo, Spain; The Dead Sea-Arava Science Center, Tamar Regional Council, Neve Zohar 86910, Israel; Department of Theoretical Ecology and Modelling, Leibniz Centre for Tropical Marine

Research, Bremen, Germany; Tomás Azcárate-García, The Dead Sea-Arava Science Center, Tamar Regional Council, Neve Zohar 86910, Israel; Institute of Marine Sciences (ICM-CSIC), Passeig Marítim de la Barceloneta 37-49, Barcelona 08003, Catalonia, Spain; Mirta Teichberg, Leibniz Centre for Tropical Marine Research (ZMT) GmbH, Bremen, Germany; The Ecosystems Center, Marine Biological Laboratory, Starr 7 MBL Street Woods Hole, MA 02543, United States of America; Priyanka Patra, The Dead Sea-Arava Science Center, Tamar Regional Council, Neve Zohar 86910, Israel; Farhan Feroze, The Dead Sea-Arava Science Center, Tamar Regional Council, Neve Zohar 86910, Israel; Maria J. González, Department of Oceanography, Institute of Marine Research (IIM-CSIC), Vigo, Spain; Isabel Medina, Department of Oceanography, Institute of Marine Research (IIM-CSIC), Vigo, Spain; *Gidon Winters*, The Dead Sea-Arava Science Center, Tamar Regional Council, Neve Zohar 86910, Israel

Famous for its coral reefs, the Gulf of Aqaba (the northern Red Sea) also supports extensive seagrass meadows, dominated by *Halophila stipulacea*. Nutrient loading and warming are considered the biggest threats to seagrass meadows, and their combination can potentially amplify their negative effects. We exposed two seagrass populations with different eutrophication "history" to control (27ºC) and simulated warming (31ºC), with and without nutrients (20 µg DIN). Results showed that exposure to only thermal stress actually favored growth, while exposure to only eutrophication reduced F_v/F_m and elongation but favored algal proliferation. Combined effects negatively enhanced seagrass performance with the highest mortality rates observed after four weeks of combined exposure. Negative effects of combined stressors were stronger in the population with low eutrophication "history". Lipidomic analyses showed stress significantly decreased ratios of the fatty acids 16:3n-3/16:2n-6 and 18:3n-3/18:2n-6 with bigger declines in these ratios following exposure to the interaction of both stressors. These results have important ecological and management implications to the seagrass meadows in the GoA and elsewhere. Recent studies showed that the GoA's water is actually warming faster than the average of the world's coastal warming trends. While it might be difficult to directly control the effects of ocean warming, sources of eutrophication are usually on local scales, due to anthropogenic activity such as coastal development and terrestrial runoffs from local agricultural fields. For seagrasses to survive climate change, managers must put efforts into limiting other stressors such as eutrophication that would reduce the resilience of meadows to future changes.

Spatial and Temporal Distribution of Intertidal Seagrass Meadows at Banc d'Arguin

Mohamed Ahmed Sidi Cheikh, Caisse dépots et developpement; ME. Hacen, University of Groningen; OY. Lemhaba, Parc National of Banc d'Arguin; S. Bandeira, University of Moputo; M. Poutouroglou, WRI

Since the beginning of the 20s, seagrass beds have undergone considerable human anthropogenic pressure, which is at the origin of their strong regression in several sites around the world. This degradation has caused a major disturbance in biodiversity due to the loss of ecosystem services provided by these habitats. However, in the West Africa region, scarce knowledge is available on the spatial and temporal variation as well as on the conservation status of seagrass meadows. This study aims to investigate the current trend of the dynamics of seagrass beds in the Banc d'Arguin National Park. This world heritage site shelters the largest area of seagrass beds in West Africa, and constitutes the most important East Atlantic Flyway for seabird migration. The combined analysis of remote sensing imagery coupled with field surveys allowed the mapping of

the abundance and spatiotemporal distribution of the *Zostera noltei* species. The results showed an increase of the seagrass coverage since the 1990s. To explain the variability observed, several abiotic factors were tested on three topographic levels of the mudflat complex. The most marked variations in the seagrass beds seem to be explained by specific conditions related to climate drivers such as dust loading. Beyond the causes of inter annual variation, the intertidal seagrass of the Gulf of Arguin showed a rapid natural regeneration. This work demonstrates also a strong sensitivity of the ecosystem to climate change impacts and supports the hypothesis that the protection status of this park promotes resilience to stressors of natural origin.

Envisioning the future for seagrass ecosystems under climate change: critical role of nutrient management for a vegetated Chesapeake Bay

Marc J. S. Hensel, Virginia Institute of Marine Science; Christopher J. Patrick, Virginia Institute of Marine Science; Jonathan S. Lefcheck, Tennenbaum Marine Observatories Network; David J. Wilcox, Virginia Institute of Marine Science

Climate change puts undue pressure on coastal seagrasses because novel environmental conditions threaten foundation species that support fisheries and coastal protection. Habitat management usually operates off of past knowledge but evidence suggests that future ecosystem change is uncharted by historical observations. Thus, predicting a future that is outside of the realm of the past is a critical challenge in creating a sustainable relationship between humans and nature. Here, we explore future scenarios with a novel predictive modelling technique to project how climate change (i.e., temperature and rainfall) and human activities (i.e., nutrient management) will affect the four major seagrass communities of the Chesapeake Bay over the next 40 years. While we find that temperature extremes will exacerbate shifts in dominant foundation species identity, we identify a crucial role for expanded nutrient reductions to mitigate the risks of future human activities to bay grasses. Increased nutrient management generates the only future with any temporal stability for all seagrass communities, and supports large-scale expansion of climate-tolerant plants in the mid- and upper-bay to fuel total Chesapeake vegetated area. Ecological predictions allow us to identify options for better managing our relationship with ecosystems, and seagrasses should be at the forefront of predictive ecology and foresight-driven management of a changing coastal seascape. Because adaptations, acclimation, and recovery potential across temperate and tropical seas elevate seagrass foundation species as a potential winner in the Anthropocene, predicting the future for seagrass ecosystems is the path forward to create a sustainable relationship between humanity and nature.

Monitoring reveals similar recovery progress among sediment-tube-based propeller scar restoration approaches

Savanna Barry, University of Florida; Nature Coast Biological Station, Cedar Key, FL; Shelby Thomas, University of Florida, School of Forest, Fisheries, and Geomatics Sciences, Apollo Beach, FL; Conor MacDonnell, University of Florida, Florida Sea Grant, Gainesville, FL; Brittany Scharf, University of Florida, School of Forest, Fisheries, and Geomatics Sciences, Ruskin, FL; Josh Patterson, University of Florida, School of Forest, Fisheries, and Geomatics Sciences, Apollo Beach, FL

Propeller scaring is a growing problem in Florida’s coastal waters, especially high traffic, shallow areas. In 2018, propeller scars within a seagrass bank near Crystal River, FL were

restored using the sediment tube approach. Different restoration treatments (tubes alone, tubes + planting, tubes + planting + cage, and unrestored control) were applied to a subset of scars. These scars (n = 4 for treatments, n = 2 for control) underwent quarterly monitoring for two years where percent total seagrass cover, percent cover by species, and blade lengths were measured in five randomized 0.25 m^2 quadrats per scar and two quadrats from undisturbed seagrass adjacent to each scar. After 2 years, total seagrass cover in treatment scars ranged from a mean ± SEM of 38.6 ± 4.6% (tubes alone) to 44.7 ± 6.8% (tubes + planting + cage) while untreated control scars had only 0.3 ± 0.1% cover. Adjacent, undisturbed seagrass cover ranged from 73.8 ± 10.8% (tubes alone) to 83.8 ± 8.2% (tubes + planting + cage) for treatments and 97.5 ± 2.5% for unrestored control. At two years post-restoration, scars that received tubes, regardless of planting or caging, reached total seagrass % cover that was slightly more than 50% of adjacent seagrass cover values while unrestored scars showed no signs of recovery. This suggests investment in plantings or cages provide no additional benefit in this system and tubes alone are sufficient to achieve restoration goals. Ongoing investigation into species composition and temporal dynamics may yield a more nuanced understanding.

Hurricanes and Humans: Conflicts in seagrass restoration and mitigation efforts

Paul A. X. Bologna, Montclair State University; Robert Fiorile, Matrix New World Engineering

Natural and anthropogenic disturbances reset the clock in seagrass recovery and restoration. Over the last 20 years we have been conducting both restoration and mitigation for seagrass losses to enhance ecosystem services. In several locations we have demonstrated long-term success (>10 years), including survival post Super Storm Sandy in 2012, only to find these sites devastated by human activities like aquaculture and shoreline stabilization. While both of these activities provide economic and ecological benefits, it presents a dilemma in sighting new areas for restoration. While modeling efforts demonstrate the potential to identify high priority regions for restoration activities, multiple competing groups may also be designating these regions for their activities. In New Jersey, the eelgrass (*Zostera marina*) distribution is relegated to shallow water due to reduced water clarity and restricted to one remaining coastal lagoon. These shallow regions are also favored by aquaculture for access during low tide, as well as near shore in regions dealing with erosion and sea level rise looking for options to stabilize shorelines. We present the success and challenges for restoration efforts in the context of these user conflicts and potential management solutions.

Degradation and recovery of seagrass carbon stocks under thermal stress: a large seagrass disturbance field experiment

Carolyn J. Ewers Lewis, University of Virginia; S. Tassone, Department of Environmental Sciences, University of Virginia and Virginia; Coast Reserve Long-Term Ecological Research Program; M. Pace, Department of Environmental Sciences, University of Virginia and Virginia Coast; Reserve Long-Term Ecological Research Program; Karen McGlathery, Department of Environmental Sciences, University of Virginia and Virginia Coast Reserve Long-Term Ecological Research Program

Seagrass ecosystems have suffered substantial global losses over the last century, but success stories of large-scale restorations and natural recovery offer signs of hope. Still, the impact of the accelerating stressors of climate change on the resilience and recovery of seagrasses and the ecosystem services they provide are poorly understood. In the Virginia Coast Reserve

Long-Term Ecological Research site, a large-scale restored seagrass site was hit by a marine heatwave in 2015 that resulted in a massive die-off and loss of sediment carbon stocks. However, the meadow was not impacted uniformly, and it is believed that differences in water temperatures and residence times played a key role in the degree of impact of the heatwave and recovery thereafter. We set up the largest in situ seagrass disturbance experiment to date in two areas of the meadow that experience differing degrees of thermal stress to 1) measure the impact of seagrass loss, as would be experienced during a heatwave, on sediment carbon stocks, and 2) characterize the recovery trajectory of carbon stocks and sequestration rates in disturbed sites. Using a novel in situ sediment plate method, we tracked changes in surface elevation to quantify changes in sediment accumulation, carbon stocks, and sequestration rates, as well as organic matter and grain size. This study will help elucidate the role of thermal stress in seagrass carbon stock preservation during disturbance and recovery trajectories concurrent with seagrass recolonization.

A process-based modelling approach to assessing soil carbon assimilation and sequestration in eelgrass meadows

Siti Maryam Yaakub, DHI Water & Environment; Danielle Su, Kadri Kuusemae; Dayna Hui, Rikke Margrethe Closter; Erik Kock Rasmussen; Anders Chr. Erichsen; Jessica Hinojosa

Seagrass meadows are effective carbon sinks, but the rate of carbon assimilation and sequestration varies greatly. Manual assessments of carbon accumulation are both laborious and time-consuming. Here we explore the use of process-based dynamic models evaluating carbon accumulation over time in eelgrass meadows. We conducted a pilot study modelling rates of carbon sequestration in two eelgrass (Zostera marina) meadows – one in the Chesapeake Bay and a second meadow in the costal inlets of South Bay using a previously established eelgrass model for Danish estuaries created using the MIKE ECO Lab module in MIKE Software. We modelled two scenarios at each site; with eelgrass present and without eelgrass present to compare accumulation rates in soil organic carbon. Results of the model runs in Chesapeake Bay showed good calibration with monitoring data of key water quality parameters collected from stations within Chesapeake Bay. Accumulated carbon content (g C/m2) in eelgrass meadows was approximately two times that of areas without eelgrass in Chesapeake Bay, whereas it was more than twice in the coastal inlets of South Bay. This pilot study demonstrates the portability and scalability of process-based models and paves the way for using biogeochemical models as a faster and cost-effective approach to understanding carbon accumulation rates in eelgrass meadows. This is an important component that contributes towards understanding and managing eelgrass meadows and their capacity to act as effective carbon pools.

***Halodule uninervis* above- and belowground lipids in varying environmental conditions in Tambac Bay, Philippines**

Caroline Marie B Jaraula, University of the Philippines, Marine Science Institute; William P Dimalanta, University of the Philippines, Marine Science Institute; Maria Anna Michaela R. De La Cruz, University of the Philippines, Marine Science Institute; Rene N Rollon, University of the Philippines, Institute of Environmental Science and Meteorology

Lipids of the cell membrane is the first line of defense of a cell and have expressed chemical qualities for adaptation to environmental factors. Above- and belowground lipid profile of *Halodule uninervis*, a common and widely distributed seagrass in the Indo-Pacific, is studied. The tropical Indo-Pacific consist of the largest and most diverse bioregion in seagrass species.

Samples were collected from contrasting areas of sedimentation, dissolved oxygen content and open water conditions along a discharge pathway from Tambac Bay to Lingayen Gulf in Bolinao, Philippines. *Halodule uninervis* was present in all sites, even monospecific in the most turbid, anoxic, hottest (34.4°C) and saline (34.5 PSU) site. As with seagrass lipids in the temperate areas, C16 and C18 fatty acids predominate, comprising 92% to 99% of the total fatty acids. We verified this in the above- or belowground components. The tri-unsaturated moiety, C18:3, linked to photosynthetic activity, is consistently higher in aboveground components than in their belowground counterparts. Moreover, C18:3 systematically varies with seagrass density. Aboveground component of *H. uninervis* has a carbon range C_{21} to C_{25}, whereas below component has longer chain components, C_{21} to C_{29}. Odd-numbered carbon predominance in the anoxic area reflects better preservation of seagrass lipids, whereas branched hydrocarbons in more open conditions indicate prevalence of oxidative biodegradation.

Posters:

How local environment and neighboring habitat influence seagrass stability – a 13 year case study

Alyson Hall, Virginia Institute of Marine Science; Enie Hensel, Virginia Institute of Marine Science; Michael Hannam, National Park Service; Donald Weller, Smithsonian Environmental Research Center; Dave Wilcox, Virginia Institute of Marine Science; Christopher J. Patrick, Virginia Institute of Marine Science

Seagrasses create biogenic habitats that are threatened worldwide due to climate change and human activities. Seagrass meadows are stabilized through positive feedback loops that include interactions between the meadow and the abiotic environment, other organisms, and itself. Importantly, these feedback loops can improve local water quality, buffering local stressors, and thus prevent future die-off through patch persistence and recolonization within the meadow. However, few studies have quantified this to date. Here, we leveraged interannual, spatially explicit seagrass and water monitoring data from the St. Mary's River in the Chesapeake Bay and quantified how neighboring seagrass density (e.g., percent cover and patch proximity) and environmental conditions interact to affect local-scale stability of *Ruppia maritima*. Examining 10 m2 patches, local seagrass stability (i.e., presence) was defined as either not present, newly colonized, or persistent. Using a Bayesian hierarchal occupancy model, we found that the probability of seagrass colonization and persistence was positively related to neighboring density but responded to different environmental conditions. Specifically, colonization was positively related to salinity and negatively related to water depth and =total suspended solids, while patch persistence was only negatively related to depth. Our work quantifies how intraspecific facilitation can influence stability ranging from dense to sparse seagrass patches, and how high density can buffer whole meadow loss under declining environmental conditions. Our findings provide a framework for considering patch configuration for effective conservation and restoration plans and how thoughtful density goals may improve resilience to degradation.

Where does the plastic go? Microplastic loading in seagrass

Angela Capper, CQUniversity; K.L. Jones, Heriot-Watt University; M.G.H. Hartl, Heriot-Watt University; M.C. Bell, Heriot-Watt University; A. Irving, CQUniversity; A. Anastasi, CQUniversity

Plastic pollution from anthropogenic activities on land and sea is a ubiquitous global issue. Much less conspicuous is the extent of microplastics (<5 mm) contamination. Microplastic fibres, fragments and particles, which sorb multiple contaminants, are now found in every aquatic ecosystem, including seagrass habitats. These highly dynamic habitats reduce water velocity, increasing the settling of small particles. In a recent study in Orkney, Scotland, we found microplastics adhered to biofilms on *Zostera marina* blades, with likely trophic transfer to important seagrass grazers. Microplastic loading was also significantly higher in *Z. marina* sediments than bare adjacent sediments and sediment grain size may be linked to trapping capability. Seagrass may actually play a beneficial role in trapping microplastics and reducing flux to offshore habitats. An ideal location to investigate this potential buffering role is Gladstone, central Queensland, Australia, where seagrass (predominantly *Z. muelleri*) are often referred to as the 'kidneys of the Great Barrier Reef'. The results of this research will be discussed: (1) microplastic loading of seagrass beds in relation to urban and industrial proximity; (2) microplastic trapping capabilities as a function of sediment grain size; and (3) the potential impacts of trapping and adherence on seagrass productivity in leaves and root systems. This research will provide vital information on the impacts of microplastic contamination in seagrass ecosystems.

Restoring eelgrass meadows following invasion of the European green crab in Placentia Bay, Newfoundland, Canada

Elanor Dillabough, Marine Institute of Memorial University of Newfoundland; A. Le Bris, Marine Institute of Memorial University of Newfoundland; T Prystay, Marine Institute of Memorial University of Newfoundland; C Brennan, Marine Institute of Memorial University of Newfoundland; G Adams, Marine Institute of Memorial University of Newfoundland; M Clarke, Marine Institute of Memorial University of Newfoundland

Following the invasion of the European green crab in 2007 in Placentia Bay, Newfoundland, the percent cover of eelgrass decreased by 50% to 100% at several sites. This decrease was accompanied by a 10-fold decline in fish abundance and biomass. In 2017, as part of Canada's Ocean Protection Plan, restoration for eelgrass was initiated in Placentia Bay. The first objective was to reduce local density of green crab through a mitigation fishery, as the main stressor for eelgrass. Between 2017 and 2021, around 375 metric tons of green crab were removed from Placentia Bay. Preliminary analyses suggest that, while catch rates are still high, average size of green crab has significantly decreased. The second objective was to facilitate the recovery of seagrass extent at five sites using a combination of restoration techniques, including sod transplants and seed bag deployments. Recovery of seagrass meadows extent was apparent at two sites 2 to 3 years after the start of restoration activities. Restoration was less successful at two other sites and ineffective at one site. Green crab catches rates did not explain restoration success rates. Proximity of remaining eelgrass and sediment types seemed to better explain restoration success rates. Future monitoring will help better understand the factors influencing recovery and help evaluate if eelgrass restoration benefited local fish diversity, density and biomass.

Intertidal seagrass restoration in the UK -Pilot study assessing the potential for re-establishment of ecosystem services

Emma A. Ward; Bronwen Paxton; Hannah Stead; Tim Ferrero; Ian Hendy; Joanne Preston

Seagrass habitat provides a wealth of ecosystem services including increased biodiversity, carbon sequestration and nutrient filtration, yet is suffering major declines globally. In the UK historic loss of seagrass (44-92%) highlights the scope for restoration to restore associated ecosystem services. This pilot study focused on restoration of intertidal Zostera noltei off the South Coast of England. Restoration happened in three stages, spathe collection, seed preparation and seed deployment. Z. noltei spathes were collected on foot from seagrass beds adjacent to the restoration sites. Over 21,000 seeds were extracted after a 3-month rotting process and seed separation. Seeds with mixed sediment were placed in hessian pouches at densities of 15 seeds bag^{-1} and 30 seeds bag^{-1} . Seed pouches were deployed on foot at 60cm intervals across two restoration sites of low (43 seeds m^{-2} , 15 seeds bag^{-1}) and high density (82.5 seeds m^{-2} , 30 seeds bag^{-1}) in December 2021. Effectiveness of restoration trials to increase ES provision will be assessed with a Before-after-control-impact (BACI) design. Seasonal monitoring of the restoration sites and three reference seagrass meadows will be conducted for: seagrass metrics (abundance, shoot density, blades $shoot^{-1}$, blade length and width), habitat biodiversity (infauna and epifauna) and carbon storage (sedimentary standing stock, plant productivity and algal mat biomass). This will assess the potential for seagrass restoration activities and the synergistic reestablishment of ecosystem services, in temperate intertidal seagrass habitat. Quantification of a broad range of ecosystem services will support the upscale of seagrass restoration and commercialisation through stacked ecosystem finance accreditation.

A trajectory of *Zostera marina* ecosystem recovery, pre- and post-Hurricane Sandy degradation in Barnegat Bay, New Jersey

James J. Campanella, Montclair State University, Dept. of Biology; Paul A.X. Bologna, Montclair State University, Dept. of Biology; Abdullah Alhaddad, Montclair State University, Dept. of Biology; Adi Ackerman, Montclair State University, Dept. of Biology; Julia Kopell, Montclair State University, Dept. of Biology; Edgar Medina, Montclair State University, Dept. of Biology; Nicole Rodriguez Ortiz, Montclair State University, Dept. of Biology; Mya Theodore , Montclair State University, Dept. of Biology

In 2010/2012, studies were published examining the population genetic structure of both natural and restored *Zostera marina* in Barnegat Bay, NJ. In late 2012, Hurricane Sandy struck Barnegat Bay, scouring the sea bed, ripping up extensive beds of *Z. marina*, and causing major benthic ecosystem disruptions. The results of those previous studies suggested low heterozygosity, low connectivity, and high levels of inbreeding among both natural and restored populations. After such devastation, we became concerned with the fate of these plant populations that were already threatened by such serious genetic issues. This present study tracks the trajectory of the Barnegat Bay *Z. marina* ecosystem over a period of 12-13 years before and after the major disturbance of the hurricane. In 2021, we collected populations of eelgrass (N=30/population) from grass beds throughout the bay (Oyster Creek, Ham Island, Connective Sedge, Rt.72 South, and Barnegat Inlet). Additionally, we obtained frozen stock populations from 2013 and 2017 (Oyster Creek 2013 & 2017, Connective Sedge 2017, Ham Island 2017, Barnegat Inlet 2013& 2017) (N=30/population). In combination with the published data from 2010 and 2012, we are ascertaining what genetic changes have occurred in these populations in the decade since they were decimated. We will make historical comparisons of heterozygosity, fixation, diversity, inbreeding, and differentiation, and investigate evidence for genetic drift and bottlenecking.

Additionally, we will compare the genetic structure of theses populations using Markov chain Monte Carlo techniques. These studies are performed in the hopes of obtaining more directed and successful restoration for these populations.

A post-hurricane Sandy examination of the population genetic "health" and diversity of Zostera marina (eelgrass) in Barnegat Bay, New Jersey

James J. Campanella, Montclair State University, Dept. of Biology; Paul A.X. Bologna, Montclair State University, Dept. of Biology; Abdullah Alhaddad, Montclair State University, Dept. of Biology; Adi Ackerman, Montclair State University, Dept. of Biology; Julia Kopell, Montclair State University, Dept. of Biology; Edgar Medina, Montclair State University, Dept. of Biology; Nicole Rodriguez Ortiz, Montclair State University, Dept. of Biology; Mya Theodore , Montclair State University, Dept. of Biology

Hurricane Sandy struck the New York metropolitan region on October 29, 2012. The storm severely impacted the physical state of Barnegat Bay, New Jersey, with its heavy storm surge which scoured the sea bottom, affecting many forms of benthic life and ripping up extensive beds of Zostera marina. Previous studies of the genetic status of Z. marina in Barnegat Bay suggested low levels of heterozygosity and high levels of inbreeding. We are presently examining the long-term effects of Hurricane Sandy on the eelgrass beds of New Jersey. Preliminary data among all population sites studied (Oyster Creek, Ham Island, Connective Sedge, Rt.72 South, and Barnegat Inlet) suggest that present observed levels of heterozygosity are low compared to expected levels (mean Ho = 0.499+0.089 and He=0.560+0.060), indicating worsening diversity. Overall mean inbreeding levels (Fis = 0.202+0.102) indicate little outbreeding within grass beds and the fixation index (mean Fst = 0.175+0.106) suggests low connectivity between populations with a "medium" level of differentiation. Phylogenetic cladograms generated using Chord and Delta Mu distances coincide with Fixation values and indicate differentiation among these populations. This initial analysis suggests that the genetic health of grass beds in Barnegat Bay have declined in the last decade. We continue to study these Z. marina populations with additional polymorphic alleles.

Monitoring reveals similar recovery progress among sediment-tube-based propeller scar restoration approaches

Savanna Barry, University of Florida, Nature Coast Biological Station, Cedar Key, FL; Shelby Thomas, University of Florida, School of Forest, Fisheries, and Geomatics Sciences, Apollo Beach, FL; Conor MacDonnell, University of Florida, Florida Sea Grant, Gainesville, FL Brittany Scharf, University of Florida, School of Forest, Fisheries, and Geomatics Sciences, Ruskin, FL; Josh Patterson, University of Florida, School of Forest, Fisheries, and Geomatics Sciences, Apollo Beach, FL

Propeller scaring is a growing problem in Florida's coastal waters, especially high traffic, shallow areas. In 2018, propeller scars within a seagrass bank near Crystal River, FL were restored using the sediment tube approach. Different restoration treatments (tubes alone, tubes + planting, tubes + planting + cage, and unrestored control) were applied to a subset of scars. These scars (n = 4 for treatments, n = 2 for control) underwent quarterly monitoring for two years where percent total seagrass cover, percent cover by species, and blade lengths were measured in five randomized 0.25 m^2 quadrats per scar and two quadrats from undisturbed seagrass adjacent to each scar. After 2 years, total seagrass cover in treatment scars ranged from

a mean ± SEM of 38.6 ± 4.6% (tubes alone) to 44.7 ± 6.8% (tubes + planting + cage) while untreated control scars had only 0.3 ± 0.1% cover. Adjacent, undisturbed seagrass cover ranged from 73.8 ± 10.8% (tubes alone) to 83.8 ± 8.2% (tubes + planting + cage) for treatments and 97.5 ± 2.5% for unrestored control. At two years post restoration, scars that received tubes, regardless of planting or caging, reached total seagrass % cover that was slightly more than 50% of adjacent seagrass cover values while unrestored scars showed no signs of recovery. This suggests investment in plantings or cages provide no additional benefit in this system and tubes alone are sufficient to achieve restoration goals. Ongoing investigation into species composition and temporal dynamics may yield a more nuanced understanding.

Piney Point Seagrass and Macroalgae Response Monitoring

Sheila Scolaro, Tampa Bay Estuary Program; Marcus W. Beck, Tampa Bay Estuary Program; Maya C. Burke, Tampa Bay Estuary Program; Edward T. Sherwood, Tampa Bay Estuary Program; Gary E. Raulerson, Tampa Bay Estuary Program

From March 30 to April 9, 2021, 215 million gallons of nutrient-rich phosphate mining wastewater and salt water-mix was discharged into Lower Tampa Bay. An estimated 205 tons of nitrogen, the estuary's primary limiting nutrient, was released into Lower Tampa Bay. Because excess nitrogen can create unfavorable seagrass growing conditions, both seagrass and macroalgae communities were monitored as part of a larger monitoring effort in response to the release from Piney Point. Seagrass and macroalgae density and diversity were monitored approximately biweekly along 38, 50-meter transects in Lower Tampa Bay from April to September 2021, with data visualizations available in an open science format. Macroalgae diversity and density varied throughout the monitoring period. Red macroalgae (Rhodophyta) was the dominant phyla observed at all transects, except in June when filamentous cyanobacteria (Dapis spp.) abundance increased. Large floating and benthic mats of cyanobacteria were observed in Anna Maria Sound near the mouth of Tampa Bay and at Port Manatee near the release site. Green macroalgae (Chlorophyta) was observed along transects beginning in July, but at generally low abundances. Overall diversity and density of seagrass remained stable and did not change throughout the monitoring period. Long-term impacts of the Piney Point discharge on seagrass and macroalgae communities in Tampa Bay is uncertain. Continued monitoring and additional data on the long-term seasonal trends of macroalgae and seagrasses is needed to better understand the results of the 2021 response-based monitoring.

Large-scale transplantation success of Zostera marina in Danish estuaries through site-selection and identification of stressor thresholds

Timi L. Banke, Department of Biology University of Southern Denmark; Troels Lange, Department of Biology University of Southern Denmark; Rune C. Steinfurth, Department of Biology University of Southern Denmark; Paula Canal-Verges, Department of Biology University of Southern Denmark; Mikkel Keller Lees, Department of Biology University of Southern Denmark; Niels Svane, Department of Biology University of Southern Denmark; Mogens R. Flindt, Department of Biology University of Southern Denmark

In Denmark, seagrass habitats have undergone a massive decline and less than 10 - 20 % remains today, which is similar to the global decline tendencies of seagrass. This has resulted in a growing interest in restoring seagrass habitats and is in Denmark planned to be implemented as a marine measure to reach a good ecological status in according to the EU Water Frame Directive

(WFD). Researchers from the University of Southern Denmark have since 2014 been developing and testing technics to successfully restore eelgrass (Zostera marina). Through identification of stressor thresholds (e.g. nitrogen loading parameters and destructive bioturbation) and careful site-selection three large-scale transplantations (> 5.000 shoots) of Zostera marina have been successfully established. These large-scale transplantation efforts have reached shoot densities similar to those of natural meadows within app. two years. The transplantations were made in the shallow Danish estuaries (one in Horsens Fjord and two in Vejle Fjord) and are one of the few examples of a successful large-scale restoration of seagrass in Europe. This presentation highlights the site-selection process, the identification of stressor thresholds and the temporal development of the successful transplantations.

Session 2B: Seagrass wasting disease: understanding host-pathogen interactions to ensure success in seagrass conservation & management

Session Convener(s): Randall Hughes, Northeastern University; Forest Schenck, Northeastern University; Torrance Hanley, Northeastern University

The largest reported seagrass die-off was caused by an outbreak of seagrass wasting disease, caused by parasitic protists in the genus Labyrinthula, along both sides of the Atlantic in the 1930's. In a sign of success, eelgrass has largely recovered across this region, and disease outbreaks of similar magnitude have not re-occurred. In addition, we have made great progress in our understanding of wasting disease since it was first hypothesized to be behind the declines of eelgrass in the 1930s. Key highlights include the identification of Labyrinthula spp. as the causative agents of wasting disease, the development of visual and molecular parasite detection protocols, and the identification of environmental factors that moderate the seagrass-wasting disease interaction.

However, wasting disease is endemic throughout the range of eelgrass, and infections have now been observed in all four major seagrass families - Cymodoceaceae, Hydrocharitaceae, Posidoniaceae, and Zosteraceae - suggesting that seagrasses remain at risk of future large-scale outbreaks. This session will bring together seagrass scientists and managers to share our emerging understanding of seagrass-wasting disease interactions, identify remaining areas of uncertainty, and discuss strategies for seagrass management and conservation.

Talks:

Temperature and host characteristics predict large-scale patterns in wasting disease prevalence

Forest Schenck, MA Division of Marine Fisheries; A. Randall Hughes, Northeastern University

Biogeographic patterns in the prevalence of plant and animal diseases arise from interactions between large-scale forcing factors and regional- and local-scale abiotic and biotic processes. Recently, global climate change has coincided with shifts in the distribution of many diseases, suggesting temperature is a key mediator of disease. Past outbreaks of seagrass "wasting disease" have decimated populations of eelgrass, *Zostera marina*, and small-scale studies have identified temperature as well as salinity, nutrients, eelgrass density, and eelgrass leaf length to be mediators of wasting disease. However, the relative importance of these risk factors in determining large-scale patterns of wasting disease distribution has yet to be explored, and this

knowledge gap has limited our understanding of wasting disease and its potential response to global change. We sampled 20 eelgrass beds among oceans and across >20º of latitude in the Northern Hemisphere to document geographic variation in wasting disease prevalence and to examine how a suite of abiotic, biotic, and spatial variables contribute to biogeographic gradients in disease prevalence. Large-scale seawater temperature and local-scale eelgrass density were the strongest predictors of prevalence. The shape of these relationships generally matched predictions from small-scale studies. However, contrary to expectations, seawater salinity and nutrient content were not as strongly related to biogeographic gradients in wasting disease. These results suggest warming seawater temperatures may shift the distribution of wasting disease poleward, but they also highlight the important role of local-scale biotic factors in mediating disease prevalence in this system.

Disease surveillance using artificial intelligence links seagrass wasting disease to ocean warming across latitudes

Lillian R Aoki, University of Oregon; Brendan Rappazzo, Cornell University; Deanna Beatty, University of California – Davis; Lia K Domke, University of Alaska – Fairbanks; Ginny L Eckert, University of Alasksa – Fairbanks; Olivia J Graham, Cornell University; Leah Harper, Smithsonian Institution; Timothy L Hawthorne, University of Central Florida; Margot Hessing-Lewis, Hakai Institute; Kevin Hovel, San Diego State University; Zachary L Monteith, Hakai Institute; Ryan Mueller, Oregon State University; Angeleen M Olson, Hakai Institute; Carolyn Prentice, Hakai Institute; Carmen Ritter, Smithsonian Institution; John J Stachowicz, University of California – Davis; Fiona Tomas, Oregon State University; Bo Yang, San Jose State University; J Emmett Duffy, Smithsonian Institution; Carla Gomes, Cornell University; C Drew Harvell, Cornell University

Ocean warming endangers coastal ecosystem through increased risk of infectious disease, yet detection, surveillance, and forecasting of marine diseases remain limited. Eelgrass (*Zostera marina*) meadows provide essential coastal habitat and are vulnerable to seagrass wasting disease, caused by the protist *Labyrinthula zosterae.* We assessed seagrass wasting disease sensitivity to warming temperatures across a 2,500 km study range over three years by combining long-term satellite remote sensing of ocean temperatures with field surveys from 32 meadows along the Pacific coast of North America. From 2019-2021, wasting disease infected up to 90% of plants and damaged up to 30% of plant tissue across the study range. In 2019, disease prevalence was 3x higher in locations with warm temperature anomalies in early summer, suggesting that the risk of seagrass wasting disease will increase with climate warming. Over the three-year study period, wasting disease severity increased with temperature anomalies in spring, highlighting the importance of local warming in determining meadow disease status. Aerial imagery from annual drone surveys captured significant losses of upper intertidal meadows at some locations. Resilience of local populations to disease is likely important to infection dynamics over time and may interact with temperature effects. Continental-scale surveys were made possible by the Eelgrass Lesion Image Segmentation Application, an artificial intelligence system that quantifies wasting disease 5000x faster and with comparable accuracy to a human expert. This work highlights the value of artificial intelligence in marine biological observing, specifically for the detection of widespread climate-driven disease outbreaks.

Under every stone? Phytomyxid parasites in seagrass meadows

Viktorie Kolátková, University of Victoria; Martin Vohník; Joel Elliott; Ryan Gawryluk

Phytomyxids are a group of obligate intracellular biotrophic protists that have been recognized as parasites of seagrasses for over a century. Since our understanding of their prevalence and diversity in seagrass meadows has historically been based on incidental findings of galls in seagrass shoots, they are generally considered rare in coastal ecosystems and remain overlooked and greatly understudied. However, our recent surveys applying systematic screening and modern molecular methods show that seagrass-associated phytomyxids are most likely ubiquitous and highly diversified microorganisms. In 2017, we began searching for phytomyxid-induced galls in the petioles of the invasive seagrass *Halophila stipulacea* and found evidence of widespread and well-established infection throughout both native and alien *H. stipulacea* populations, with the prevalence reaching up to 50% of infected shoots in some microsites. Subsequent molecular analyses of the 18S rRNA gene of phytomyxids collected from three different species of *Halophila* revealed three host-specific congeneric parasites, indicating that phytomyxids have been long-present and co-evolving with their seagrass hosts. Recently, we also observed this phenomenon in the eelgrasses *Zostera marina* and *Zostera japonica* from the Salish Sea (Northeast Pacific), in which primary phytomyxid life stages - root hair galls - were reported for the first time in the marine environment. Shockingly, unlike much scarcer shoot galls (*i.e.*, the secondary infection), root hair galls were present in >99% of examined eelgrass specimens. As the effect of phytomyxids on seagrass health remains poorly understood, we urge that further research is necessary to assess their ecological role in these vital ecosystems.

Marine herbivores facilitate transmission of a seagrass pathogen

Olivia J. Graham, Cornell University; Natalie Nivlin; C. Drew Harvell

Invertebrate herbivores play key ecological roles in food webs and ecosystem dynamics. Herbivores can positively and negatively influence hosts—by stimulating growth, reducing photosynthesis, or vectoring disease. While herbivores commonly vector terrestrial plant pathogens, their role in transmitting marine plant pathogens remains unknown. Here, we tested three hypotheses to determine if eelgrass (*Zostera marina*) herbivores facilitate transmission of the pathogen *Labyrinthula zosterae* (Lz), the causative agent of seagrass wasting disease: i) Herbivores can directly vector Lz through mouthparts and feces or indirectly via grazing scars. ii) Some herbivores preferentially feed on diseased over healthy eelgrass. iii) Herbivores that consume diseased eelgrass contain Lz. We used three eelgrass herbivores, including amphipods (*Ampithoe lacertosa*), snails (*Lacuna* spp.), and isopods (*Pentidotea wosnesenskii*) in vector experiments, herbivory choice assays, molecular diagnostics (qPCR), and fecal assays. Herbivores did not directly transmit Lz from diseased to healthy eelgrass, but indirectly facilitated disease transmission by increasing disease in eelgrass via grazing scars. In choice assays, amphipods selected diseased over healthy eelgrass, while snails and isopods selected healthy eelgrass. qPCR analyses confirmed that herbivores that consumed diseased eelgrass contained Lz. Finally, Lz was isolated from herbivore feces, demonstrating herbivores that eat diseased eelgrass can pass the live pathogen. This is the first report of herbivores indirectly facilitating the spread of a marine plant pathogen. Herbivore-facilitated pathogen transmission could be more common in marine systems than previously believed and has important implications for plant-herbivore-pathogen interactions. More

broadly, these interactions can have important consequences for disease transmission in the ocean.

Pacific oysters are a sink and potential source of the eelgrass pathogen, *Labyrinthula zosterae*

M. Victoria Agnew, Institute of Marine and Environmental Technology, University of Maryland Baltimore County; Maya L. Groner, Prince William Sound Science Center; Morgan E. Eisenlor, Department of Ecology & Evolutionary Biology, Cornell University; Carolyn S. Friedman, School of Aquatic & Fishery Sciences, University of Washington; Colleen A. Burge, Institute of Marine and Environmental Technology, University of Maryland Baltimore County

Seagrasses and oysters are ecosystem engineers that often co-occur and are vital to the ecological and economic value of coastal ecosystems. Global declines in seagrasses, including *Zostera marina*, have recently been observed in association with multiple factors, including diseases such as seagrass wasting disease (SWD) caused by the protist *Labyrinthula zosterae* (*Lz*). Consequential protection of seagrasses has led to restrictions on oyster aquaculture due to concerns regarding the negative impacts from bivalve aquaculture on seagrass population growth and density. An important aquaculture species, the Pacific oyster (*Crassostrea gigas*), can filter *Lz* from the water, potentially reducing pathogen transmission. However, oysters may be a source of infection if they accumulate and release live *Lz* into the water. We investigated if oyster presence decreases lesion severity and infection intensity in eelgrass, or act as a vector of *Lz*, via laboratory experiments in the San Juan Islands, WA, USA. Oysters and eelgrass were exposed to *Lz* for 24hrs and kept at 11ºC or 18ºC for 13d. The presence of oysters significantly decreased lesion severity and infection intensity, but oysters previously exposed to *Lz* did transmit the pathogen to naïve eelgrass. Temperature did not affect the oysters' ability to mitigate SWD; however, increased temperature caused significantly increased lesion severity and infection intensity in eelgrass shoots. Further research is needed regarding oysters as vectors of *Lz* and to demonstrate these results in the field, but these results have important implications for co-habitation of oysters and eelgrass.

Effects of eelgrass (*Zostera marina*) source identity and diversity on wasting disease prevalence and restoration success

Randall Hughes, Northeastern University; Tay Evans, Massachusetts Division of Marine Fisheries; Jill Carr, Massachusetts Division of Marine Fisheries; Forest Schenck, Massachusetts Division of Marine Fisheries

Eelgrass (*Zostera marina*) serves as a model system both for our understanding of disease in the ocean and for tests of the ecological effects of genetic diversity. Although theory predicts that genetic diversity will decrease disease prevalence, the clear positive effect of eelgrass genetic diversity on plant production and density could instead result in disease amplification through increased transmission. We conducted multiple eelgrass restoration experiments in Salem Sound, MA, to test the effects of eelgrass source identity and diversity on wasting disease prevalence, eelgrass density and percent cover, and ultimately, restoration success. We manipulated the number of source sites as our metric of diversity, with 1-source, 3-source, and 5-source plots. At annual intervals from the time of planting in 2017-8 through summer 2021, we measured eelgrass presence/absence, canopy height, percent cover, and flowering and vegetative shoot density in multiple quadrats within each plot. One year following planting, we also measured

wasting disease prevalence and intensity. We found variation in wasting disease and plant production based on source identity, with the relative performance of source sites generally consistent across experiments. In contrast, there were few clear effects of source diversity on plant metrics, and wasting disease prevalence and intensity were higher in multi-source plots than in single-source plots. These results suggest that using multiple source sites in restoration efforts does not result in increases in plant production as observed in small-scale manipulations of genetic diversity, and this practice may even increase the prevalence and intensity of wasting disease.

Session 3A: Ecosystem ecology: Advances in understanding seagrass and submersed aquatic vegetation ecosystem functioning

Session Convener(s): Cassie Gurbisz, St. Mary's College of Maryland; Lillian Aoki, Cornell University

Ecosystem ecology is the integrated study of living and non-living components of ecosystems and their interactions within an ecosystem framework. The field emphasizes energy and matter flows through an ecosystem and the ecological functions that drive these flows. Ecosystem ecologists aim to understand how changing ecosystem structures, human stressors, climate change, and ecological interactions affect these functions and how, in turn, ecosystem services are affected. The aim of this session is to highlight new work that advances our understanding of these concepts as they apply to seagrass and submersed aquatic vegetation ecosystems. Presentations will touch on primary production and energy flows, biogeochemical cycling, carbon and nutrient dynamics, ecological interactions, feedback processes, and other topics that frame research questions from an ecosystem perspective. In keeping with the conference theme, the session will emphasize but is not limited to research that draws linkages between ecosystem functioning and seagrass recovery.

Talks:

Linkages between seagrass tissue O2 dynamics and ecosystem oxidation and feedbacks revealed using microsensors in situ

Marguerite Koch, Florida Atlantic University; Chris Johnson; Kasey MacLeod; Chris Madden; Ole Pedersen

Water column hypoxia, low tissue pO_2 and H_2S intrusion, a known phytotoxin, are linked to global seagrass decline. While many lab experiments have examined these relationships, only field studies capture the complexity of gas dynamics *in situ*. We examined internal pO_2 and H_2S dynamics in a dominant tropical seagrass *Thalassia testudinum* using microsensors. Based on 12 field deployments (48–72-h) across seasons, we show that *T. testudinum* has a high capacity for daytime leaf oxidation (42–53 kPa) that sustains oxic conditions in its tissues and supersaturates the water column with O_2 (>21 kPa). While internal daytime O_2 is consumed near sunset, positive feedback between seagrass O_2 production and the supersaturated water column going into the night contributes to buffering of internal plant hypoxia at the beginning of the night. Leaf meristems went anoxic/hypoxic (0.6 kPa) at night even with high daytime irradiance, indicating a high ecosystem O_2 consumption, and reliance on water column pO_2 (19 kPa) through leaf pO_2 (9 kPa) to prevent H_2S from entering the meristem at night. Newly recruiting

shoots into bare sediment also had the ability to minimize H_2S intrusion. At ambient irradiance, we only detected H_2S in the meristem when water column pO_2 was hypoxic (<2 kPa) coincident with maximum water column temperatures (33 ^oC), an occurrence likely to increase with global warming. These data reinforce the importance of water quality management to sustain seagrass-dominated systems, particularly in nutrient-enriched estuaries and coastal lagoons.

Assessing the role of light and epibiota in seagrass sulfide incorporation

Katherine Haviland, Cornell University; Robert W. Howarth, Cornell University; Roxanne Marino, Cornell University; Melanie Hayn, Cornell University

Under future climate scenarios, many coastal ecosystems are expected to receive less light as a result of enhanced eutrophication. Eutropic conditions can produce highly sulfidic sediments in seagrass meadows. We carried out a mesocosm experiment assessing levels of sulfide intrusion in seagrass (*Zostera marina*) under various levels of shading, and with and without epiphytes. Light and temperature were continuously monitored during the 8-week experiment, with PAR and porewater sulfide measured weekly. At the end of the experiment we sampled all plants for epiphyte biomass, and leaf and rhizome/root tissue sulfur isotopic composition ($d^{34}S$) and percent sulfur (%S). We saw different relationships between dissolved sulfide and light depending on epiphyte presence. Where epiphytes were present, sulfide decreased as light increased, but the opposite occurred in treatments without epiphytes, suggesting the role of epiphytes in seagrass oxygen transport dynamics. Additionally, we saw responses of $d^{34}S$ and %S to both epiphyte and light treatments, with ^{34}S enriched in the tissues of plants grown in high light and depleted in light-limited plants, while %S followed the opposite pattern. Plants with epiphyte cover had greater %S than those without epiphytes across all treatments, and a higher $d^{34}S$ than plants without epiphytes. Our results indicate that epiphytes impact the relationship between seagrass and sulfide beyond light limitation alone, by impacting sulfide uptake through alterations in gas transport throughout the plant.

Herbivory as a driving force of seagrass species composition and resilience in Caribbean seagrass ecosystems

Fee Smulders, AEW, Wageningen University & Research; J.E. Campbell, Institute of Environment, Florida international University; E.S. Bakker, Netherlands Institute of Ecology (NIOO-KNAW); J.A. Vonk, IBED, University of Amsterdam; M.J.A. Christianen, AEW, Wageningen University & Research

Global warming and anthropogenic impacts as the introduction of exotic species can alter the local ecological equilibrium of coastal ecosystems, by shifting plant-herbivore and other ecological interactions. We studied how seagrasses respond to shifts in temperature, nutrients, herbivory and seagrass invasion by performing manipulative field experiments in the Caribbean Sea. We found that herbivores can shape plant communities in invaded seagrass ecosystems: on the one hand sea turtles facilitate invasion, while on the other hand diverse fish communities are able to provide biotic resistance, resulting in spatial patterns of seagrass species dominance depending on herbivore presence. Additionally, in a region-wide experiment, seagrass above- and belowground recovery rates and therefore resilience was found to vary with latitude and was mainly driven by a combination of temperature and herbivore grazing pressure, with implications for plant-herbivore equilibria in a warming sea. Overall, our findings increase our understanding

of seagrass ecosystems in times of change, leading to management recommendations to improve the conservation and restoration of these valuable coastal ecosystems.

The macrobenthic invertebrate assemblage of a newly established intertidal seagrass meadow in SW England

Oliver Thomas, Marine Research Plymouth; Professor Melanie Austen, The University of Plymouth; Professor Martin Attrill, The University of Plymouth; Dr. Dan Smale, The Marine Biological Association; Dr. Lauren Biermann, Plymouth Marine Laboratory

Macrobenthic invertebrate assemblages of intertidal seagrass meadows are poorly studied within the United Kingdom. Elsewhere, existing studies have focused on the macrobenthic assemblages of established meadows, or those recovered from degradation. This study investigated whether the assemblage of a newly established seagrass meadow (<5 years old) differed from surrounding bare sediment. Samples were collected from a 7.3 ha monospecific intertidal *Zostera noltei* meadow situated within the Tamar estuary, SW England. Twenty-five sediment cores were collected along two transects covering both seagrass and bare sediment biotopes. Sediment cores were sieved to 0.5mm and macrobenthos were identified to the lowest possible taxonomic level. Findings demonstrated significant differences between macrobenthic assemblages sampled from bare sediment (<10% seagrass cover/0.5m^2) and seagrass (>10% seagrass cover/0.5m^2). Macrobenthic assemblages did not significantly differ among samples >10% seagrass cover. Mean biodiversity was lower in bare sediment samples (Simpsons Index: 0.52, Delta+: 82.5) than samples collected from seagrass (Simpsons Index: 0.67, Delta+: 85). Bare sediment samples also had a high abundance of opportunistic species, and were classed as *'Heavily disturbed'* on the AMBI Marine Biotic Index. Sediment samples from >10% seagrass cover contained fewer opportunistic species and were classed as 'Slightly disturbed'. In total 55 species were recorded across all biotopes: 45 of which were found in samples with >10% seagrass cover. These findings suggest that, even within a relatively short period of time from initial establishment, intertidal seagrass meadows can significantly alter the benthic communities associated with the underlying sediment.

An agent-based model approach to assessing the role of vegetative fragments in seagrass connectivity

Samantha Lai, National Parks Board, Singapore; Theophilus Zhi En Teo, DHI Water & Environment; Arief Rullyanto, DHI Water & Environment; Jeffery Low, National Biodiversity Centre; Karenne Tun, National Biodiversity Centre; Peter A. Todd, Experimental Marine Ecology Laboratory; Siti Maryam Yaakub, DHI Water & Environment

Understanding how populations in the marine environment exchange genetic material is vital for the implementation of suitable conservation measures. However, dispersal can be challenging to empirically assess as they occur over such vast distances. Increasingly, agent-based models (ABMs) are being used to predict the potential dispersal pathways of populations, including seagrass. Most seagrass ABMs have been based on sexual propagules (i.e. fruits, seeds, spathes), overlooking the potential role of asexual vegetative fragments in long-distance dispersal. In this study, we have developed two contrasting ABMs, *one for vegetative fragments and another for fruits and seeds*, to evaluate (i) the dispersal potential of these two dispersal strategies and (ii) the local and regional seagrass connectivity around Singapore. Our models demonstrated that vegetative fragments could potentially be an effective mode of dispersal, having similar

establishment patterns to fruits/seeds and establishing at greater distances on average. Most meadows were well connected locally and regionally, regardless of the mode of dispersal, although exchange of propagules was uneven between selected sink and source sites. The ABMs identified potential source and sink meadows that should be conserved to provide a repository of genetic material, as well as a supply of propagules for recruitment. We highlight the need to include vegetative fragments alongside sexual propagules when evaluating seagrass connectivity in future modelling efforts.

Local pressures alter seagrass survival to climate change

Jessica Pazzaglia, Stazione Zoologica Anton Dohrn/University of Trieste; E. Dattolo, Stazione Zoologica Anton Dohrn; M. Ruocco, Stazione Zoologica Anton Dohrn; A. Santillán-Sarmiento, Stazione Zoologica Anton Dohrn; A. Terlizzi, Stazione Zoologica Anton Dohrn; L. Marín-Guirao, Centro Oceanográfico de Murcia; *G. Procaccini*, Stazione Zoologica Anton Dohrn

Posidonia oceanica (L.) is one of the most abundant seagrass species in the Mediterranean Sea, ranking amongst the slowest-growing and longest-lived plants on earth. However, sea warming and the occurrence of different anthropogenic pressures result in cumulative impacts that are forcing native populations to respond quickly. In this context, studying populations living under different stress regimes is fundamental for exploring their resilience capacity against further pressures and the molecular background that have favored their survival to past environmental changes. Here, we explored the response capacity of *P. oceanica* plants growing in environments with different nutrient conditions (oligotrophic, Ol; eutrophic, Eu) to altered temperature and nutrients levels and their combination, through a multi-level approach. Performing a mesocosm experiment, we first assessed plants' performances measuring morphological and physiological traits after tress exposures. then we analyzed transcriptomic reprogramming in leaves and shoot apical meristems (SAMs), concluding with the analysis of DNA-methylation. The complex plant's responses underlined that local conditions modulate plant ability to cope with single and multiple stressors, being temperature the most impacting one. The organ-specific vulnerability observed by a different transcriptomic reprogramming indicated that leaves were more vulnerable to nutrient enrichment, while SAMs were particularly affected by heat stress, whose intensity depends on the plant's origin. The dynamics of DNA-methylation observed between plants strengthens the importance of local disturbances in stress responses. These findings could have important implications for conservation and restoration management of seagrass ecosystems underling the relevance of local pressures in driving different responses to climate changes.

Posters:

Trajectories of nutrient flows and ecosystem trophic status in a low-salinity freshwater submerged aquatic vegetation bed

Cassie Gurbisz, St. Mary's College of Maryland; Cindy Palinkas, University of Maryland Center for Environmental Science Horn Point Laboratory; Jeremy Testa, University of Maryland Center for Environmental Science Chesapeake Biological Laboratory; Lora Harris, University of Maryland Center for Environmental Science Chesapeake Biological Laboratory

Chesapeake Bay submerged aquatic vegetation (SAV) has been increasing in abundance, most notably in low-salinity reaches of the estuary. As SAV recovers, the diverse ecosystem services

it provides are also presumably returning to the system. However, most research on submerged macrophyte ecosystem functioning, particularly in relation to carbon and nutrient cycling, has focused on seagrasses in marine waters. Here, we investigate trajectories of restored ecological functioning in tidal fresh upper Chesapeake Bay SAV beds by synthesizing several datasets, including publicly available monitoring data, simulation model output, and a suite of physical and biogeochemical field measurements. Our analyses demonstrate how a large, recovering SAV bed affects regional sediment and particulate nutrient transport and seasonal and long-term carbon and nutrient retention. We also make inferences about how shifts in autotrophic dominance from pelagic production by phytoplankton to benthic vascular plants might impact the overall trophic status of the ecosystem.

The Impact of Artificial Shading on the Seagrasses at Sandals South Coast, Westmorland, Jamaica

Hugh Small, University of the West Indies, Mona; Mona Webber

Jamaica, the third largest Caribbean island, has a coastline of 675 km, lined by mangrove forests, rocky shores and sandy beaches. Beyond the tidal zone lie expansive seagrass meadows which function as fish nurseries, primary producers for the food web, (carbon sequestration) and sediment stabilizers. Seagrasses in Jamaica are poorly described with few studies conducted on their ecology and value in providing ecosystem services.
The paucity of attention to seagrasses in Jamaica, evidence of their losses through direct and indirect factors and the non-existent understanding of the impact of light loss on the seagrasses are the reasons for this study. The opportunity to conduct this investigation was created by the construction of over-water structures (bungalows) which cause differential shading of a Thalassia testudinum dominated seagrass bed on Jamaica's south coast.
Fourteen (14) stations were established for monthly data collection of physicochemical parameters (e.g., pH, DO, turbidity/light attenuation) and T. testudinum biological parameters including shoot density, spatial coverage and blade length. Permanent plots were established to conduct long-term monitoring of light attenuation throughout the duration of the study. Physicochemical parameters (pH, dissolved oxygen and turbidity) were found to be significantly different between stations. Light attenuation was also found to be significantly different with the stations clearly differentiated into shaded and non-shaded. Significant correlations between seagrass cover/density and decreasing light intensity were established. However, contrary to expectations, blade length weakly correlated with light levels. All biological parameters associated with the seagrasses were shown to be deleteriously affected by shading of the bungalows.

Will overgrowth of cyanobacteria hinder submerged aquatic vegetation resurgence in Chesapeake Bay?

Judith M. O'Neil, University of Maryland Center for Environmental Science; Cassie Gurbisz, Saint Mary's College of Maryland; J. Brooke Landry, Maryland Department of Natural Resources; Catherine Wazniak, Maryland Department of Natural Resources; Jeffrey Cornwell, University of Maryland Center for Environmental Science

One of the 'signs of success' in terms of ecosystem recovery in the Chesapeake Bay is the increase in submerged aquatic vegetation (SAV) in response to Chesapeake Bay-wide improvements in water quality over the last several decades. Nowhere is this more profoundly

evident than in the northern portion of the bay at the Susquehanna Flats where the largest (~50 km^2) and most diverse continuous SAV bed has re-emerged after disappearing 50 years ago due to degrading water quality and Tropical Storm Agnes. This SAV bed acts as a significant seasonal nutrient sink, which is important given the large particulate nutrient load delivered to the Chesapeake Bay from its largest tributary, the Susquehanna River. Co-occurring benthic cyanobacteria, dominated by *Lyngbya* (*Microseira*) *wollei*, have been observed proliferating attached to and over-topping the SAV (predominantly *Vallisneria americana*). This may be problematic, as overgrowth of cyanobacteria on SAV leads to reduced light availability and inhibits gas exchange, which ultimately decreases photosynthetic rates of the aquatic grasses and increases sediment anoxia and nutrient fluxes. Consequently, the severity of cyanobacteria coverage can be strongly related to changes in sediment biogeochemistry, SAV losses and sediment stability. It is unclear what is causing increases in *Lyngbya* growth and whether it could threaten long-term SAV recovery and resilience. Therefore, we are investigating how these cyanobacteria are functioning in this system, and what controls the dynamic interplay between the cyanobacteria and SAV in terms of biogeochemical processes, including nitrogen fixation.

Changing foundation species in Chesapeake Bay: implications for faunal communities of two dominant seagrass species

Lauren Alvaro, VIMS; Christopher J. Patrick; Marc Hensel

Foundation species, such as seagrasses, provide many ecosystem functions in coastal habitats and support diverse food webs. Environmental changes and anthropogenic activities are strongly impacting coastal ecosystems globally. When these changes cause shifts in foundation species, whole food webs can be transformed. Thus, there is a need to understand how these changes are affecting coastal ecosystems. Seagrass meadows in the Chesapeake Bay are an ideal study system for studying these impacts, because a shift in the dominant foundation species of two structurally different seagrasses is occurring in the lower bay. Due to rising water temperatures over the last few decades, the once-dominant species, *Zostera marina*, has been declining, while *Ruppia maritima* has been expanding on large spatial scales. To understand how the structure and function of faunal communities differ between *Z. marina* and *R. maritima* meadows, we performed quantitative surveys on epifaunal, nektonic, and infaunal communities associated with these species. Preliminary results indicate that Z. *marina* meadows had higher diversity and richness of epifauna while *R. maritima* meadows had a higher total abundance of individuals. Nekton also had a higher total abundance in *Z. marina* meadows compared to *R. maritima* meadows. Overall, this study advances our understanding of how the shift occurring in the lower Chesapeake Bay impacts the food web and serves as a case study for predicting how changes in the identity of foundation species may affect community structure in other estuaries.

Effects of epiphytes on the thermal tolerances of edge-of-range seagrasses in NC, USA

Mike Wheeler, University of North Carolina Wilmington; Dr. Jessie Jarvis, University of North Carolina Wilmington; Dr. Martin Posey, University of North Carolina Wilmington; Troy Alphin, University of North Carolina Wilmington

North Carolina, USA seagrass meadows consist of two species located at their edge of distributional range: *Zostera marina*, a seasonally heat-stressed temperate species, and *Halodule wrightii*, a seasonally cold-stressed tropical species. Epiphytes, micro- and macroalgae that grow on the leaf surface of seagrasses, have been shown to create a thermal boundary layer with the

potential to alter the temperature of the leaf microenvironment. Warmer nutrient-rich waters associated with climate change and coastal development have the potential to increase epiphyte biomass which may influence and potentially aggravate heat stress in *Z. marina*. However, these same conditions may alleviate cold stress in *H. wrightii* providing a mechanism to withstand winter temperatures. The ability of epiphytes to alter the microenvironment of edge-of-range seagrasses was quantified in two separate laboratory experiments. Seagrasses were collected from Topsail Sound, NC, and placed in treatments with and without epiphytes and under optimal (23°C Zm; 25°C Hw) and stressful (30°C Zm; 10°C Hw) temperatures (N=6). Experiments were run for 6 weeks to mimic in situ stressful conditions, and seagrass structural and physiological responses were quantified bi-weekly. Results of this study will provide understanding of how the interactions between abiotic and biotic stressors may influence the survival and persistence of edge-of-range seagrasses.

Trait and taxonomic diversity of macrophytes shapes benthic community structure in mixed surfgrass, kelp, and wakame meadows

Mizuho Namba, Hokkaido University; Kensuke Ichihara, Hokkaido University; Teruo Tomioka, Hokkaido University; Chikako Nagasato, Hokkaido University

The linkage between the functional trait diversity of foundation species and the community structure of associated fauna has been suggested. However, less is explored about how the traits of the faunal communities and foundation species are linked. We examined the effects of morphological and taxonomical differences of macroalgae and seagrass on the trait and taxonomic-based benthic community structures in mixed macrophyte meadows of Muroran, Hokkaido, Japan. We sampled the benthic fauna attached to above and below-ground parts of three coexisting macrophyte species wakame *Undaria pinnatifida*, kelp *Saccharina japonica*, and surfgrass *Phyllospadix iwatensis* in June 2021. The univariate measures of faunal biomass differed between the morphologically and taxonomically similar *Undaria* and *Saccharina*, but the abundance, species richness, and the taxonomic-based community structure did not vary. By contrast, the univariate measures and taxonomic-based community structures of surfgrass *Phyllospadix* and the two macroalgal species varied significantly, and similar trends were observed in August and October. Moreover, fourth-corner analysis showed that the linkage between the specific traits of macroalgae and benthic fauna appears to explain the abundance patterns of the benthic communities. These results suggest that the morphological and taxonomical differences of macrophyte species shape the benthic community structures in the mixed meadows, and the coexistence of diverse macrophyte species enables taxonomically and functionally diverse fauna to inhabit. We also present that changes in the compositions of foundation species may impact the associated fauna, but the effects may be minimized when functionally redundant species are present.

Seasonal and Spatial Dynamics of the Tropical Seagrass Halophila stipulacea in the Gulf of Aqaba

NetaLy Lipkin, Oceanographic and Limnological Research; Department of Marine Biology, Charney School of Marine Science, University of Haifa; The Interuniversity Institute for Marine Sciences of Eilat, Israel; G. Rilove, Oceanographic and Limnological Research; Department of Marine Biology, Charney School of Marine Science, University of Haifa; G. Winters, The Dead Sea and Arava Science Center (ADSSC), Jerusalem, Israel; Eilat Campus, Ben-Gurion

University of the Negev, Eilat; The Interuniversity Institute for Marine Sciences of Eilat, Israel Israel; J. Silverman, Oceanographic and Limnological Research; Department of Marine Biology, Charney School of Marine Science, University of Haifa; A. Al-Sawalmih, Marine Science Station, Aqaba, Jordan

The tropical seagrass *Halophila stipulacea* occupies extensive areas of the benthos along the Israeli and Jordanian coast in the Gulf of Aqaba (GoA, northern Red Sea). It is also known as a successful invader in the Mediterranean and more recently in the Caribbean Sea. Despite its prevalence and ecological importance within its native region in the GoA, on both sides of the Gulf, *H. stipulacea* receives much less scientific and public attention compared to its coral neighbors. Believing the seagrasses go beyond borders, we have launched a collaboration with scientists from Jordan, aiming to assess the seagrass ecosystem services as well as its vulnerability to climate change in this region. For that, we first explore the patterns and drivers influencing *H. stipulacea*'s temporal and spatial dynamics in two areas of different bathymetry and sediment attributes and at two depths. Specifically, we follow the ecological status of *H. stipulacea* meadows: meadow (% cover, biomass, shoot density), plant morphology (leaf area, % of apical shoots), as well as environmental conditions including water chemistry (Total alkalinity, nutrient content) and sediment composition in permanent shallow (5m) and deep (12m) transects mainly in two areas: the gentle slope of the North Beach and the steep slope of the South Beach. So far, we have found strong seasonality in the plant condition, but also considerable variability among sites and depths that are probably related to local conditions at each site (local sediment type, light, and nutrients). We are currently expanding these monitoring sites into Aqaba (Jordan).

Sulfide intrusion in the seagrass *Halodule wrightii* as assessed by tissue sulfur isotopic composition

Patrick Larkin, Texas A&M University-Corpus Christi; Allyson Girard (1st author), Department of Physical & Environmental Sciences, Texas A&M University-Corpus Christi

Seagrass meadows are important to coastal ecosystems, providing many services to marine fauna and humans alike. However, seagrass populations are declining considerably due to anthropogenic pressures, such as nutrient loading into coastal waters. Excessive nutrient availability in marine environments stimulates the rapid proliferation of phytoplankton, limiting the availability of light in the water column to seagrasses for photosynthesis.This effectively results in anoxic sediment conditions, under which the activity of anaerobic sulfate-reducing bacteria increases, and hydrogen sulfide (H_2S) is allowed to accumulate. This small molecule is known to poison enzymes involved in energy metabolism, yet seagrasses withstand relatively high concentrations of H_2S in their environments. Stable isotope analyses have been helpful in investigating this phenomenon, as the unique isotopic signature of sediment-derived sulfur can be used to trace the uptake of H_2S by seagrasses and its subsequent distribution throughout the plant. There are many factors known to influence the rate of sulfate reduction in marine sediments, including organic matter content, temperature, and dissolved oxygen concentrations. Still, the tissue sulfur isotopic compositions reported for the many species studied to date are wide-ranging, and mechanisms underlying the uptake and distribution of sulfide in seagrass tissues are not fully resolved. The purpose of the present study was to assess sulfide intrusion in the seagrass *Halodule wrightii* from various locations along the Texas Gulf Coast and determine

whether the uptake and distribution of sulfide-derived sulfur in *H. wrightii* vegetation spatially differs in this region.

Session 3B: General/Open Call Session 1

Session Convener(s): Jud Kenworthy, NOAA retired; Penny Hall, FWC retired

This session will include talks and posters covering a range of topics that don't fit perfectly in any of the other WSC sessions.

Talks:

Using Seedlings to Restore *Posidonia* Seagrass

Jason Tanner, SARDI Aquatic Sciences

Since 1949, ~6200 ha of seagrass has been lost off Adelaide, South Australia, primarily in shallow waters, due to increased nutrients. With a concerted effort to reduce nutrient inputs, a seagrass rehabilitation program was commenced in 2002, initially trialling conventional techniques such as transplanting and planting seedlings. However, the relatively high wave energy along the Adelaide coastline resulted in poor success. This high wave energy, as well as high levels of bioturbation, also limit natural recolonization. The use of hessian sandbags has been more promising, as well as relatively low cost, as it works with the life-history of the local *Amphibolis antarctica*, which viviparously produces seedlings that have evolved to entangle in Posidonia root matte. While effective for *Amphibolis*, these bags do not attract recruits of the other large habitat forming genus often lost in temperate Australia – *Posidonia*. Instead, seedlings have to be manually planted into the bags. This has produced established patches that survived to 8 years, and modifications now allow the seedlings to be planted prior to the bags being deployed, eliminating the need for divers. The Seeds for Snapper community program in South Australia now use this technique, and have deployed 800 planted sandbags over the last 2 years.

Understanding the importance of local adaptation and trait-based selection for seagrass restoration success

Elizabeth Andrews, CQUniversity; Emma Jackson, CQUniversity; Andrew Irving, CQUniversity; Craig Sherman, Deakin University

Within the natural environment, intraspecific phenotypic variation enables seagrasses to increase their distributional ranges and inhabit a range of environmental conditions. Insight into whether phenotypic variations among sub-populations are primarily driven by environmentally driven plasticity or local adaptations is required to understand the importance of trait-based selection of propagules to promote the resilience and persistence of restored seagrass meadows. Within Port Curtis, Central Queensland, Australia intraspecific morphological variations have been observed among four genetically differentiated *Zostera muelleri* sub-populations. Assessment of the sub-populations morphometric variability and meadow specific environmental conditions indicate *Z.*

muelleri exhibit a range of morphological characteristics in spring and autumn that may correlate with local meadow environmental conditions, such as light availability. To test whether intraspecific variations in light related traits is primarily due to a strong underlying genetic component, the degree of phenotypic plasticity exhibited by *Z. muelleri* plants under different light treatments was examined within a controlled mesocosm environment. Initial survival rates indicate the *Z. muelleri* plants from all four populations were able to acclimate to reduced light conditions over a three-month period, suggesting light related trait-based selection of *Z. muelleri* from within Port Curtis may not be of high importance for restoration purposes.

Linking population genetics, connectivity, and adaptation in seagrass species with contrasting dispersal strategies

Laura K. Reynolds, University of Florida IFAS, Soil and Water Sciences Department; Savanna C. Barry, University of Florida IFAS, Nature Coast Biological Station; Alexandra L. Bijak, University of Florida IFAS, Soil and Water Sciences Department; Thomas K. Frazer, University of South Florida, College of Marine Sciences; Charles A. Jacoby, St Johns River Water Management District; Christine B. Rohal, University of Florida IFAS, Soil and Water Sciences Department; Jamila Roth, University of Florida IFAS, School of Natural Resources and the Environment

Long- distance dispersal facilitates adaptation and migration in response to environmental change, recovery from disturbance, and overall maintenance of genetic diversity. We used two seagrass species (*Thalassia testudium* and *Halodule wrightii*) distributed across a naturally occurring phosphorous gradient along the Gulf coast of Florida USA to look at the links between dispersal, population connectivity, and adaptation. We expected *Thalassia* to disperse long distances effectively via floating fruits, while we expected *Halodule* to have more limited dispersal since its seeds are negatively buoyant. Analyses confirmed expected differences in long-distance dispersal. While genetic diversity of both species is high, between population differentiation is higher for *Thalassia* (F_{ST} = 0–0.07) than for *Halodule* (F_{ST} = 0.03–0.16). Despite clear differences in dispersal, species responded similarly to environmental change. Plants of both species were significantly shorter in a low phosphorous environment (*Thalassia* 129mm (2.6 SE); *Halodule* 99mm (4.2SE)) and taller in a high phosphorous environment (*Thalassia* 586mm (4.2 SE); *Halodule* 442mm (2.1 SE)). We grew plants from both environments in a common garden. Over six months, *Thalassia* heights became more similar, but an interaction between collection site and time indicated that the taller plants did not remain taller throughout the experiment. *Halodule* plants also became more similar, and there was no significant interaction between site and time. Together, these results suggest that responses to their environments differ for these two species, with phenotypic plasticity potentially being more important for *Thalassia.*

Marine warming and heat waves effects on *Posidonia oceanica* across a longitudinal gradient in the Mediterranean Sea: the importance of a reconstruction technique to forecast seagrass ecology in a changing environment

Patrizia Stipcich, Dipartimento di Architettura, Design e Urbanistica, Università degli Studi di Sassari; Eugenia T. Apostolaki, Institute of Oceanography, Hellenic Centre for Marine Research; Niki Chartosia, Department of Biological Sciences, University of Cyprus; Pavlos T. Efthymiadis, Hellenic Centre for Marine Research; Carlos E. Jimenez, Enalia Physis Environmental Research

Centre (ENALIA); Gabriella La Manna, MareTerra Onlus, Environmental Research and Conservation, Dipartimento di Chimica e Farmacia, Università degli Studi di Sassari; Arianna Pansini, Dipartimento di Architettura, Design e Urbanistica, Università degli Studi di Sassari; Elena Principato, Area Marina Protetta "Isole Pelagie"; Vasilis Resaikos, Enalia Physis Environmental Research Centre (ENALIA); Giulia Ceccherelli, Dipartimento di Chimica e Farmacia, Università degli Studi di Sassari

Global warming and Marine Heat Waves (MHWs) are having large-scale impacts on the seagrasses and their effects on the Mediterranean endemic *Posidonia oceanica* need to be properly defined. This study aimed to sharpen the knowledge on *P. oceanica* response to the warming by correlating the canopy architecture and the productivity of the seagrass to a range of temperature conditions and MHW occurrence, both current and past events. Two correlative experiments, along a Mediterranean longitudinal range, were conducted: one explored the effects of summer 2021 Sea Surface Temperature (SST) and MHWs on *P. oceanica* architecture and the other used a reconstruction technique (lepidochronological analysis) to relate the seagrass productivity to temperature variability and MHW occurrence during shoot life span. The results showed that the mean summer temperature affects the phenological traits of *P. oceanica* (# of leaves, tot leaf area, and % of necrosis) and that heat events change the architecture of the plant by lowering the leaf area. Interesting results were also found relating the past MHWs to the productivity of the seagrass, since rhizome biomass and length have been negatively affected by the number and the duration of MHWs. This study provides fundamental insights about *P. oceanica* changes linked to warming and MHWs, identifying the potential plant indicators assisting future experimental and modelling studies. To the best of our knowledge, this is the first time a reconstruction technique is used to evaluate the effects of past MHWs on the architecture and productivity of a plant species.

OSMOTIC SEAGRASS: osmotic pressure is the only cause of stress responses in seagrasses under desalination brine discharges? Implications for stress biology research and biomonitoring

Fabio Blanco-Murillo, Departamento de Ciencias del Mar y Biología Aplicada, Facultad de Ciencias, Universidad de Alicante; Lázaro Marín-Guirao, Grupo de Ecología de Fanerógamas marinas, Centro oceanográfico de Murcia, Instituto Español de Oceanografía; Jose Luis Sánchez-Lizaso, Departamento de Ciencias del Mar y Biología Aplicada, Facultad de Ciencias, Universidad de Alicante; Claudio A. Sáez, Programa de Doctorado Interdisciplinario en Ciencias Ambientales, Facultad de Ciencias Naturales y Exactas, Universidad de Playa Ancha, Valparaíso

Considering the global change context, seawater desalination is projected to increase in the next decades. The effect of brine discharges from the desalination process on marine ecosystems should be properly assessed to develop a sustainable activity. *Posidonia oceanica*, the most relevant seagrass species in the Mediterranean, has shown to be a good bioindicator of salinity changes, although early warning metabolic aspects are still poorly understood. *P. oceanica* shoots were collected and installed in 9 aquaria where 3 treatments were run for up to 10 days: control (37 psu), salinity increased with artificial marine salts (43 psu) and salinity achieved with desalination brines (43 psu). Samples were collected at 1, 3, 6 and 10 days after exposure and photobiological and biochemical parameters were measured. Moreover, shoot samples were collected to address for phenological changes. Photochemical analyses revealed that effective yield (Df/Fm') and electron transport rate (ETRmax) decreased in the artificial salts treatments, while photoprotection was higher under brines exposure. In terms of oxidative responses, brine

treatment displayed the lowest ratios between reduced and oxidised ascorbate, evidencing greater activation of the reactive oxygen metabolism. Leaf growth was significantly higher in controls while leaf necrosis was lower compared with hypersalinity treatments. Differences in metabolic and physiological responses in *P. oceanica* exposed to brine reveals affection beyond osmotic imbalance; thus, the potential impacts of desalination in laboratory experiments appears to be more appropriate upon using real brines. These descriptors should be considered as biomonitoring tools for the diagnosis of desalination impacts in the field.

Impacts of Coastal Activities and Marine Protected Areas on Seagrass Cover in Zanzibar from 2006 to 2019

Danielle Purvis, School for International Training; Narriman Jiddawi

Seagrass meadows are located abundantly in Zanzibar, Tanzania and provide essential ecosystem services, such as sediment nutrient enrichment and blue carbon sequestration. However, seagrasses have been less researched or protected than other marine ecosystems. Although environmental variables affect seagrass health, evidence suggests that anthropogenic impacts are their greatest threats. The rapid expansion of seaweed farming and tourism and widespread use of harmful small-scale fishing practices in Zanzibar have contributed to the degradation and removal of seagrass meadows, disrupted coastal marine food chains, and reduced local biodiversity that seagrasses support. Public or private marine protected areas (MPAs) protect most of Zanzibar's coastal marine ecosystems, yet evidence is unclear whether MPAs effectively conserve marine ecosystems. Using geographic information systems (GIS) to estimate the change in percent of seagrass cover from 2006 to 2019, we conducted Spearman's rank correlation analyses to identify whether seagrass degradation was correlated with seaweed farming, fishing, or tourism and whether MPA management plans were protective. On average, seagrass cover decreased by 11.76% from 2006 to 2019. Some tourism activities were negatively correlated with seagrass cover, $rs(9) = -0.64$, $p = 0.044$, suggesting that tourism is an important driver of seagrass declines in Zanzibar. No other variables were significantly correlated with seagrass cover decline, though seaweed farming had a weak protective effect on seagrass cover ($rs(9) = 0.28$, $p = 0.426$). To improve seagrass meadow management, plans must identify seagrasses as critical ecosystems, expand seagrass restoration projects, and address harmful practices in the tourism industry and other human impacts.

Posters:

Assessing the oxidative damage and physiological tolerance of the seagrass *Posidonia oceanica* to brine exposure: a field experiment

Fabio Blanco-Murillo; Iván Sola; Lázaro Marín-Guirao; Jose Luis Sánchez-Lizaso; Claudio A. Sáez

Seagrasses are known for their high vulnerability to environmental impacts and salinity changes are among the more conditioning factor which determine meadow development. Hypersalinity caused by brine discharges from desalination plants have been previously assessed but mainly in mesocosm experiments and field approaches have mainly focused on the physiological damage. With the aim of understanding the biochemical mechanisms behind osmotic stress in real conditions for the endemic seagrass Posidonia oceanica, a field experiment was conducted by installing seagrass transplants at 3 distances from a brine discharge. Environmental salinity

was measured at each location showing 3 different salinity conditions: 43 PSU, 40 PSU and 37.3 PSU (control). Leaf samples were collected at 1, 3 and 6 days and frozen at -80oC for posterior analysis. On the 6th day also shoot meristems were collected. Markers of oxidative damage such as hydrogen peroxide and TBARs were measured as well as antioxidants like ascorbate (ASC), dehydroascorbate and glutathione. Preliminary results reveal oxidative damage occurring in plants under the influence of brine discharge both in leaves and meristem. Higher levels of hydrogen peroxide indicate reactive oxygen species production and low concentrations of reduced ascorbate are possibly due to its consumption to cope with oxidative stress. Reactive oxygen metabolism activation could be used as an early warning indicator of posterior physiological damage. Differences with previous mesocosm experiments highlight the necessity of performing field experiments to properly understand the effect of a potential stressor in the environment instead of under controlled conditions.

Persistent Clones and Local Seed Recruitment Contribute to the Resilience of *Enhalus acoroides* Populations Under Disturbance

Jasper Dierick; Thi Thuy Hang Phan; Quang Doc Luong; Ludwig Triest

Human-induced land use in coastal areas is one of the main threats for seagrass meadows globally causing eutrophication and sedimentation. These environmental stressors induce sudden ecosystem shifts toward new alternative stable states defined by lower seagrass richness and abundance. *Enhalus acoroides*, a large-sized tropical seagrass species, appears to be more resistant toward environmental change compared to coexisting seagrass species. In this study, eight populations of *E. acoroides* in four lagoons along the South Central Coast of Vietnam were genetically analysed using 11 polymorphic microsatellite loci to determine how reproductive strategy and extent of seedling recruitment are altered under disturbance and contribute to the persistence and resilience of *E. acoroides* meadows. We classified land use in 6 classed on Sentinel-2 L2A images and analysed the effect of human-induced land use at different spatial scales on population genetic indices including clonal richness and structure, fine-scale genetic structure and genetic diversity. No evidence of population size reductions due to disturbance was found, however, lagoons were strongly differentiated and may act as barriers for seed dispersal. The proportion and size of clones were significantly higher in populations with larger areas of agriculture, urbanization and aquaculture in their surrounding catchments from which we hypothesize that large resistant genets contribute to the resilience of *E. acoroides* meadows under high levels of disturbance. Although the importance of clonal growth increases with disturbance, our study indicates that sexual reproduction and the subsequent recruitment of seedlings remains an essential strategy for the persistence of populations of *E. acoroides.*

When Anthropogenic Sediment Disturbances Collide Over Seagrass Beds

Kirk Cammarata, TX A&M University-Corpus Christi; Carissa Pinon, TX A&M University-Corpus Christi, Life Sciences; Hua Zhang, TX A&M University-Corpus Christi, College of Engineering; Patrick Nye, Ingleside On The Bay Coastal Watch Association; Austin Hamilton, TX A&M University-Corpus Christi, Life Sciences; Collin Kerr, TX A&M University-Corpus Christi, Life Sciences; Jorge Jimenez, TX A&M University-Corpus Christi, Life Sciences

Seagrasses are impacted by a variety of sediment disturbances ranging from erosion to burial. A study of such impacts was performed on *Thalassia testudinum*-dominated mixed seagrass beds along Corpus Christi Bay, TX and adjacent to shipping activities that included large tanker docking and passage, shrimping, dredging and prop scarring. UAS aerial imagery, compared to

prior NAIP imagery, suggested decreasing seagrass presence near a tanker docking terminal. Tug boat prop wash directly impacted seagrasses during docking. Potential sediment impacts were hypothesized to exhibit a gradient away from the terminal. Tanker docking events were captured by light loggers and sediment traps which, respectively, recorded light levels near zero at seagrass canopy height for almost 3 hrs, and >500 g/m^2-d dry sediment settled at 200 m from the terminal. Light attenuation was observed over 800 m away from the terminal. TSS during an undocking operation was 2.7-fold higher compared to immediately prior, and the inorganic content of the sediment was greater during disturbance. Seagrass indicators, including biomass, leaf morphometrics, leaf density, epiphyte biomass, and % inorganic content of epiphytes, exhibited gradients with distance from the terminal to about 500 m. However, some impacts then increased with greater distance from the terminal. A variety of observations suggest erosion from boat wakes and prop scarring dominate this location. Erosional scouring was observed near the terminal in summer, but nearby dredging in winter appears to have resulted in partial burial of seagrasses at the same site. Monitoring efforts were challenged by the rapidly changing anthropogenic disturbances.

The changing Indian River Lagoon and the pursuit of persistent seagrass beds

Lori Morris, St. Johns River Water Management District; Lauren M. Hall, and Charles A. Jacoby, St. Johns River Water Management District, FL, USA

Seagrass is a major structural habitat in the Indian River Lagoon. Maps documented locations and areal extents of beds periodically since the 1940s, and surveys of fixed transects yielded changes in percent cover and depths at the end of the canopy since 1994. Areal extent increased by ~7,000 ha from 1994 to 2009, mean percent cover within beds decreased from ~40% to ~20%, and mean percent cover standardized to maximum transect length remained near 20%. Thus, conditions supported a consistent biomass because cover decreased as areal extent increased. Between 2011 and 2019, ~19,000 ha or ~58% of seagrasses were lost, with offshore ends of canopies moving shoreward and shallower, and standardized mean percent cover decreased to ~4%. These changes coincided with blooms of phytoplankton, and £ 27% of incident subsurface irradiance at 0.9 m was stressful. Decreases in mean percent cover per month of stress became larger when initial mean cover per transect was < 20%, which suggested that the ratio of aboveground to belowground tissues in the expanded and sparser beds led to respiratory demand that was not met by photosynthesis. Despite intermittent improvements in light penetration, widespread recovery of seagrasses has not occurred potentially due to detrimental feedbacks. For example, loss of seagrass exposed sediments to waves, and the resulting disturbance may have hampered recruitment of new shoots. Fortunately, data showed that patches of seagrasses at depths of 0.5–0.9 m persisted for 22–24 years, which suggested that this depth zone could hold the key to recovery.

Upscaling intertidal eelgrass (Zostera marina) restoration enhances restoration success by suppressing an unexpected negative feedback

Max Gräfnings, University of Groningen; Tjisse van der Heide, University of Groningen & Royal Netherlands Institute for Sea Research; Jannes Heusinkveld, The Fieldwork Company Dieuwke Hoeijmakers, The Fieldwork Company; Quirin Smeele, Natuurmonumenten Maarten Zwarts, The Fieldwork Company; Valérie Reijers, Utrecht University; Laura Govers, University of Groningen & Royal Netherlands Institute for Sea Research

Including positive, self-reinforcing feedbacks into restoration designs has proven to be a promising strategy for amplifying coastal restoration success. Targeting density dependent feedbacks in restoration trials show promise for seagrasses, as higher seagrass densities have been shown to facilitate their own survival, growth and reproduction. Recently, high eelgrass (Zostera marina) densities were for the first time successfully restored in the intertidal Wadden Sea. However, contrary to expectations, high restored eelgrass densities (>10 plants/m²) were found to have a self-inhibitory effect in the intertidal zone. High densities resulted in increased sedimentation, which in turn made the plants more susceptible for desiccation and sulfide stress. This result forced the re-evaluation of our restoration goals for intertidal eelgrasses. We therefore studied, in a follow-up experiment, how the size of the restoration area (4, 40 and 400 m²) and seeding density (10 and 50 injections/m²) affected eelgrass survival and sexual reproduction. We found that self inhibition was only prevalent at small spatial scales, due to sedimentation rates decreasing with larger restoration areas. At the largest scale (400m²), eelgrass plants grew larger and produced more reproductive spathes, which resulted in larger second generations in the 2nd year after seeding. Additionally, lower initial seeding densities benefited restoration efficiency, further proving that high eelgrass densities should not be a target for intertidal restoration projects. We conclude that upscaling intertidal eelgrass restoration is not only feasible, but can also be performed effectively if knowledge of ecological feedbacks are incorporated into restoration designs.

Comparative responses of a small-bodied seagrass *Halophila stipulacea* and a large-body seagrass Posidonia oceanica to nutrient enrichment and warming

Mirta Teichberg, Marine Biological Laboratory, Woods Hole, MA, USA; Stephanie Helber, Institute of Chemistry and Biology of the Marine Environment, University of Oldenburg, Wilhelmshaven, Germany; Pedro Beca- Carretero, Department of Oceanography, Institute of Marine Research, Vigo, Spain; Alex Santillan-Sarmiento, Stazione Zoologica Anton Dohrn, Naples, Italy; Hauke Reuter, Leibniz Centre for Tropical Marine Research, Bremen, Germany; Gabriele Procaccini, Stazione Zoologica Anton Dohrn, Naples, Italy; Gidon Winters, The Dead Sea Arava Science Center, Mount Masada, Israel

Determining how seagrasses respond to changing environmental conditions is crucial to understanding the fate of seagrass meadows under future local and global change. In this study, we experimentally tested the effects of *in situ* nutrient enrichment on *Posidonia oceanica*, a key seagrass species in the Mediterranean, and *Halophila stipulacea*, a key seagrass species in the Red Sea, growing under differing ambient nutrient conditions. Field experiments were carried out off the coast of Naples, Italy and Eilat, Israel during the seasonal high temperature peak in each region to capture how nutrient enrichment may impact these two morphologically different species under high temperature conditions. We found that while *P. oceanica* was more severely impacted by nutrient enrichment under high ambient nutrient conditions, decreasing number of leaves per shoot and leaf area index, and changing leaf and rhizome carbohydrate reserves, *H. stipulacea* was more positively affected under similar conditions. Laboratory experiments support some of these findings. Differences in morphological, biochemical, and physiological responses between the seagrasses show how these two species may be impacted by future changes in nutrient availability and warming, which may also have implications in the Mediterranean due to the predicted expansion of *H. stipulacea* in this region.

A new conservation park and changes in governance promote trampling and

seagrass loss

Joel Creed; Thais de Souza Pereira

The intense use of the intertidal and very shallow subtidal coastal zone, including seagrass beds, may lead to localized trampling. In 2011 the Costa do Sol State Park was created nearby one of the largest seagrass beds along the southeast Brazilian coast. We tested the hypotheses that changes in governance: 1) capped increase in visitation; 2) reduced or stopped seagrass damage. Data were obtained from Google Earth, a computer program that renders a 3D representation of Earth based primarily on satellite imagery. Forty images (1985-2021) were used to obtain four measures of visitation visible from space, as well as area measures of damage from trampling (lighter areas). Beach going increased over time and was higher in summer. Trampling was first noted in April 2016 just over a year after governance closed a car park and opened another. The change in car parking modified the public's vision and perception of the beach and concentrated visitors trampling along a narrow high frequency 'path'. Maximum trampled area was found in January 2017 (5653 m2) and minimum area was found in July 2020 (260 m2). Trampling was higher in summer than at other times and seagrass was more damaged after the park was created. The number of cars parked and the closure of Car Park 1 predicted most (R2 = 0.84) of the trampling damage. The COVID-19 pandemic reduced trampling damage, so if trampling was managed (reduced or ceased) in summer we would expect quite rapid recovery of the *Halodule wrightii* beds.

Exploring the public perception of eelgrass in Atlantic Canada: Considerations for management

Tanya Prystay, Marine Institute of Memorial University of Newfoundland; B. Neis, Department of Sociology, Memorial University of Newfoundland; A. Le Bris, Centre for Fisheries Ecosystems Research, Fisheries and Marine Institute, Memorial University of Newfoundland

Societal awareness of the importance of seagrass meadows and the services they provide is crucial for management decisions to be supported by the public. It is generally assumed that public knowledge of the benefits seagrasses provide is limited, yet knowledge differences between sectors is seldom explored. We present findings from an online survey on the perception of eelgrass (*Zostera marina*) and its management by coastal communities in Atlantic Canada. Of the 117 participants, 60% did not work in an environmental conversation related field. Responses revealed that eelgrass meadows play a multi-functional role to the wellbeing of participants, and participants are aware of the services eelgrass provide. Specifically, participants identified fish habitat, water quality maintenance, and coastal protection as the three most important services. Only 51% selected climate change mitigation as a valuable eelgrass service. Perceptions of regional trends in eelgrass meadow extents agreed with recent trends in scientific literature, supporting the notion of using citizen science to monitor local trends. Coastal development, climate change, and invasive species were identified as the most likely drivers of change. Finally, >80% of participants indicated there should be more management (e.g., restoration/protection), and 76% agreed that the public should be more involved in all aspects of management. Hence, our results not only show that the Canadian Atlantic public is familiar with eelgrass, but also support management actions. The public's indication to be more involved in management stresses the need for a robust framework outlining how conservation project managers can include the public moving forward.

Session 4A: Plant-animal interactions that affect success

Session Convener(s): Bradley J. Peterson, Stony Brook University; Ken Heck, Dauphin Island Sea Lab; Bradley T. Furman, Florida Fish and Wildlife Conservation Commission; John M. Carroll, Georgia Southern University; Diana Chin, Stony Brook University; Allison Rugila, Stony Brook University

There is a rich history of plant-animal interactions within seagrass meadows. As foundation species, seagrasses host a diverse array of associated fauna. Although the direct positive impact of seagrass habitat structure on faunal diversity and abundance is widely acknowledged, the role of animals on seagrass productivity and resilience range dramatically from positive to negative. Often these plant-animal interactions even involving the same species change along gradients of environmental stress. This session will present recent work focusing particularly on plant-animal interactions that may affect restoration success. Some presentations will address how animals ameliorate environmental stress. Studies of infaunal bivalves modulating light and nutrient resources to the plant as well as how chemosynthetic bivalves reduce sediment sulfide stress will be discussed. Others will discuss the role that animals play in both positive and negative ways on seagrass reproductive output. The positive impact of epi and infaunal bivalves enhancing seed production as well as the negative impact of seed predators on seed production and subsequent recruitment. The demonstrated negative impact of direct herbivory will be presented with particular attention to impacts on seagrass restoration. Finally, the role of the plant on shellfish restoration will be presented focusing on the impact of the plants CO2 drawdown on recruiting shellfish growth and survival. Animal-plant interactions are critical components of many ecological processes within seagrass meadows affecting seed production and pollination, light and nutrient resource availability, ameliorating environmental stress and disruption of primary production via consumption. Therefore these interactions may have significant consequences on restoration success.

Talks:

Herbivory on Seagrassses: an Evolving Paradigm

Ken Heck, Dauphin Island Sea Lab; John Valentine, Dauphin Island Sea Lab

In the past few decades, much has been learned about the importance of seagrass-herbivore interactions, especially those at low latitudes. A review of this body of knowledge has produced updated evidence for: 1) the widespread and substantial consumption of living seagrass leaves; (2) the role of nitrogen as it influences seagrass consumption by different types of herbivores; 3) factors that underpin the ability of seagrasses to respond to herbivore damage; 4) how food web alterations have affected grazer impacts; 5) how climate-driven poleward movements of tropical herbivores are increasing grazing intensity in temperate meadows; (6) the consumption of seagrass pollen, flowers and seeds; and (7) the effects of human removal of seagrass megaherbivores. After discussing these seven topics we identify gaps that remain in our understanding of seagrass herbivory and some ways in which future studies can help to fill them.

Effects of CO2, light, and invasive amphipod herbivory on eelgrass (Zostera marina) in San Francisco Bay, CA

Christian Tettelbach, Estuary & Ocean Science Center, San Francisco State University
Katharyn Boyer, Estuary & Ocean Science Center, San Francisco State University

Understanding and mitigating the impact of environmental stressors on seagrass restoration can be difficult, particularly in the presence of multiple co-occurring stressors whose interactive effects are poorly understood. In San Francisco (SF) Bay, the invasive amphipod *Ampithoe valida* consumes eelgrass leaves and inflorescences, damaging natural beds and challenging restoration efforts. In addition, high turbidity throughout SF Bay negatively impacts eelgrass through a reduction in light availability. However, as climate change intensifies, it is unclear how the overall influence of these stressors might change in the presence of ocean acidification (OA), whose projected benefit to eelgrass could help to counteract the negative impacts associated with direct herbivory and low light. In order to examine the cumulative effects of *A. valida* herbivory, low light, and OA on eelgrass, we conducted a mesocosm experiment in which plants were exposed to varying levels of CO_2, light, and *A. valida* density. As expected, eelgrass exhibited a negative response to low light conditions and *A. valida* herbivory. Surprisingly, increased CO_2 conditions did not enhance eelgrass growth or biomass as typically seen in other seagrass-OA studies. This lack of CO_2-benefit was likely due to the light levels targeted in this experiment that, while realistic for SF Bay, remain low compared to other seagrass systems. The results of this study further highlight the negative effects of direct herbivory and low light on eelgrass performance, but also support the growing idea that seagrass benefits attributed to OA are not universal and depend on additional environmental factors such as light.

Simulated megaherbivore grazing as a driver of *Zostera muelleri* flowering

Manuja U. Lekammudiyansea,* CSIRO Oceans and Atmosphere, Queensland Bioscience Precinct, St Lucia, QLD, 4067, Australia; Megan I. Saunders, CSIRO Oceans and Atmosphere, Queensland Bioscience Precinct, St Lucia, QLD, 4067, Australia; Nicole Flint, School of Health, Medical and Applied Sciences, CQUniversity, North Rockhampton, QLD, 4701, Australia; Andrew D. Irving, Coastal Marine Ecosystems Research Centre, CQUniversity, Gladstone, QLD, 4680, Australia; Emma L. Jackson, Coastal Marine Ecosystems Research Centre, CQUniversity, Gladstone, QLD, 4680, Australia

Seagrass meadows are an important habitat for iconic megaherbivores like Sirenia (dugong and manatee) and Testudines (sea turtles). Megaherbivore grazing can influence on structuring seagrass meadows and also have been found to relate to seagrass phenological strategy. However, it is unclear whether their grazing patterns drive such changes or if the changes are related to other environmental factors due to the lack of controlled experiments. An aquaria experiment had conducted to find the impacts of turtles and dugong grazing on the timing (i.e., number of days to first and peak flowering), abundance (i.e., the density of spathes and the percentage of flowering shoots) and morphology (i.e., the height and the number of spathes per shoot) of the flowering of *Zostera muelleri.* Prior to flowering season, plants were cropped to 1 cm and 3 cm lengths to represent dugong and turtle grazing respectively (n = 5) and measured the flowering metrics weekly over two consecutive flowering seasons. Cropping had no significant influence on the timing and morphology of flowering while two morphological variables were strongly correlated in both plant groups. However, cropping significantly reduce the maximum density of spathes due to resource allocation differences among vegtative and sexual reproduction. The percentage of flowering was significantly reduced only in 1 cm group

indicating the plant's ability to cope with stress. Results showed that cropping can influence the overall flowering densities but not the timing of flowering which will be a concern for seed-based restoration activities in grazed and designing seed nurseries.

Multiple plant-animal interactions in an eelgrass bed: modelling the impact of shellfish on eelgrass and vice versa

Masahiro Nakaoka, Hokkaido University; Minako Abe Ito, National Museum of Nature and Science; Hiroya Abe, National Institute for Environmental Studies

Plants and animals in seagrass beds affect each other through various processes. Shellfish including aquaculture species such as the Pacific oyster *Crassostrea gigas* are major herbivores that affect eelgrass by consumption of phytoplankton and by nutrient supply. On the contrary, eelgrass can affect shellfish by providing additional microalgal foods attached on aboveground parts (epiphytes). In addition, it has recently been acknowledged that seagrass can locally mitigate ongoing ocean acidification by absorbing CO2, which may positively affect shellfish growth and productivity. We investigated the strength of these multiple interactions between eelgrass and shellfish by a combination of long-term monitoring of abiotic/biotic variables and ecosystem modelling/simulation of nutrient and inorganic carbon dynamics in Akkeshi-ko estuary, northeastern Japan. A three dimensional lower-trophic ecosystem model successfully reproduced spatio-temporal variations of water quality observed by in-situ monitoring. Results of simulation showed that the presence or absence of aquaculture shellfish greatly changes phytoplankton abundance in the estuary, which can indirectly affect eelgrass production. Further simulation assuming future environmental changes revealed that progress of ocean acidification significantly elevated the probability of shell malformation in juvenile oysters, but the negative impact can be ameliorated in the presence of eelgrass bed. These findings suggest that eelgrass-shellfish interactions play important roles in determining ecosystem dynamics at the whole estuary scale. The obtained data are useful for successful conservation of eelgrass beds and adaptive management of sustainable fisheries and aquaculture.

Functional trait complementarity and dominance both determine benthic secondary production in temperate seagrass beds

Melisa C. Wong, Fisheries and Oceans Canada; Michael Dowd, Dalhousie University

Defining relationships between biodiversity and ecosystem functioning (BEF) is key to understanding the consequences of biodiversity loss. Although species functional traits are strongly linked to ecosystem processes, their integration into marine BEF models has been limited. We examined the BEF relationship between secondary production and benthic invertebrate taxonomic and functional diversity for seagrass beds located across a range of environmental conditions. Specifically, we evaluated the role of complementarity (i.e., dissimilarity in species or traits) and dominance (disproportional importance of traits) in determining secondary production using metrics of taxonomic diversity, functional diversity, and functional traits. Here, diversity metrics represent complementarity and functional traits represent dominance. We used elastic-net regression and commonality analysis to evaluate the BEF model, because its properties (i.e., few observations, highly correlated predictors) precluded more standard approaches. Functional richness and five functional traits (crawling, surface deposit feeding (SurDF), living on sediment surface, short lifespan, and semi-continuous breeding) were identified as important determinants of secondary production, explaining 74% of

the variance. SurDF was the most important predictor that acted in isolation, while all other predictors acted together. All six selected variables in three different combinations explained 68% of the total variance in the BEF model. These results indicate that both dominance and complementarity mechanisms were important for the BEF relationship, and explained patterns in secondary production across seagrass beds. We show that inclusion of the functional landscape into BEF models allows implications of species loss to be mechanistically understood, providing insight into the role of fauna in seagrass ecosystems.

Environmental context dependence of positive interactions between chemosymbiotic bivalves and seagrasses

Diana Chin, Stony Brook University (present: University of Florida); Jimmy de Fouw, Radboud University Nijmegen; Tjisse van der Heide, Radboud University Nijmegen (present: NIOZ Royal Netherlands Institute of Sea Research and University of Groningen); Brianna Cahill, Stony Brook University (present: Florida Atlantic University); Kevin Katcher, K2 Consulting
Valerie Paul, Smithsonian Marine Station; Justin Campbell, Smithsonian Marine Station (present: Florida International University); Bradley Peterson, Stony Brook University

Environmental context can change the strength of positive interactions critical to the resilience of coastal foundation species. Lucinid clams, which derive the majority of their nutrition from sulfur-oxidizing gill endosymbionts, facilitate seagrass growth and survival worldwide by decreasing potentially phytotoxic sulfide levels in seagrass sediments. We highlight the results of two factorial mesocosm experiments conducted using different lucinid-seagrass species pairs from Florida, USA and Mediterranean France to determine how environmental stress on seagrasses (reduced light availability and increased sediment porewater sulfide levels) may alter the degree of benefit they derive from association with lucinids. In one study, seagrass tissue growth rates were significantly lower than those in controls when environmental stress was increased in the absence of lucinids. If lucinids were present, seagrass growth was similar to or slightly increased relative to controls. In contrast, seagrass did not survive in the other study without lucinids to decrease very high ambient sediment sulfide levels. Experimental enhancement of environmental stress was not necessary to produce this effect. These two studies provide experimental evidence that lucinid facilitation of seagrasses may range from facultative to obligate depending on environmental context, and suggest two different ways in which lucinids may be incorporated into seagrass conservation and restoration efforts.

Mix or match? Choosing donor beds for eelgrass restoration in San Francisco Bay

Katharyn Boyer, Estuary & Ocean Science Center, San Francisco State University; Keith Merkel, Merkel & Associates; Geana Ayala, Estuary & Ocean Science Center, San Francisco State University; Margot Buchbinder, Estuary & Ocean Science Center, San Francisco State University; Melissa Patten, Estuary & Ocean Science Center, San Francisco State University

Restoration of eelgrass (*Zostera marina*) in San Francisco Bay has progressed considerably in the last decade, with best practices guided by experimentation built into the projects. Here we describe an experiment that tests the source of the donor material transplanted into restoration sites. We asked, should we source transplant material from the nearest natural bed, from a bed similar in environmental conditions, or from a mixture of donor beds to perhaps hedge bets that a suitable source is present in the mix or that complementary traits will be present among the sources? We collected shoots from three beds spanning 15 km, rigged them into paper-stick

transplant units, and planted them separately and all together within six quarter-ha plots. We then tracked coverage using interferometric sidescan surveys, measured shoot densities within patches, and collected shoots to determine shoot characteristics, epiphyte loads, and epibenthic invertebrate abundances and species composition. Coverage was consistently high for the mixture, and most plots had similarly high coverage for the local donor, although another donor that shares similar site conditions elsewhere in the bay also had high coverage in some of the plots. We did not detect differences in shoot densities within patches, shoot characteristics, or epiphyte loads by donor; thus, we were surprised to find epifauna assemblages with higher species richness and diversity in mixed-donor and local-donor plantings. We hypothesize that greater coverage achieved with the mixtures and local plantings improved refuge from predation.

Seagrass *Zostera marina* restoration in the German Baltic Sea enhances biodiversity while biodiversity in turn regulates transplant success

Tadhg O Corcora, GEOMAR Helmholz Centre for Ocean Research Kiel; Angela Stevenson, GEOMAR Helmholz Centre for Ocean Research Kiel; Marvin Lehmann, GEOMAR Helmholz Centre for Ocean Research Kiel; Matteo Lattuada, Landscape Ecology and Environmental Systems Analysis, Institute of Geoecology, TU Braunschweig, Braunschweig, Germany; Katharina Kesy, Aquatic Microbiomes, Institute of Microbiology, University of Greifswald, Greifswald, Germany; Anne Brauer, Aquatic Microbiomes, Institute of Microbiology, University of Greifswald, Greifswald, Germany; Mareike Taphorn, Ludwig Franzius Institute of Hydraulic, Estuarine and Coastal Engineering, Leibniz University Hannover, Hannover, Germany; Boris Schröder, Landscape Ecology and Environmental Systems Analysis, Institute of Geoecology, TU Braunschweig, Braunschweig, Germany; Mia Bengtsson, Aquatic Microbiomes, Institute of Microbiology, University of Greifswald, Greifswald, Germany; Maike Paul, Ludwig Franzius Institute of Hydraulic, Estuarine and Coastal Engineering, Leibniz University Hannover, Hannover, Germany; Thorsten Reusch, GEOMAR Helmholz Centre for Ocean Research Kiel

Seagrasses are responsible for a wide range of ecosystem functions and services, for example enhancing biodiversity, regulating hydrodynamics, and carbon storage. Global losses have driven a rise in restoration efforts, with low success rates and requiring region-specific modifications. The SeaStore project is the first pilot restoration project in the German Baltic Sea. While northern European seagrass beds are often monospecific, consisting of *Zostera marina*, their importance in terms of biodiversity enhancement of associated flora and fauna in relatively homogenous environments is well established. Within SeaStore, restoration via the single shoot method has been carried out at two locations in the southwestern Baltic, chosen for their variety in hydrodynamic conditions, sediment type, and proximity to a natural meadow.

In an attempt to quantify the impact of invertebrates present on site prior to planting, we investigated how spatfall and adult *Mytilus edulis* and *Arenicola marina* act as stressors on the initial transplantation, as well as the pressures added by pioneer herbivores on newly transplanted seagrass shoots. We assess the short-term colonizing speed of these species, along with all macrofauna, comparing differences between sites, and addressing whether colonization rates impact the survival success of restoration works. We contrast the changing community composition with that of adjacent natural meadows, and try to evaluate if and when restored sites reach levels similar to that of a natural meadow.

In addition, we outline lessons learned during parallel works on *Z. marina* seed harvesting and storage, and the potential influence of seagrass-associated biodiversity on these processes.

Positive Ecological Interactions and the Success of Seagrass Restoration

Stephanie R. Valdez, Division of Marine Science, Nicholas School of the Environment, Duke University; Y. Stacy Zhang, University of Chapel Hill's Institute for Marine Science; Tjisse van der Heide, Groningen Institute for Evolutionary Life Sciences, University of Groningen and Royal Netherlands Institute for Sea Research and Utrecht University; Mathew A. Vanderklift, CSIRO Oceans & Atmosphere, Indian Ocean Marine Research Centre; Flavia Tarquinio, CSIRO Oceans & Atmosphere, Indian Ocean Marine Research Centre; Robert J. Orth, Virginia Institute of Marine Science, William & Mary; Brian R. Silliman, Division of Marine Science, Nicholas School of the Environment, Duke University

Seagrasses provide multiple ecosystem services including nursery habitat, improved water quality, coastal protection, and carbon sequestration. However, seagrasses are in crisis as global coverage is declining at an accelerating rate. With increased focus on ecological restoration as a conservation strategy, methods that enhance restoration success need to be explored. Decades of work in coastal plant ecosystems, including seagrasses, has shown that positive species relationships and feedbacks are critical for ecosystem stability, expansion, and recovery from disturbance. We reviewed the restoration literature on seagrasses and found few studies have tested for the beneficial effects of including positive species interactions in seagrass restoration designs. Here we review the full suite of positive species interactions that have been documented in seagrass ecosystems, where they occur, and how they might be integrated into seagrass restoration. The few studies in marine plant communities that have explicitly incorporated positive species interactions and feedbacks have found an increase in plant growth with little additional resource investment. To begin to test these ideas, we tested the impacts of light limitation on seagrass transplant success with and without mutualistic clams on *Halodule wrightii*. Following the stress gradient hypothesis, we predicted that clams would be more important under high stress. We discuss our results in this context. As oceans continue to change and stressors become more prevalent, harnessing positive interactions between species through innovative approaches will likely become key to successful seagrass restoration.

Posters:

Is biodiversity associated with eelgrass more strongly affected by the environment or by its foundation species?

Alexandre Muller, IFREMER, Laboratoire d'Ecologie Benthique Côtière; Stanislas F. Dubois, IFREMER, Laboratoire d'Ecologie Benthique Côtière; Aurélien Boyé, IFREMER, Laboratoire d'Ecologie Benthique Côtière; Ronan Becheler, IFREMER, Laboratoire d'Ecologie Benthique Côtière; Gabin Droual, IFREMER, Laboratoire d'Ecologie Benthique Côtière; Mathieu Chevalier, IFREMER, Laboratoire d'Ecologie Benthique Côtière; Marine Pasquier, IFREMER, Laboratoire d'Ecologie Benthique Côtière; Loïg Roudaut, IFREMER, Laboratoire d'Ecologie Benthique Côtière; Jérôme Fournier, Museum National d'Histoire Naturelle, CNRS UMR 7204; Isabelle Auby, IFREMER, Laboratoire Environnement Ressources d'Arcachon; Flávia L. D. Nunes, IFREMER, Laboratoire d'Ecologie Benthique Côtière

Eelgrass habitats are widely recognized as supporting high levels of benthic diversity because of their complex structure and high productivity. Here, combining taxonomic and trait-based approaches with structural equation modeling, we explored the mechanisms governing community assembly in habitats associated with a foundation species, *Zostera marina* in five

meadows located over a distance of 800 km along the French coast in the Northeast Atlantic. We assessed the spatial variability of eelgrass-associated invertebrate communities as affected by environmental parameters or morphological traits of the eelgrass and linked these mechanisms to their impacts at local and regional scales through analyses of the taxonomic and functional alpha and beta diversities. We then quantified the direct and indirect effects of environmental factors on macrofaunal structure and composition. At the regional scale, eelgrass diversity was comparable between sites, with high species turnover observed among them, and each site being characterized by different species and different sets of traits. These differences were due in part to morphological traits of the meadows, but the explanatory variables that best explained the differences among the meadows were environmental conditions. Eelgrass appear to harbor subsets of species from the regional species poll, rather than harboring eelgrass-specific assemblage. The processes that maintain eelgrass diversity appear to reflect a seascape-scale meta-community composed of many habitats connected by source-sink dynamics. Given that eelgrass enhances the diversity and abundance of species found in neighboring habitats, conservation programs should consider ecosystem-level protection spanning multiple habitats, including eelgrass, in order to maximize the protection of biodiversity.

Biodiversity of Scottish seagrass meadows across trophic levels: from infauna to avifauna

Isabel Key, University of Edinburgh; Sebastian Hennige, University of Edinburgh; Richard Lilley, Project Seagrass; Richard Unsworth, Swansea University; Flora Kent, Marine Scotland

Seagrass meadows in the UK are biodiverse habitats that support more species than adjacent sand or mudflats. However, understanding of this is limited both geographically and taxonomically, with a particular lack of data on biodiversity of seagrass meadows in Scotland. This study is the first assessment of biodiversity in Scottish seagrass meadows that assesses several trophic levels, with the ultimate aim of understanding how seagrass supports semi-aquatic predators that feed in seagrass. We use baited-video cameras, visual surveys and field sampling to quantify the following variables across three subtidal and three intertidal *Zostera* meadows and control sites: the extent, density and canopy height of the meadow; the diversity and abundance of benthic macrofauna, invertebrate megafauna, and fish; and the diversity and abundance of semi-aquatic predator species (diving and wading birds, and the Eurasian otter). We will present and discuss how biodiversity across trophic levels varies between subtidal *Zostera marina*, intertidal *Zostera noltii*, and unvegetated sediment. This will include assessment of species of conservation interest such as curlew and oystercatcher, which have declining populations globally and are ‘charismatic’ species that attract public interest. Our results strengthen evidence of the ecological and social benefits of protecting and restoring seagrass in Scotland, and set the scene for further research into the trophic links between seagrass and conservation-priority species.

Initial lag phase in Common Eelgrass (*Zostera marina*) growth during a restoration experiment. How will it affect plants through winter?

Matteo Lattuada, Landscape Ecology and Environmental Systems Analysis, Institute of Geoecology, TU Braunschweig, Braunschweig, Germany; Tadhg Ó Corcora, Marine Evolutionary Ecology, GEOMAR Helmholtz Center for Ocean Research Kiel, Kiel, Germany; Marvin Lehmann, Marine Evolutionary Ecology, GEOMAR Helmholtz Center for Ocean Research Kiel, Kiel, Germany; Katharina Kesy, Aquatic Microbiomes, Institute of Microbiology,

University of Greifswald, Greifswald, Germany; Anne Brauer, Aquatic Microbiomes, Institute of Microbiology, University of Greifswald, Greifswald, Germany; Thorsten B. H. Reusch, Marine Evolutionary Ecology, GEOMAR Helmholtz Center for Ocean Research Kiel, Kiel, Germany; Maike Paul, Leibniz University Hannover, Ludwig Franzius Institute of Hydraulic, Estuarine and Coastal Engineering, Hannover, Germany; Mia Bengtsson, Aquatic Microbiomes, Institute of Microbiology, University of Greifswald, Greifswald, Germany; Boris Schröder, Landscape Ecology and Environmental Systems Analysis, Institute of Geoecology, TU Braunschweig, Braunschweig, Germany

Seagrass meadows promote biodiversity and provide important ecosystem services for coastal protection, climate change mitigation and biodiversity. The Common Eelgrass Zostera marina is the dominant species in the Northern Hemisphere. In the Baltic Sea it is under threat, as the size of its meadows sharply decreased in the last decades, mainly due to coastal development and reduced water quality. Thus, restoration projects have been established to help the recolonization of meadows. In SeaStore, we are testing the success of restoration in Kiel, Germany. After planting shoots collected from wild plants in a nearby donor site, we measured essential traits such as shoot length and density. Initially, we noticed a lag phase in the restored shoot growth and expansion compared to the donor site. We also observed that a considerable number of new growing shoots in the restoration site was visible only about two months after the planting. Here, we investigate and discuss hypothetical causes of this lag phase, such as the effect of herbivores. As in the restored site shoots did not reach the same length and density of the donor site before the end of the growing season, we will analyze how this affects plant survival through winter in the restoration sites. Our results will support seagrass restoration plans, especially to enhance plant survival in winter. Given the growing socioeconomical interest in seagrass meadows, we will also create a platform to share our results with a large spectrum of stakeholders aiming at promoting the development of restoration projects.

Using E-scapes to quantify the change in trophic function of seagrass habitats in response to large-scale seagrass die-off

W. Ryan James, Florida International University; Jonathan R Rodemann, MS, Florida International University, Miami, FL; Zachary W Fratto, Everglades National Park, Key Largo, FL; Bradley T. Furman, PhD, Florida Fish and Wildlife Conservation Commission, Florida Fish and Wildlife Research Institute, St. Petersburg, FL; Jennifer S Rehage, PhD, Florida International University, Miami, FL; Rolando Santos, PhD, Florida International University, Miami, FL

Seagrass habitats provide valuable ecosystem services such as essential habitat and resources for economically-important fisheries. For many seagrass systems these habitats are under threat and/or significant change due to chronic and acute disturbances (e.g. sea level rise and hurricanes, respectively) and watershed-scale land use change. While monitoring and management actions often focus on the structure of these habitats (e.g., size, species composition, and location), the associated functions such as providing support for food webs are not as prominently emphasized. Recent studies have demonstrated that similar habitat structure does not always lead to the same functions for metrics, including the productivity rates for species with ecological and economic importance. Given that habitat-driven functions directly influence key ecosystem services, managers would benefit from indicators and planning tools that incorporate function as well as structure. This is especially the case in coastal seagrass ecosystems, where anthropogenic influence is leading to drastic changes to estuarine habitats.

Here we present a novel holistic approach, the *E*-scape, that combines remote sensing and the analysis of food web energy flow with stable isotopes to spatially describe the functioning of ecosystems. We use Florida Bay as a case study to look at how a large-scale seagrass die-off has affected energetic production for food webs. This method can be used to assess ecosystem structure and function and use habitat-based drivers of ecosystem services to develop and evaluate successful management and restoration targets.

Session 4B: Advances in Seagrass and Optical Water Quality Remote Sensing

Session Convener(s): Richard Zimmerman, Old Dominion University; Paul Carlson, Florida Fish and Wildlife Research Institute

In the past, seagrass mapping and in situ optical water quality measurements have been expensive and time-consuming, limiting their spatial and temporal coverage. However, new satellites and sensors, image analysis methods, and improved access to data will allow more frequent and cost-effective mapping of seagrass and will increase the frequency and area where remotely sensed optical water quality measurements can be made. At last count, there were more than 50 satellites collecting multispectral imagery at spatial resolutions from one meter to one kilometer with spectral resolution from 3 to 10 or more bands, and revisit times range from one day to two weeks. These commercial satellites provide synoptic and seamless multispectral imagery over large areas at costs that compare favorably with conventional aerial photography but with much less processing effort.

Commercial and freely available software and workflows based on object-based image analysis make seagrass mapping faster and more reproducible than traditional manual methods. Satellites also offer the possibility of collecting estimates of transparency, phytoplankton chlorophyll, CDOM, and turbidity- key determinants of seagrass survival, distribution, and abundance. Presenters will discuss methods, obstacles, and solutions for coastal optical water quality measurements as well as new data access and delivery methods that make imagery and other data more accessible and make data analysis easier.

Talks:

Cloud-native Remotely-sensed Seagrass Extent and Blue Carbon Stock Assessment in Mozambique

Avi Putri Pertiwi, German Aerospace Center; Alina Blume, German Aerospace Center Dimosthenis Traganos, German Aerospace Center; Stefanie Broszeit, Plymouth Marine Laboratory; Stephen Widdicombe, Plymouth Marine Laboratory; Thomas Jackson, Plymouth Marine Laboratory;Didier Ramon, HYGEOS; François Steinmetz, HYGEOS; Victor Martinez-Vicente, Plymouth Marine Laboratory

The interest in the blue carbon sequestration has been increasing in the past few years due to its potential in climate change mitigation. Seagrass meadows store 10% of the world's atmospheric carbon in their soil, however, its extent has been declining at an alarming rate. Field data collection of the underwater habitats can be costly due to the environmental challenges. Our goal in the Biodiversity of the Coastal Ocean: Monitoring with Earth Observation (BiCOME) project is to develop analysis-ready products that can be used for Essential Biodiversity Variables

(EBVs) quantification and downstream impact. In this study, we mapped the bathymetry, seagrass extent, and stored blue carbon across the entire Mozambican coastline using 9,089 Sentinel-2 images. The seagrass extent was mapped with the Random Forest image classification, resulting in 1,779.3 km^2 of seagrass meadows, located between depths of 1.6 and 9.2 m. Based on our Tier 1 carbon stock assessment, the national seagrass blue carbon stock was estimated at 1.78-147 million Mg and our Tier 2 carbon stock assessment results in 1.64-4.35 million Mg. Our next goal is to pair our nationwide seagrass extent and blue carbon estimates with seagrass-related EBVs to improve the quantification and policy uptake of seagrass ecosystems in Multilateral Environmental Agreements within and beyond Mozambique.

Spatial Changes in Guam's seagrass from 1993 to 2021

Cara Lin, Guam Department of Agriculture

Recent studies of seagrass beds in the Mariana Islands, a Micronesian archipelago, have demonstrated trends of declining seagrass cover in a number of sites assessed in the past several decades. Across the Micronesia region, surveys also indicate seagrass beds of long-lived climax species may also be transitioning to smaller faster growing seagrasses or algae, potentially affecting the ecology and ecosystem services provided. These seagrasses provide important wildlife habitat and benefits to local communities, such as supporting local rabbitfish fisheries and preventing coastal erosion. Guam, the southernmost and largest island in the Mariana Islands, has seagrass beds formed primarily by the large seagrass, Enhalus acoroides. Guam's coastal lagoons also feature mixed benthic coverage of algae and two smaller seagrass species, Halodule uninervis, and Halophila gaudichaudii. This study analyzes satellite imagery between 1993 and 2021 to determine spatial changes of seagrass coverage in Guam and provide a review of historical photos and reports to better understand long term trends. Although drivers influencing seagrass cover are not fully understood, potential factors include changes in water quality, climate change impacts, and extreme low tide events. Determining how different areas of seagrass cover has changed in Guam may help elucidate our understanding of the drivers of seagrass loss, and inform future conservation and management actions. With ongoing anthropogenic threats impacting marine ecosystems, it will be increasingly important to continue to monitor spatial changes in cover.

Nationwide seagrass mapping using analysis-ready Sentinel-2 and PlanetScope data to support the Nationally Determined Contributions of Seychelles

C. Benjamin Lee, Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center)
Lucy Martin, University of Oxford; Dimosthenis Traganos, Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center); Gwilym Rolands, University of Oxford; Peter Reinartz, Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center)

There is a notable lack of spatially-explicit knowledge on seagrass meadows in many parts of the world, which hinders seagrass research, conservation, and carbon accounting efforts. With the recent introduction of the pan-tropical PlanetScope basemaps onto the Google Earth Engine (GEE) cloud platform through the Planet & Norway's International Climate and Forests Initiative (NICFI), anyone can now freely access and process the entire pan-tropical archive of the PlanetScope composites between 2015 and today. In comparison to other public optical satellite archives available within GEE, like the Sentinel-2, Planet's imagery has a shorter global revisit interval of 30.3 hours, a better spatial resolution of 4.77m, but a worse spectral resolution

of only the blue, green, red and near infrared bands. Despite the NICFI's focus on terrestrial forest monitoring in the tropics, a vast pan-tropical area of optically shallow coastal waters is included in this cloud-native public archive. This paves the way for seamless high-resolution pan-tropical seagrass mapping with large time and cost efficiency. Here, we adapt our multitemporal composition approach on GEE, initially developed for Sentinel-2, to the six-year PlanetScope archive, to map the nationwide seagrass meadows in Seychelles. We compare the feasibility and performance of the PlanetScope data to Sentinel-2 in national seagrass mapping, leveraging the synergy of cloud computing, artificial intelligence, and open reference data. The development of this approach could and will provide a comprehensive blueprint seagrass mapping and monitoring system to quantify national seagrass blue carbon stocks for the Nationally Determined Contributions, both in and beyond Seychelles.

National scale time series of seagrass ecosystems in Vietnam over 30 years using Landsat images

Xuan Truong Trinh, Institute of Industrial Science, The University of Tokyo, Meguro, Tokyo 153-8505, Japan; Wataru Takeuchi, Institute of Industrial Science, The University of Tokyo, Meguro, Tokyo 153-8505, Japan

Despite playing key roles in fishery, biodiversity and mitigating climate change, seagrass beds in Vietnam are decreasing rapidly. However, conservation activities are limited because current seagrass monitoring approaches could not reveal explicit spatial and temporal patterns in the entire nation with a consistent methodology. To bridge that gap, we analyzed all Landsat images along the coastline of Vietnam between 1984 and 2020 using Google Earth Engine. Images were filtered to remove cloud contamination, preprocessed to reduce the effects of the water column, and classified using the Random Forest classifier with training data created by visual interpretation of historical images and high resolution satellite images. Changes in each seagrass bed were analyzed. 36,185 ha of seagrass beds were mapped before 1990, but only 17,081 ha remained after 2015. A majority of seagrass meadows lost 40-85% of their area, mostly due to reclamation for aquaculture. The most rapid loss happened in the 1990s, and is still ongoing. Seagrass beds in lagoons and bays tend to be more impacted than those on intertidal flats. Moreover, we could identify minor seagrass beds that may have been omitted from the national surveys. Some of the smaller seagrass beds were destroyed due to reclamation for construction, perhaps because their presence had not been recognized. By analyzing a large number of images, this research gives a spatially explicit estimate for the seagrass inventory in Vietnam over the last 30 years. It opened new doors for the understanding of seagrass distribution and conservation studies.

Advances in Seagrass and Optical Water Quality Remote Sensing

Spyridon Christofilakos, DLR Photogrammetry and Image Analysis Department; Alina Blume, DLR Photogrammetry and Image Analysis Department; Avi Putri Pertiwi, DLR Photogrammetry and Image Analysis Department; Dimosthenis Traganos, DLR Photogrammetry and Image Analysis Department; Peter Reinartz, DLR Photogrammetry and Image Analysis Department

Recent developments in remote sensing technology including cloud computing and globally available optical satellite archives have allowed access to vast volumes of data, computation and scalability for mapping seagrasses and their environment. Yet, beyond the traditional accuracy assessment, there is a broader lack of knowledge and methods for the per-pixel uncertainty of

remotely sensed seagrass data. Spatially-explicit uncertainty is not the only essential for more accurate remote sensing of seagrass extent, health and bathymetry, but could also aid more effective quantification of seagrass' ecosystem services like blue carbon stocks and coastal biodiversity maintance. In this study, we utilize the open satellite image archives of Sensintel-2 and PlanetScope, through the Google Earth Engine (GEE) platform to develop per-pixel uncertainties of thematic benthic habitat mapping and continuous satellite based bathymetry data according to machine learning probabilistic principles. We present our uncertainty metrics and applications in two nationwide case studies in Bahamas and Belize. In contrast to traditional approaches that estimate uncertainty for the whole image/distribution, our approach, quantifies the uncertainty per pixel of both thematic and continuous remotely sensed data across large spatial scales and up to 5m resolution. Our approach can improve the confidence and scalability of large-scale assessments of seagrass extent, condition and ecosystem services, supporting more effective policy uptake of seagrass ecosystems.

Upscaling seagrass monitoring using underwater drones and automated image processing

Rod M. Connolly, Global Wetlands Project, Griffith University; Ryan M. Pearson, Global Wetlands Project, Griffith University

Further improvements in capacity for mapping and monitoring seagrass are required to overcome deficiencies in global distribution maps, and to enable more rapid condition reporting. Along with improvements in remote sensing from satellites and aerial drones, underwater technology has advanced to the point where automated methods can monitor in more places, more often, for less cost. Underwater vehicles and drones now reliably scan the seabed collecting vast amounts of imagery, operating in waters of any depth without putting divers at risk. The manual processing of imagery has, however, been a major bottleneck in extracting useful information from imagery about benthic habitats such as seagrass. We use the latest machine learning procedures, known as deep learning, to provide computer vision software that detects seagrass and records plant characteristics rapidly and reliably. Tested against thousands of manual records of seagrass presence and percentage cover, the accuracy of automated measures is 86%. Accuracy improves further when information about the position of images in relation to other images is incorporated. The automated presence data are ideal for detecting meadow edges and monitoring of seagrass depth range. Percentage cover can be used as one indicator of seagrass condition, and is beginning to be paired with automated records of morphological type and species. Automation is substantially increasing the scale of seagrass surveys, and increasing reproducibility from sequential visits.

Posters:

Mapping shallow macrophytes in fjords in Southwest Greenland using Sentinel-2 MSI imagery

Daniel F. Carlson, Helmholtz-Zentrum Hereon; Antoni Vivó-Pons, Technical University of Denmark; Urs Treier, Aarhus University; Eva Mätzler, Government of Greenland; Lorenz Meire, Greenland Institute of Natural Resources; Mikael K. Sejr, Aarhus University; Dorte Krause-Jensen, Aarhus University

Seagrasses and macroalgae provide important ecosystem functions and services, such as contributing to carbon sequestration and biodiversity. Macrophyte cover along polar coastlines,

including those in Greenland may be changing due to ocean warming. The remote and harsh environment makes *in situ* monitoring difficult and costly and a lack of baseline data complicates efforts to assess changes in macrophyte abundance. Here, we provide the first fjord-scale distribution estimates for eelgrass and macroalgae in fjord systems in SW Greenland using Sentinel-2 MSI imagery. Presence/absence was estimated by applying commonly used vegetation indices and spectral mixture analysis. The Sentinel-2 images are also used to quantify the spatiotemporal variability of turbidity to examine possible relationships between the impacts of turbid meltwater on light availability and the distribution of macrophytes. Classification of coastal macrophytes in this region is complicated by large changes in solar zenith angle, topographic shading, sea ice cover, icebergs, turbidity, and a 4 m tidal range. The analysis period was restricted to the months of June-July to minimize these effects. Centimeter-scale drone orthomosaics were used to validate the satellite-derived macroalgae distributions. Our approach to classify coastal marine macrophytes in glacially-modified fjord environments with strong gradients in inherent optical properties in Greenland form the basis for expanding the mapping along in coastal Greenland and elsewhere in the Arctic.

Development of a continuous depth-invariant vegetation index for mapping seagrass cover

Jonathan Rodemann, Florida International University; W. Ryan James, Florida International University; Daniel Gann, Florida International University; Jennifer Rehage, Florida International University; Rolando Santos, Florida International University

Advances in technologies such as high resolution remote sensing sensors and mapping algorithms have increased our ability to understand complex patterns and processes within marine seascapes. As technologies evolve, it is crucial to focus on what metrics and indicators are most useful for characterizing and monitoring spatio-temporal patterns in seascapes and over what scales these should be measured. These questions are usually answered using discrete methods such as supervised classification mapping and calculating landscape metrics within a window of a certain size. However, this decreases the amount of information used from remote sensing data as well as introduces human bias. To begin to address these issues, this study aims to create a vegetation index similar to terrestrial NDVI to map shallow (<2m) seagrass cover using depth-invariant bands. To remove the effect of the water column, we calculate 10 depth-invariant bands on WV2 imagery. We then add field data to create a depth-invariant vegetation index correlated with seagrass cover. Future steps will include using a scaling algorithm to apply the depth-invariant vegetation index to LandSat imagery. Creating a vegetation index removes the need to create discrete classes when mapping seagrass and facilitates the ability to quantify seascape properties using continuous metrics, which could help our understanding of the causes and relationships of patterns and processes at multiple scales. Futhermore, the depth-invariant vegetation index created in this study will provide a quick, accurate, and cost-effective method of mapping shallow water seagrasses that can be used to inform management and conservation.

Quantifying the impact of the March 2018 nor'easter on seagrass distributions and density on the eastern shore of Virginia, through the use of use high spatial resolution satellite images from PlanetScope.

Kylie Harrison, Old Dominion University; Victoria Hill, Old Dominion University; Richard Zimmerman, Old Dominion University

In early March 2018, a strong nor-easter impacted the coast of Virginia. Cobb Island, a coastal barrier island on the Eastern Shore was overwashed by the storm surge. A previously small inlet in the middle of the island was significantly widened effectively cutting the island in two. The island was significantly remodeled by the ocean in the months and years after the storm. In this study, we quantify the changes to Cob Island and the impact on seagrass distribution and density behind the island from pre-storm conditions, to the immediate aftermath of the storm and the continued impact through to the Fall of 2021. Using high spatial resolution imagery from PlanetScope and supervised classification techniques paired with support vector machine learning we are able to quantify the changes in the areal coverage of beach, marsh, submerged sand, and seagrass from 2017 through 2021.

Quantifying variability in areal extent and percent cover of North Carolina (USA) seagrass meadows using unmanned aerial vehicles (UAV).

Madison Lytle, UNCW; Jessie Jarvis, UNCW; Brandon Puckett, NC NERR; W. Judson Kenworthy, UNCW

North Carolina (NC) USA, located along the western Atlantic, has two dominant seagrass species, Zostera *marina* and Halodule wrightii. Both are at the edge of their geographic range and can be found as single or mixed species meadows, with temperate *Z. marina* most abundant during cooler periods (November – June) and tropical *H.* wrightii most abundant during warmer periods (July-October). This study aims to provide insight on the frequency and magnitude of intra-annual changes in meadow area during the transition periods between the two species, and if change can be related to environmental or biological driver(s) (e.g., temperature, turbidity, species co-occurrence). To assess shifts in seagrass species abundance, UAV imagery was collected monthly and paired with in situ measurements to quantify variability in areal extent, seagrass percent cover, and percent cover by species at three seagrass meadows. All sites displayed expected seasonal shifts; two meadows showed a shift in species abundance (*Z. marina* to *H.* wrightii) and were able to maintain seagrass cover and extent. At the third site there was spatial segregation between the two species leading to larger seasonal changes in extent. Mixed meadows show stability during the seasonal shift in species abundance, indicating species diversity could be contributing to maintaining meadow extent.

Mapping seagrass across the United States using high-resolution, commercial satellite imagery

Megan Coffer, ORISE USEPA; David Graybill, ORISE USEPA; Blake Schaeffer, USEPA

A recent review recommended the need for a consistent monitoring approach for seagrass habitats in order to adequately protect seagrass meadows. Satellite imagery may offer more consistent monitoring over time compared to traditional photointerpretation methods. This study leverages high spatial resolution, commercial satellite data from DigitalGlobe's (now Maxar) WorldView-2 and WorldView-3 satellite platforms to classify seagrass presence and absence at eleven coastal sites across the United States, representing three of the six global seagrass bioregions and each of the coastal climate regions defined by the National Centers for Environmental Information. Reference data and a single satellite image were acquired at each study area. Classification agreement was assessed depending on the reference data type; statistical tests included balanced agreement and the nonparametric Mann-Whitney U and Kruskal-Wallis tests. Despite temporal offsets of up to 16 years between satellite imagery

acquisition and reference data collection, balanced agreement ranged from 58 to 86% and both the Mann-Whitney U test and the Kruskal-Wallis suggested strong agreement between satellite-indicated seagrass percent cover within reference-delineated seagrass density classes. Additionally, at a single study area, reference data consisting of point observations of seagrass percent cover spanning 0 to 100% was used to estimate WorldView-2's seagrass minimum detection level. Results indicated that a satellite pixel containing a minimum of approximately 43% seagrass will be classified as seagrass. This study offers a large-scale assessment of a standardized seagrass classification approach, demonstrating its performance across various seagrass bioregions, optical water types, and seagrass ecosystems.

Leveraging remote sensing and suitability modelling for informed site selection in seagrass restoration in Western Port, Victoria, Australia

O. Dalby, Deakin University; N. Pucino, Deakin University; Y.M. Tan, Deakin University; E.L. Jackson, Central Queensland University; P.I. Macreadie, Deakin University; R.A. Coleman, Melbourne Water; M.A. Young, Deakin University; D. Ierodiaconou, Deakin University; C.D.H. Sherman, Deakin University

Seagrass restoration requires a thorough understanding of a target species spatial and temporal ecology. Contemporary information on species presence and density can reflect local environmental conditions, whilst assessments of temporal change can highlight changes in environmental conditions that have occurred over time. Restoration projects can make use of this information to identify areas that may be suitable for restoration, however, considerations of future environmental conditions are also needed to predict changes to currently suitable restoration sites under future climate scenarios. This talk provides a summary of remote sensing and geostatistical modelling undertaken in a globally significant RAMSAR site, Western Port, Victoria, Australia, as a prelude to restoration efforts. The studies set out to i) identify contemporary seagrass distributions, density, and species compositions, ii) quantify spatio-temporal trends in seagrass presence over the past ~50 years, and iii) predict contemporary and future environmental suitability under future climate conditions. Remotely sensed distributions predicted a bay-wide recovery in seagrass spatial extents and an eastward range expansion not seen since before large scale declines occurred in the 1970s; mirroring predicted improvements in benthic light availability. Suitability modelling highlighted contemporary environmentally suitable sites adjacent to areas of persistent seagrass cover and recent recovery but also identified areas that, whilst currently suitable, are at risk of reduced suitability under predicted climate change scenarios. Results of both studies can assist spatial planning of seagrass restoration and can help improve restoration success by targeting areas with suitable environmental conditions both now, and in the future.

Using daily PlanetScope imagery to map annual distributions of submerged aquatic vegetation at several sites within the Chesapeake Bay.

Victoria Hill, Old Dominion University; Richard Zimmerman, Old Dominion University; Rhianne Cofer, Old Dominion University; Katrina Shortorban, Old Dominion University

Remote detection of submerged aquatic vegetation (SAV) in turbid coastal waters is challenging due to the need for satellite passes coincident with low tide and low turbidity conditions in order to detect SAV. In the past this has meant that targeted aerial imagery has been the preferred collection medium for monitoring SAV distribution. Commercial high resolution satellites from

PlanetScope constellation now provide us with daily coverage of coastal waters of the US, this collection frequency can help overcome previous issues with turbidity and tidal state, by providing multiple images per month. Here we use the high frequency os passes available from PlanetScope to retrieve distribution of SAV in the coastal bays of Virginia and at several sites within the Chesapeake Bay for 2019, 2020 and 2021. All passes in which SAV were visible were processed to presence/absence using fixed training patches and support vector machine learning available in ArcGIS Pro. The frequency with which a pixel was classified as SAV was found to be correlated with density previously estimated as percent cover from aerial imagery. The changing distribution and density from the spring through the summer was also detectable allowing us to highlight the reduction in SAV density after the warm summer months. The evidence points towards using frequency presence as a measure of SAV density throughout the Chesapeake Bay, an area that has been difficult to monitor from satellites in the past.

Session 5A: General/Open Call Session 2

Session Convener(s): Bob Murphy, Tetra Tech

This session will include talks and posters covering a range of topics that don't fit perfectly in any of the other WSC sessions.

Talks:

Changes in sediment carbon stock following seagrass restoration in Shark Bay, Western Australia

Yusmiana P. Rahayu, School of Biological Sciences, the University of Western Australia; Marine Research Centre, Ministry of Marine Affairs and Fisheries Republic of Indonesia; Gary A. Kendrick, School of Biological Sciences, the University of Western Australia; Mathew A. Vanderklift, CSIRO Oceans and Atmosphere; Matthew W. Fraser, the University of Western Australia

Seagrass restoration can contribute substantially to climate change mitigation efforts by enhancing carbon sequestration capacity. However, there have been few empirical investigations into changes in sediment organic carbon stock following seagrass restoration. This study aims to compare patterns of sediment organic carbon stock in early ages of seagrass Posidonia australis restoration (6 month, 2 year, 2.5 year and 5 year) to adjacent unvegetated sand and continuously vegetated seagrass in Shark Bay, Western Australia. Our study shows that seagrass restoration in Shark Bay experiences a lag period in accumulating carbon in the sediment. Furthermore, carbon stock in restored seagrass sediment in the study sites indicate that carbon storage in early ages of restoration (up to 5 years) is still not showing differences from that of unvegetated areas. We highlighted the importance of designing location for seagrass restoration, adequate restoration project duration and long-term monitoring to justify seagrass restoration better success/failure. This study contributes to the growing body of literature on seagrass restoration and blue carbon by adding information on sedimentary carbon stocks in the early ages of restoration.

Reactive persistence and seagrass restoration

Christopher Aiken; Sergio Navarrete; *Emma Jackson*

A common goal of restoration is to promote species persistence. The classical theoretical tool for assessing conditions for metapopulation persistence - the "invasibility criteria" which characterizes the asymptotic, or long-term, stability of a small colonizing population - is overly strict for the noisy systems found on nature, constantly subject to disturbance. A colonisation event may, in fact, persist for long periods even when the invasability criteria predicts extinction. We explain this so-called "reactive persistence" with reference to the restoration of *Zostera* meadows in Port Curtis, Australia. Using a numerical estimate of the connectivity between meadows, we show how a restoration strategy based on the reactive persistence concept yields a superior outcome at the metapopulation level compared to one based on the invasability criteria.

Trailing vs Leading Edge Seagrasses: Influence on Meadow Resilience and Recovery

Jessie C. Jarvis, University of North Carolina Wilmington; Katie Stevenson, University of North Carolina Wilmington; W. Judson Kenworthy, University of North Carolina Wilmington

In North Carolina, USA (NC), seagrass ecosystem services are provided by two species, *Zostera marina*, a temperate seagrass at the trailing edge of its distribution and *Halodule wrightii*, a tropical seagrass at its leading edge. For *Zostera*, daily mean water temperatures routinely exceeding 30°C in July and August result in large-scale annual changes in abundance. Recovery is initiated by seed germination and *Z. marina* biomass returns to pre-decline levels the subsequent growing season. *Z. marina* declines of similar magnitude in other systems required several years, not months, to recover. One potential explanation for accelerated recovery and persistence in NC meadows is the presence of *H. wrightii*. The tropical species maintains aboveground biomass year-round, thereby reducing sediment resuspension and maintaining water clarity at levels required for successful *Zostera* seedling growth and establishment. The presence of *H. wrightii* could inhibit recovery by reducing *Z. marina* overall germination success via a well oxygenated rhizosphere, which creates less than optimal germination conditions. To quantify the effects of *H. wrightii* on *Z. marina* recovery, biomass and percent cover were quantified across monospecific *Z. marina* and mixed-species seagrass meadows in Back Sound NC between 2017 and 2020. To test the effects of *H. wrightii* on *Z. marina* seed germination five replicates of 25 *Z. marina* seeds were germinated with and without *H. wrightii* shoots under controlled experimental conditions. Results of these studies will provide essential information on the impacts of leading-edge seagrass species on the resilience and recovery of temperate seagrass under a changing climate.

Assessing seed- and shoot-based techniques for restoring the intertidal seagrass, *Zostera muelleri,* in temperate Australia.

Yi Mei Tan, Deakin University; Oliver Dalby, Deakin University; Rhys Coleman, Melbourne Water; Emma Jackson, Central Queensland University; Peter Biro, Deakin University; Peter Macreadie, Deakin University; *Craig Sherman*, Deakin University

Seagrasses are some of the most important coastal marine habitats, yet they are being lost at accelerated rates of decline globally. Since the 1970s, Western Port, Australia has experienced a 70% loss of seagrass coverage. Despite significant catchment management efforts to improve conditions and encourage rehabilitation, natural recovery has been slow and restoration efforts are urgently needed. Over the course of two years, we undertook the first large-scale field trials in Western Port to assess the performance of shoot- and seed-based restoration approaches for

Zostera muelleri. Four shoot-based techniques were used, anchoring using hessian discs, nails, metal frames, and plugs; while seeds were placed in small hessian bags and buried. Of the shoot-based techniques used, plugs showed the greatest promise, with initial areal coverage increment and longest survival. More importantly, this study was the first to show successful germination of Z. muelleri in the natural environment. We were able to quadruple germination rates between trials, from an average overall germination of 3.67% during the pilot trials to 12.21% during the large-scale trial. Additionally, we found that germination rates were unaffected by seed source but was instead likely affected by site-specific conditions and stressors. The results from these experimental studies are encouraging and have resulted in a greater understanding of the processes underscoring successful intertidal seagrass restoration. Seed-based restoration approaches are viable and effective in the Western Port environment and it is now critical to build upon this research to improve germination and seedling survival, and work towards successful seagrass restoration.

Fluctuating fortunes enhance multiple stressor science for seagrass ecosystems

Andria Ostrowski; Rod M. Connolly; Christopher J. Brown; Michael Sievers

Seagrass ecosystems are under enormous pressure from multiple anthropogenic stressors. These stressor adversely affect seagrass ecosystem structure, function, and provision of vital services. Manipulative experiments are being conducted to predict impacts from stressors and inform stressor management. However, most experiments introduce stressors under static (constant) conditions and do not consider how natural environmental variability influences stressors or biological responses. Given seagrass ecosystems are in a constant state of change, this approach may lead to inaccurate conclusions and predictions of cumulative stressor effects. To incorporate dynamism in experimental design, we investigate the effects of more realistic applications of multiple stressors on the seagrass, *Halophila ovalis*, by incorporating changes in stressor intensity and timing. Responses differ based on how stressors are introduced. Fluctuating stressors reduced biomass more than static stressors. This has implications for how multiple stressor experiments should be conducted, enhances our understanding of multiple stressor effects within seagrass ecosystems, and can aid in developing more effective management strategies to mitigate stressor impacts.

What turned off the lights; introduction of the non-native seagrass Halophila stipulacea into a bioluminescent bay, Vieques, Puerto Rico?

W. Judson Kenworth; Manuel Merello, Merello Marine Inc.; Ben Scheelk, The Ocean Foundation

Puerto Mosquito is a shallow waterbody on the south shore of Vieques Island, Puerto Rico renowned as one of the brightest bioluminescent bays in the world. During benthic surveys in 2020 we documented the distribution, cover, and abundance of macrophytes including native tropical seagrasses, macroalgae and a recently introduced non-native species Halophila stipulacea. We are uncertain when H. stipulacea first colonized Puerto Mosquito; however, observations from other nearby locations in Puerto Rico (e.g., Jobos Bay) indicate arrival was likely in 2015 and the species has spread rapidly into water bodies with and without seagrass. In Puerto Mosquito, H. stipulacea was observed at 57 of 129 stations sampled and had the highest average cover and abundance of all macrophytes including the tropical climax species Thalassia testudinum. In the physically protected conditions of Puerto Mosquito H. stipulacea establishes

high biomass and tall canopy forming meadows comparable to or exceeding the native seagrasses. Growth rates of colonizing patches ranged between 0.1 and 0.5 m2 d-1 indicating this species is spreading quickly by clonal growth and dispersing clonal fragments to unvegetated and vegetated sediments in the Bay. In the past decade, the Bay experienced dramatic fluctuations in nocturnal "brightness" and complete bioluminescent blackouts attributed to several stressors including altered hydrology, low precipitation, nutrients, and land use. Our benthic macrophyte surveys and complementary data for depth, sediment composition, temperature, and light are being used to evaluate whether colonization of this non-native seagrass could further affect the dinoflagellate (Pyrodinium bahamense) responsible for the Bay's bioluminescence.

Posters:

Seagrass meadows management and restoration to address natural and societal challenges at Ria de Aveiro (Portugal)

Ana I. Sousa, CESAM - Centre for Environmental and Marine Studies, Dpt of Biology, University of Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal; Marta Lopes, CESAM - Centre for Environmental and Marine Studies, Dpt of Biology, University of Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal; J. Pedro Coelho, CESAM - Centre for Environmental and Marine Studies, Dpt of Biology, University of Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal; Valentina Costa, CESAM - Centre for Environmental and Marine Studies, SZN, Dpt Integrative Marine Ecology, 87071 Amendolara, Italy; Paulo Raínha, Centre for Environmental and Marine Studies, Dpt of Biology, University of Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal; Diana Sousa-Guedes, CESAM - Centre for Environmental and Marine Studies, CICGE - Centro de Investigação em Ciências Geo-Espaciais, Alameda do Monte da Virgem, 4430-146, Vila Nova de Gaia, Portugal; Sílvia Luís, Universidade Lusófona de Humanidades e Tecnologias de Lisboa, Escola de Psicologia e Ciências da Vida, Campo Grande 376, 1749-024, Lisboa, Portugal; Mogens R. Flindt, Dpt of Biology, University of Southern Denmark (SDU), Campusvej 55, dk-5230 Odense M, Denmark; Ana I. Lillebø, CESAM - Centre for Environmental and Marine Studies, Dpt of Biology, University of Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal

Seagrass meadows conservation, integrated management and restoration are crucial, and highlighted by the UN Sustainable Development Goals and the UN Decade for Ecosystem Restoration (2021-2030). Having the LTsER platform Ria de Aveiro coastal lagoon (Portugal) as a case study, wherein a lugworm bio-invasion took place and is threatening seagrass meadows, a transdisciplinary approach was implemented to address related natural and societal challenges. In the scope of BioPradaRia project (MAR2020/EMFF), we tested Z. noltei transplant and restoration methodologies in situ and effectiveness of natural membranes as nature-based solutions (NbS) to mitigate Arenicola spp. (non-indigenous species) bioturbation, towards the seagrass resilience increase. Through participative methods (questionnaires), we assessed the stakeholders' risk perceptions (bait diggers, shellfish harvesters) on seagrass degradation, native versus non-indigenous species of polychaetes and their spatial distribution at Ria de Aveiro. Critical areas of Z. noltei vulnerability due to Arenicola spp. bioturbation were obtained by integrating a high-resolution ground-truth sampling and the stakeholders' perceptions. Overall, the application of a natural membrane significantly decreased the bioturbation impacts by Arenicola spp., and the use of sod is the best transplanting method, and less invasive to the donor

meadow. A stepwise approach with guidelines for seagrass restoration is provided, towards the Z. noltei resilience improvement in intertidal coastal systems management, to enhance the success of Z. noltei restoration plans. Priority areas for seagrass restoration and conservation are identified through a transdisciplinary approach, paving the way for integrated up-scaled seagrass restoration and management plans, liable to be implemented in other seagrass vulnerable coastal areas.

Living on the edge; the status of a large western Atlantic seagrass ecosystem in North Carolina, USA

W. Judson Kenworthy, Albemarle Pamlico National Estuary Partnership; Dean Carpenter, Albemarle Pamlico National Estuary Partnership; Don Field, Albemarle Pamlico National Estuary Partnership; Tim Ellis, Albemarle Pamlico National Estuary Partnership; Jessie Jarvis, University of North Carolina Wilmington

The Albemarle Pamlico Estuary (APES) in North Carolina and southern Virginia is the second largest estuary on the east coast of the United States. Situated at the convergence of warm Gulf Stream waters and the colder Labrador current, APES supports a unique mix of northern and southern western Atlantic flora and fauna. The flora includes seagrasses with temperate (*Zostera marina),* tropical (*Halodule wrightii),* and eurythermal (*Ruppia maritima*) affinities. Aerial photographic surveys produced digital multispectral imagery whose interpretation identified up to 40,810 hectares of patchy and continuously distributed seagrass meadows in the polyhaline region of APES. The areal extent of seagrasses declined by 5.6% between two coastwide surveys in 2007 and 2013. Despite this change and given the declines of seagrasses in neighboring Atlantic coastal systems, APES currently has the largest seagrass acreage along the U.S. Atlantic seaboard. In-water surveys documented monospecific and mixed species meadows growing throughout the polyhaline system that exchange species dominance seasonally; *Zostera* is more abundant in cooler months and *Halodule* dominates in the warmer summer and fall periods. Annually, this unusual combination of temperate and tropical species ensures and extended period of primary production, habitat structure and ecological services. However, with one species growing at its trailing edge of range (*Zostera*) and the other at the leading edge (*Halodule*), it remains to be determined how this seagrass ecosystem with respond to the longer-term implications of climate change. We address this uncertainty with results from companion studies at sentinel sites investigating seagrass resilience metrics at higher resolution.

Exploring possibilities for subtidal eelgrass (Z. marina) restoration in the Dutch Wadden Sea

Katrin Rehlmeyer, Conservation Ecology Group, Groningen Institute for Evolutionary Life Sciences, University of Groningen, P.O. Box 11103, 9700 CC Groningen, the Netherlands; Maite L. Vogel, Conservation Ecology Group, Groningen Institute for Evolutionary Life Sciences, University of Groningen, P.O. Box 11103, 9700 CC Groningen, the Netherlands; Oscar Franken, Conservation Ecology Group, Groningen Institute for Evolutionary Life Sciences, University of Groningen, P.O. Box 11103, 9700 CC Gjroningen, the Netherlands; Tjisse van der Heide, Conservation Ecology Group, Groningen Institute for Evolutionary Life Sciences, University of Groningen, P.O. Box 11103, 9700 CC Groningen, the Netherlands; NIOZ Royal Netherlands Institute for Sea Research, Department of Coastal Systems, Utrecht University, PO Box 59, 1790 AB Den Burg, the Netherlands; Han Olff, Conservation Ecology

Group, Groningen Institute for Evolutionary Life Sciences, University of Groningen, P.O. Box 11103, 9700 CC Groningen, the Netherlands; Wouter Lengkeek, Bureau Waardenburg, Varkensmarkt 9, 4101 CK Culemborg, the Netherlands; Karin Didderen, Bureau Waardenburg, Varkensmarkt 9, 4101 CK Culemborg, the Netherlands; Laura L. Govers, Conservation Ecology Group, Groningen Institute for Evolutionary Life Sciences, University of Groningen, P.O. Box 11103, 9700 CC Groningen, the Netherlands; NIOZ Royal Netherlands Institute for Sea Research, Department of Coastal Systems, Utrecht University, PO Box 59, 1790 AB Den Burg, the Netherlands

Extensive subtidal eelgrass (*Zostera marina*) meadows once covered the Dutch Wadden Sea. In the 1930s, the population vanished completely. Since then, conditions in the Dutch Wadden Sea system have changed substantially and the meadows have never recovered. However, loss of these meadows has also resulted in the loss of associated biodiversity and ecosystem services. We therefore aim to assess the possibilities for subtidal eelgrass restoration in the Dutch Wadden Sea. For this we specifically aim to 1) identify suitable restoration sites and 2) determine critical restoration bottlenecks. For this, we have taken a two-step approach. First, we have constructed a habitat suitability map based on a combination of field measurement data and available spatial data. To identify critical bottlenecks, we secondly conducted a transplant experiment in the field where we aimed to implement eco-engineering applications to facilitate eelgrass settlement by reducing hydrodynamic forcing (by sea wall placement) and increasing sediment stability (by applying biodegradable biomimicry structures). The habitat suitability map indicates that high bed shear stress is one of the most critical bottlenecks. By applying anchoring devices, seagrass tolerance ranges for parameters like shear stress can be increased, decreasing the unsuitable areas from more than 95% to approximately 30%. The field experiment showed mixed results: Sea wall placement altered sedimentation and erosion processes, causing seagrass burial and mortality, while increasing sediment stability prolonged seagrass survival. Eco-engineering can thus potentially facilitate seagrass settlement in highly dynamic systems by allowing it to overcome critical settlement bottlenecks at carefully selected restoration sites.

Effects of tidal variation and light limitation on the flowering of the seagrass *Zostera muelleri*

Manuja U. Lekammudiyanse, Coastal Marine Ecosystems Research Centre, CQUniversity and CSIRO Oceans and Atmosphere; Megan I. Saunders, CSIRO Oceans and Atmosphere; Nicole Flint, Coastal Marine Ecosystems Research Centre, CQUniversity and School of Health, Medical and Applied Sciences, CQUniversity; Andrew Irving, Coastal Marine Ecosystems Research Centre, CQUniversity; Emma L. Jackson, Coastal Marine Ecosystems Research Centre, CQUniversity.

Zostera muelleri is a dominant seagrass species that is distributed widely in intertidal and subtidal waters on the subtropical coasts of Australia. The flowering of Zostera is likely to be influenced by environmental stresses associated with tidal fluctuations and light limitation. An aquaria experiment was designed to test two levels of tidal flux (i.e., intertidal and subtidal) and light (i.e., shaded and unshaded) variations on the flowering metrics (1) number of days to first flowering, (2) number of days to peak flowering, (3) the density of spathes, (4) percentage of flowering shoots, (5) height of flowering shoot, (6) number of spathes per flowering shoot and (7) the duration of flower maturity over 24 weeks. The earliest and highest intensity of flowering was recorded in the subtidal-unshaded group, with no flowers observed in the intertidal shaded group. Tidal variation had a pronounced effect on the flowering metrics 1, 3, 4, and 5 and the

shading significantly effect on the flowering metrics 1 and 3. As per the results, subtidal-unshaded conditions will be beneficial for seagrass nurseries that are aimed at flower production. Understanding flowering variabilities is critical to understanding seagrass meadow resilience and facilitating restoration when reestablishment is led by sexual reproduction and designing the protocols of seed nurseries.

The necessity for multidisciplinary stakeholder collaboration in increasing seagrass restoration success

Roosmarijn van Zummeren, Van Oord; Jesper Elzinga, Van Oord; Jannes Heusinkveld, The Fieldwork Company

Coastal developments dedicated to protect the coastline and rehabilitate local ecosystems are undertaken in Romania. These joint goals should be reached through coastal infrastructure works halting (breakwaters) and reinstating (beach nourishment) coastal erosion, all while facilitating abiotic factors including sediment type and wave protection to support reinstatement of 2.8ha of Zostera noltii, a species lost from the local ecosystem. To date, large-scale techniques to restore Z. noltii in the Black Sea have not been documented and therefore an approach whereby researchers, coastal managers and marine contractors collaborate is necessary to design a suitable site and select rehabilitation techniques dedicated to reaching the required scale. Due to seed unavailability local Romanian sediment was imported to The Netherlands for experimental tests. Seeds were collected along the German Wadden Sea coast in early September 2020 and stored under controlled conditions before planting. In May 2021, the seeds were planted in mesocosms and in the field at a wind-sheltered and exposed site. Seeds were planted in Romanian sediment and Wadden Sea sediment (control) with small and large hessian bags, and through hand- (mesocosm) and dispenser- (field) injectors. Germination rates in mesocosm experiments varied between 10 and 17%, with highest germination rates using large hessian bags on Romanian sediment. No germination was observed in the field. Romanian sediments are likely to be suitable for growth of Z. noltii giving confidence in the abiotic aspects of the rehabilitation site. More practical experience remains to be gained in the reinstatement strategies and methods for the rehabilitation site.

Hunting for Trends in Volunteer Collected SAV Data in the Patuxent River

Samina Soin-Voshell, CCC Member CBNERR-MD DNR; Rebecca Swerida, CBNERR-MD DNR

The Chesapeake Bay National Estuarine Research Reserve - Maryland (CBNERR-MD) has monitored submerged aquatic vegetation (SAV) at its Jug Bay component, located on the Patuxent River, both professionally and through community science observation programs over the past decades. As a place-based system, incorporation of community-based monitoring at the Reserve is important not only as a source of data that informs the status of local, state, and regional SAV targets and management, but also as a form of public engagement. Projects like the Chesapeake Bay Program's (CBP) regional "Chesapeake Bay SAV Watchers" allow volunteers to collect valuable SAV data that fills a gap CBP has identified between geographically large-scale but low-specificity aerial imagery, collected by the Virginia Institute of Marine Science (VIMS), and limited-scale but high-specificity scientific transect surveys throughout the Chesapeake. This qualitative analysis of SAV observations in CBNERR-MD's Jug Bay component seeks to illustrate the value of volunteer collected data as a central part of the pyramid of understanding SAV habitat status over time. Here, a decade (1986-1996) of

volunteer-collected data from the now phased-out “SAV Hunters” program is combined with long term monitoring transect data (2007-present) collected by CBNERR-MD staff and VIMS SAV aerial imagery. These comparisons will further inform implementation of “SAV Watchers” monitoring at CBNERR-MD’s Jug Bay component in the coming years and clarify the history of SAV diversity and dynamics in the Patuxent River.

Changing Boater Behavior to Protect Seagrass

Ben Scheelk, The Ocean Foundation; Alexis Valauri-Orton, The Ocean Foundation; Alyssa Hildt, The Ocean Foundation; Rebecca Murphy, ShoreRivers

Despite efforts to reduce damage to underwater grasses, scarring from boater activity remains an active threat. In 2016, The Ocean Foundation developed a toolkit describing how to use best practices in behavior change theory to design and implement effective social marketing strategies to inspire boaters to operate their boats more carefully around underwater grasses, thereby preserving this critical carbon sink and ecosystem. Built on behavior change research and previous outreach campaigns, the toolkit provides effective, low-cost tools that can be used by local resource managers. TOF partnered with ShoreRivers, an implementing organization in the Chesapeake Bay, to test the applicability and usability of the toolkit by designing a behavior change social marketing campaign, “For a Healthy Bay, let Grasses Stay," which focuses on protecting submerged aquatic vegetation in the Bay. With campaign signs posted at eleven marinas during the summer of 2021 and two marinas in our previous testing years, this campaign has already engaged more individuals within Maryland’s recreational boating community than ever before in this effort to protect SAV through improved boating behavior. It will continue to do so as each of our partners (ShoreRivers, Arundel Rivers Federation, Havre de Grace Maritime Museum’s Environment Center, and Magothy River Association) move forward with their plans to post more signs this summer.

Meadows of Knowledge - Putting West Africa on the Global Seagrass Map

Marco Vinaccia, GRID-Arendal

While seagrass beds are globally recognized for the numerous ecosystem services they provide, they have received very little attention in most West African countries. The extensive presence of these treasured meadows has been identified and documented in the Parc National du Banc d´Arguin, in Mauritania, but there is little evidence of their occurrence in other countries. As a result of this lack of knowledge, threats could not be spelt out nor addressed properly.

Given the importance of this ecosystem, the ResilienSEA project aimed to expand the knowledge about its distribution and identify the main threats it is facing in the region, so that in the long term conservation programs may be implemented to protect biodiversity and secure the services provided by seagrass beds in this part of the world. Scientific research was therefore identified as one of the priorities, along with capacity building, information, sensitization, and policy advocacy. As shown in this Atlas, some crucial discoveries of seagrass presence were made along the way in several countries. Data about seagrass distribution in the seven countries has increased significantly in the past four years.

Socio-economic context and gender affect reliance on seagrass provisioning services

T. E. Angela L. Quiros; Masahiro Nakaoka

Ecosystem services are benefits that nature provides to humans; these services change in space and time, and are largely dependent on context. Here, we study seagrass provisioning services through a close look at seagrass small-scale fisheries and the communities that utilize them. Using a mixed-methods approach with on the ground landing surveys, seagrass ecological surveys, household interviews, and in-depth interviews with key informants, we overlay biophysical variables with social data from six commnities on Busuanga Island, Philippines. We employed the Indo-Pacific Seagrass Network (IPSN) methodology in collecting the data.

We found that reliance on seagrass provisioning services were pervasive in our study sites, but individual reliance (home consumption versus bringing to market) on those fisheries changed, based on unique social and ecological contexts. Seagrass condition (as measured by abundance and diversity) influenced provisioining benefits derived from seagrass beds. Threats to these systems included tourism and coastal development, which had an impact on individual reliance on seagrass. Lastly, female fishers in some communities greatly benefited from artisanal seagrass fisheries, while in some communities, male fishers were more likely to bring seagrass catch to market. This work has the potential to inform management of seagras resources for food security, applicable to other locations in the coral triangle.

Seagrass meadows under multiples natural and anthropogenic disturbances: the challenges of implementing integrated conservation and management public policies

Fanny Kerninon, Lemar UMR 6539 UBO CNRS Ifremer IRD CNRS, University of Western Brittany (UBO), rue Dumont d'Urville, 29280 Plouzané, France; Claude Payri, UMR Entropie (IRD, Université de la Réunion, Université de la Nouvelle-Calédonie, CNRS, Ifremer), Institut de Recherche pour le Développent (IRD), 101 Promenade Roger Laroque, Nouméa, 98848, Nouvelle-Calédonie, France; Katia Ballorain, Marine turtle study and discovery center (CEDTM), 6, chemin Dubuisson, Appt. 5. 97436 Saint-Leu, La Réunion, France; Olivier Monnier, Office français de la biodiversité, 5 Square Félix Nadar, 94300 Vincennes, France; Teresa Alcoverro, Centre d'Estudis Avançats de Blanes (CEAB-CSIC), Carretera d'accés a la cala sant Francesc 14, 17300 Blanes, Spain / Nature Conservation Foundation, 3076/5, 4th Cross, Gokulam Park, Mysore, India; Claire Hellio, Lemar UMR 6539 UBO CNRS Ifremer IRD CNRS, University of Western Brittany (UBO), rue Dumont d'Urville, 29280 Plouzané, France

With the worldwide loss of seagrass meadows, the management and preservation of this important ecosystem is being given greater consideration. However, the operational implementation of associated public policies sometimes comes up against local features that need to be overcome in order to prevent them from being limited to ticking boxes. The initial objective of this study is to find the best descriptors to the different management objectives of Mayotte's declining seagrass meadows, which are subject to major natural and human disturbances. The island, located in the South West of Indian Ocean, shelter a particularly high population of green turtles (witch grazes intensively the intertidal seagrass meadows) and a tiny endangered population of dugongs. Mayotte has also to face an unprecedented increase in the human population leading to significant degradation of the lagoon waters quality. We investigated the responses of seagrass meadows along a gradient of anthropogenic pressures based on parameters ranging from physiological scale to ecosystem level. Challenges and difficulties for the monitoring of seagrass meadows health, the preservation of this ecosystem as a feeding ground for associated megaherbivores and their use as a bioindicator to assess coastal water quality will be discussed. This case study illustrate that the concrete implementation of

public policies can only be successful if the means are commensurate with the objectives and if they are locally integrated according to a cross-sectoral management strategy, while taking into account the natural dynamics of meadows.

Session 5B: Seagrass-shellfish interactions

Session Convener(s): Elizabeth Lacey, Stockton University

Collectively submerged aquatic vegetation and shellfish communities provide a diverse suite of services that increase the diversity and productivity of coastal ecosystems while performing additional important ecosystem functions such as sediment stabilization and water filtration. Both seagrass and shellfish habitats work synergistically to increase coastal resilience while positive feedbacks within the ecosystems can serve to support further growth and establishment of both communities. Worldwide both shellfish and seagrass communities have been in decline, attributed to habitat degradation via overharvesting, disease, and/or water quality stressors, putting these ecosystem services at risk. Recent results from efforts to understand the interactive relationships between SAV and shellfish have provided mixed results. This session will focus on those interactive components of shellfish – seagrass ecosystems and their impacts on restoration, preservation, or overall ecosystem health.

Talks:

Invasion of the reef urchins: Echinometra spp., runoff, and seagrass community composition in Bocas del Toro, Panamá

Abigail Libbin Cannon; Cynthia Peña; Deyvis Gonzalez; Arcadio Castillo; Eric Brown; Xinyuan Zhang; Andrew H Altieri; Aaron O'Dea; Jennifer E Smith

Grazing pressure on early successional species enhances the dominance of late successional species in algal systems (Brawley and Adey 1981; Lubchenco 1983), but has not been studied in seagrass beds. To determine whether macrograzers exclude early successional *Syringodium filiforme* from monospecific beds of *Thalassia testudinum,* fish and invertebrate abundance surveys and grazing assays were conducted in seagrass beds with and without *S. filiforme* across Bahía Almirante's three hydrographic zones. Urchins in the usually reef-associated genus *Echinometra* were more abundant in sites without *S. filiforme* in 2 out of three hydrographic zones but were absent from seagrass beds in the highest runoff zone. No other relationship between fish or urchins and *S. filiforme* presence or absence was detected. Response to grazing assays was positively correlated with seagrass habitat complexity, but not with other variables. Densities of fish and the urchin, *Lytechinus variegatus,* were experimentally manipulated at one site to assess the relative importance of both groups. These manipulations showed an effect of elevated *L. variegatus* densities on *T. testudinum* percent cover but no significant effect of ambient *L. variegatus* or fish densities. This suggests that grazing by *Echinometra spp.* eliminates early successional *S. filiforme* from some but not all monospecific *T. testudinum* beds. *S. filiforme's* absence from beds in the most runoff affected zone may be due to its lower tolerance for low salinity than *T. testudinum*, which challenges the assumption of early successional species being more stress tolerant. The implications of *Echinometra spp.* becoming a dominant seagrass grazer are discussed.

Using floating bags for oyster farming is compatible with healthy Posidonia australis seagrass meadows

Giulia Ferretto; Centre for Marine Science and Innovation, University of New South Wales; Adriana Vergés, Centre for Marine Science and Innovation, University of New South Wales and Sydney Institute of Marine Science; Alistair G. B. Poore, Centre for Marine Science and Innovation, University of New South Wales, Sydney, NSW, Australia AND Sydney Institute of Marine Science, Sydney, NSW; Paul E. Gribben, Centre for Marine Science and Innovation, University of New South; Wales, Sydney, NSW, AUstralia AND Sydney Institute of Marine Science, Sydney, NSW; Tim M. Glasby, New South Wales Department of Primary Industries, Port Stephens Fisheries Institute, NSW, Australia

Ocean sprawl has resulted in a proliferation of artificial structures such as seawalls, jetties, pontoons and those from aquaculture industries. Coastal aquaculture supports local economies and reduces pressure on wild stocks but can have adverse impacts on the marine environment when poorly managed. Estuaries, where oyster aquaculture is common, are critical habitats for seagrasses that are declining globally. In this study, we used field experiments to test how trays, longline baskets and floating bags, three of the most common oyster cultivation methods in New South Wales, Australia, affect the seagrass *Posidonia australis. P. australis* is listed as endangered in some estuaries where oyster aquaculture is common. Trays and longline baskets reduced light availability by 90.8% and 52.8%, respectively, and compromised *P. australis* photosynthetic efficiency. Trays and longline baskets also caused 4-fold declines in shoot density after 3 months and up to 8 times density declines under the trays after 6 months. Seagrass leaf growth did not vary among treatments, but leaves under trays and baskets were shorter than in controls. Floating bags were not associated with any declines in density or leaf length. Sediment deposition was highest under trays, yet nutrient and organic matter content did not differ among treatments. There is a strong need to prevent damage to sensitive marine habitats *like P. australis* meadows, thus, using floating bags for oyster aquaculture wherever possible will minimise impacts on seagrass while helping to meet growing demands for food.

Nearby shellfish aquaculture can promote expansion of eelgrass beds

Sarah C Lummis, UC Santa Cruz; Nicole A. Lenoski, UC Santa Cruz; Kelly Goedde-Matthews, UC Santa Cruz; Kristy, J. Kroeker; UC Santa Cruz

Many experimental and observational studies have indicated that bivalve aquaculture in shallow estuaries generally has negative impacts on associated seagrass ecosystems. However, in most of these studies, shellfish aquaculture directly impacted the seagrass ecosystem through physical damage and shading. As California state regulations prevent direct impacts to seagrass beds without compensatory mitigation, shellfish growers in California must place gear and shellfish in the shallow mudflats adjacent to eelgrass beds rather than within or suspended above the beds. To quantify how this aquaculture practice affects seagrass ecosystems, we completed a three-and-a-half-year field experiment following a Before-After-Control-Impact (BACI) design that distinguished the effect of nearby oyster aquaculture on eelgrass meadow characteristics from natural annual and interannual variability. We found that the maximum extent of the seagrass bed and the shoot density at the upper edge of the eelgrass bed increased with the installation of aquaculture in the nearby mudflats, relative to control sites, while shoot and rhizome morphology and rhizome internode distances (a proxy for growth rates) did not change. Contrary

to previous studies, these results suggest that shellfish aquaculture can be compatible with and potentially beneficial to eelgrass when it occurs parallel to existing beds rather than within them. These results increase our understanding of how to manage coastal aquaculture while protecting the health of eelgrass beds.

Seagrass Shellfish fisheries in Southern Mozambique, and the role of LMMAs in Sustainability of the Coastal Communities.

Sádia Chitará-Nhandimo, Eduardo Mondlane University; Assucena Chissico, Eduardo Mondlane University; Marlino Eugénio Mubai, Eduardo Mondlane University; António de Sacramento Cabral, Ocean Revolution Mozambique; Almeida Guissamulo, Eduardo Mondlane University; *Salomão Bandeira*, Eduardo Mondlane University

Seagrass meadows are a key ecosystem for the livelihoods of coastal communities around the world, mainly in tropical countries, through fishing, collection and sale of shellfish fisheries. We did a qualitative and quantitative assessment in two distinct Bays (Maputo Bay - MB and Inhambane Bay - IB) in southern Mozambique - an African country located in the WIO region- on how invertebrate gleaning contributes to the livelihoods of coastal communities, main problems faced, impacts on seagrasses and sustainability issues. There are about 39 invertebrate edible species, 24 at MB and 15 at IB; nearly all gleaners are women and children. Our estimates indicate that about 15 tons of invertebrates are collected in the peak catch weeks (spring low tides), 7.6 in Mb and 7.7 at IB. An estimate for the monthly total revenue for gleaners in western MB is about USD 2630, mostly from razor clams, *Solen cylindraceus*. For IB, we estimated a USD 1229.7 monthly total revenue for gleaners, mostly from *Pinna muricata* and the pearl oyter *Pinctada capensis*. Both sites face the problem of reducing catches and sizes of the resources (mainly bivalves) over the years, mainly due to bad harvesting practices, seagrass degradation, and higher number of gleaners (overexploitation). The existence of more than 1170 ha of LMMAs of fisheries management at IB, together with existing community and other stakeholder engagement, and intervention on value chains, are at the center of tangible invertebrate fishery management.

Legacies of planted eelgrass (*Zostera marina*) density and interactions with oyster reefs on plant and invertebrate community establishment

Margot Buchbinder, Estuary & Ocean Science Center, San Francisco State University; Katharyn Boyer, Estuary & Ocean Science Center, San Francisco State University

Living shorelines projects (LSPs) use restoration of living, natural elements to enhance shoreline protection. In San Francisco Bay, the experimental Giant Marsh LSP utilizes restored eelgrass (*Zostera marina*) planted alone as well as bayward and shoreward of oyster reefs to understand feedbacks between these habitats and inform designs that can maximize biological and physical benefits. Additionally, eelgrass was planted at a range of densities to explore whether facilitation may improve eelgrass establishment and habitat provision. After two years, we found that both shoot density and total shoot counts were enhanced by planting on the shoreward side of the reefs. Both measures also increased with higher density planting; however, the magnitude of the increase did not reflect the proportional differences in planted density. Eelgrass epifaunal communities were also affected by position relative to the reefs and planted density, indicating both legacy effects of planting technique and the influence of oyster reefs on eelgrass-associated communities. Specifically, total abundance of epifauna was influenced by an interaction of

position and planted density; when plantings were not protected by reefs, higher planting densities were needed to support high invertebrate abundances. We conclude that situating eelgrass plantings shoreward of oyster reefs can increase establishment success, which may further augment the services of eelgrass in habitat provision, shoreline protection, and other benefits. Whether responses to higher density plantings warrant the additional labor and harvesting from existing beds will be weighed further over time.

Using oyster berms (Crassostrea virginica) to facilitate success of eelgrass (Zostera marina) restoration

Elizabeth Lacey, Stockton University; Christine Thompson, Stockton University

Submerged aquatic vegetation (SAV) provide essential ecosystem services; however, eelgrass (*Zostera marina*) habitats in Barnegat Bay have declined as available light for necessary physiological processes is reduced and seed sources are limited following decades of decline. Project goals included the implementation of an SAV restoration program using both single habitat eelgrass (*Zostera marina*) via seed at two sites and dual habitat eelgrass and native eastern oyster (*Crassostrea virginica*) via oyster berms placed perpendicular to currents at two sites. We hypothesized that the current baffling and particle-trapping of the oyster berms at the dual habitat sites would facilitate the success of eelgrass restoration and habitat provisioning given the favorable conditions at the site, but presence of strong currents and lack of seed source limiting natural recovery. Preliminary results indicate that eelgrass densities were higher at dual habitat sites post-restoration, which also experienced significant changes in soil characteristics (grain sizes) due to hydrodynamic changes at the sites, and provided habitat for a significantly higher diversity of commercially and recreationally important fish and invertebrate species. The results and continued monitoring of this project will support SAV and oyster restoration and protection planning at both the regional and state level as it directly restores habitat and improves water quality.

<u>Session 6A:</u> Carbon ecosystem services: The role of seagrasses in carbon cycling and climate change mitigation and adaptation

Session Convener(s): Aurora M Ricart, Bigelow Laboratory for Ocean Sciences and Bodega Marine Lab, University of California, Davis; Gema Hernán, Mediterranean Institute for Advanced Studies, Department of Marine Ecology; Irene Olivé, Stazione Zoologica Anton Dohrn, Department of Integrative Marine Ecology

Ecosystem services are defined as the contributions that natural ecosystems make to human societies' welfare. Carbon ecosystem services refer to those services related to carbon cycling and carbon-related climate change mitigation and adaptation. Seagrass meadows are recognized for providing a wide variety of ecosystem services. In terms of carbon, seagrasses play an important role in oceanic carbon cycling with consequences in climate regulation. Seagrass meadows are hot spots of carbon sequestration and carbon burial, acting as relevant carbon sinks at a global scale. Moreover, the metabolic activity of seagrasses can also impact seawater carbonate chemistry potentially buffering ocean acidification effects at a local scale.

However, due to the combination of multiple biogeochemical processes involved in carbon cycling, together with a large natural spatio-temporal variability in coastal areas, large

uncertainty remains associated with the different carbon ecosystem services provided by seagrasses. At present, the quantification and valuation of the contribution of seagrasses to carbon services in relation to future scenarios of rising CO2 concentrations remain largely unknown.

This session aims to bring together the current state-of-the-art research on seagrass carbon services, as well as discuss possible future trajectories in a high CO2 world. This session welcomes research studies, educational/social initiatives, and policy strategies, aiming at the assessment, management, and restoration of carbon services in seagrass ecosystems. Particularly, we welcome works elucidating the role of seagrasses on organic/inorganic carbon fluxes, carbon stocks, and seawater carbonate chemistry and works looking at different impact scenarios of anthropogenic pressure and climate change in carbon ecosystem services.

Talks:

Carbon ecosystem services: The role of seagrasses in carbon cycling and climate change mitigation and adaptation

Aurora M Ricart, Bigelow Laboratory for Ocean Sciences & Bodega Marine Laboratory, University of California, Davis; Gema Hernán, Mediterranean Institute for Advanced Studies, Department of Marine Ecology, Balearic Islands; Irene Olivé, Stazione Zoologica Anton Dohrn, Dept. of Integrative Marine Ecology

Ecosystem services are defined as the contributions that natural ecosystems make to human societies' welfare. Carbon ecosystem services refer to those services related to carbon cycling and carbon-related climate change mitigation and adaptation. Seagrass meadows are recognized for providing a wide variety of ecosystem services. In terms of carbon, seagrasses play an important role in oceanic carbon cycling with consequences in climate regulation. Seagrass meadows are hot spots of carbon sequestration and carbon burial, acting as relevant carbon sinks at a global scale. Moreover, the metabolic activity of seagrasses can also impact seawater carbonate chemistry potentially buffering ocean acidification effects at a local scale. However, due to the combination of multiple biogeochemical processes involved in carbon cycling, together with a large natural spatio-temporal variability in coastal areas, large uncertainty remains associated with the different carbon ecosystem services provided by seagrasses. At present, the valuation of the contribution of seagrasses to carbon services in relation to future scenarios of rising CO2 concentrations remain largely unknown.
This presentation aims to set the stage of the session, in which we will bring together the current state-of-the-art research on seagrass carbon services, as well as discuss possible future trajectories in a high CO2 world.

Air-Water Gas Exchange in Temperate Seagrass Meadows

Kayleigh Granville, Department of Environmental Sciences, University of Virginia; Peter Berg, Department of Environmental Sciences, University of Virginia; Iris Anderson, Virginia Institute of Marine Science, William & Mary; Bongkeun Song, Virginia Institute of Marine Science, William & Mary; Stefanie Simpson, The Nature Conservancy, Worldwide Office

Restoration projects and carbon crediting initiatives can partially mitigate anthropogenic carbon dioxide (CO_2) emissions. Seagrass meadows are widely regarded as carbon sinks, but meadows can also emit methane (CH_4) and nitrous oxide (N_2O), greenhouse gases with global warming

potentials nearly 30 and 300 times greater than CO_2, respectively. Thus, evaluating carbon sequestration in seagrass meadows requires accurate CO2, CH4, and N2O flux measurements. However, there is a lack of air-water seagrass CO_2, CH_4, and N_2O flux measurements on local and regional scales, and existing fluxes often have high uncertainties. These uncertainties are partially attributed to methodologies that rely on ecological parameterizations to derive air-water gas fluxes. We measured air-water gas fluxes in a restored, temperate seagrass meadow (Virginia, USA) using a new technique: upside-down aquatic eddy covariance. This technique derives CO_2, CH_4, and N_2O fluxes from measured in situ O_2 fluxes and in situ greenhouse gas concentrations instead of ecological parameterizations. The resulting fluxes are measured on a broad spatial scale and for longer periods of time than standard methods (24-72 hours). In this study, we measured CO_2, CH_4, and N_2O fluxes from May to July. We compared CO_2, CH_4, and N_2O fluxes seasonally as well as over tidal and diurnal cycles. The resulting flux measurements will improve our understanding of greenhouse gas flux dynamics in temperate seagrass meadows and may support restoration and carbon crediting projects.

Carbon stocks, burial rates and environmental DNA in seagrass sediments at the Banc D'Arguin, Mauritania

Márcio Martins, Centre of Marine Sciences of the Algarve (CCMAR); Rui Santos, Centre of Marine Sciences of the Algarve (CCMAR); Carmen B. de los Santos, Centre of Marine Sciences of the Algarve (CCMAR); Fátima Abrantes, Centre of Marine Sciences of the Algarve (CCMAR), Portuguese Institute for the Ocean and Atmosphere (IPMA); Vitor Magalhães, Portuguese Institute for the Ocean and Atmosphere (IPMA); Tânia Aires, Centre of Marine Sciences of the Algarve (CCMAR); Aschwin H. Engelen, Centre of Marine Sciences of the Algarve (CCMAR); David Abecasis, Centre of Marine Sciences of the Algarve (CCMAR); João Encarnação, Centre of Marine Sciences of the Algarve (CCMAR); Cheikhna Gandega, Mauritanian Institute for Oceanographic Research and Fisheries (IMROP); Ba Mamadou Abdoul, Banc d'Arguin National Park (PNBA); Khallahi Brahim, Mauritanian Institute for Oceanographic Research and Fisheries (IMROP)Ebaye Sidina, Banc d'Arguin National Park (PNBA); Ester A. Serrão, Centre of Marine Sciences of the Algarve (CCMAR), Research Centre in Biodiversity and Genetic Resources (CIBIO-InBIO)

Seagrass meadows help mitigate climatic changes by sequestering carbon in their sediments. However, global assessments are hindered by poor knowledge of important seagrass ecosystems in the world, such as the Banc d'Arguin (western Africa), a hypertrophic system receiving coastal upwelling waters and iron-rich Saharan dust. We assessed sedimentary chronostratigraphy and carbon stocks, burial rates and sources (based on eDNA metabarcoding) within intertidal *Zostera noltei* and subtidal *Cymodocea nodosa* seagrass meadows, and adjacent unvegetated sediments. The chronostratigraphy analysis revealed the effects of a high-energy event, probably the tsunami associated with the 1755 Lisbon earthquake. Top 50-cm sedimentary carbon stocks in seagrass meadows of both species were about 25 Mg ha^{-1}, 16 times higher than in unvegetated sediments. The carbon burial rates for the past 100 years in *C. nodosa* were 15 g OC m^{-2} yr^{-1}, and 9 g OC m^{-2} yr^{-1} in *Z. noltei*. eDNA analysis revealed that the major carbon source in C. nodosa was this seagrass species itself, except for the surface layer that was dominated by diatoms. Diatoms were also the main carbon source for the entire sedimentary column in the unvegetated sediment. Sources in the *Z. noltei* were very diverse, but the most important contributor was still the autochthonous species. Interestingly, records of crop plants were found in the *Z. noltei* site at 1600 CE, suggesting nearby agriculture activities, where it is

now a desert. We conclude that Banc d'Arguin, given its high seagrass extension of ca. 4295 km^2, is a global carbon sequestration hotspot.

Influence of Cymodocea nodosa density on community metabolism and dissolved organic carbon fluxes (DOC)

Alba Yamuza; Isabel Casal-Porras; Luis G. Egea; Rocío Jiménez-Ramos; J. Lucas Pérez-Llorens; Fernando G. Brun [Department of Biology, Faculty of Marine and Environmental Sciences, University of Cádiz, Puerto Real (Cádiz), Spain]

Seagrass meadows are one of the most productive ecosystems on the planet and play an important role in the global carbon cycle. However, they are also among the most threatened due to global change and uncontrolled coastal development. Its deterioration is often associated with a partial or complete loss of shoot density, which can lead to changes at individual and community level. This study aims to analyze how the regression of seagrass communities alter the carbon metabolism and dissolved organic carbon (DOC) fluxes. Thus, an *in situ* manipulation experiment was performed on a healthy meadow of *Cymodocea nodosa* by removing shoots achieving three seagrass coverage densities (treatments): 100% (control), 60% and 25%. Experimental densities were preserved during three months at winter and summer seasons. After that period, incubation chambers were installed to monitor carbon metabolism, DOC fluxes, organisms' assemblages and sediment organic matter and chlorophyll *a* content. The results showed significant changes as a function of treatment and seasonality. Net community production and DOC fluxes decreased significantly as shoot density was reduced, shifting from an autotrophic community to a heterotrophic one in winter. Density reduction significantly decreased fauna abundance in winter, meanwhile algae abundance raised, although no significantly, in this season. Sediment organic matter decreased during summer, in contrast, chlorophyll *a* concentration didn't show a clear trend. Our results evidence that the reduction in seagrass density may result into a significant decrease in the organic carbon uptake and DOC release, modifying its role as blue carbon sink and biodiversity hotspot.

Carbon metabolism and blue carbon sequestration potential of seagrass beds across latitudinal gradients

Irene Olivé, Stazione Zoologica Anton Dohrn; Laura Soissons, UMR Marbec – INRAE; Francesca Rossi, University of Nice Antipolis; Nicholas Kamenos, University of Glasgow

Seagrass meadows are recognized as key CO_2 sinks holding a very high ecological and economic value as blue carbon storage sites associated to their productivity. Seagrasses can contribute to counterbalancing greenhouse-gas emissions by removing CO_2 and increasing carbon stores while providing key ecosystem services to coastal communities.

In Europe, seagrass meadows are considered a key contributor to blue carbon in coastal areas. Seagrass beds of the species *Zostera marina* occur along European coasts, from high sub-arctic latitudes up to temperate Mediterranean areas, covering a large latitudinal range of environmental conditions. However, at present, a latitudinal evaluation of the carbon sequestration capacity of European seagrass meadows associated to its productivity is lacking. This study determined the carbon metabolic status of seagrass communities of *Z. marina* covering a latitudinal gradient from Orkney Islands (United Kingdom) to Mediterranean (France) to estimate their role in carbon sequestration and thus potential contribution to carbon removal and the blue carbon repository.

The carbon metabolic balance of *Z. marina* individuals was estimated by determining net photosynthesis and respiration of seagrass individuals using *in situ* plant incubation chambers. A positive metabolic balance was recorded in all meadows studied indicating a good physiological and metabolic status of *Z. marina*. Different metabolic strategies were detected in *Z. marina* beds across the latitudinal gradient potentially affecting their role in carbon removal, sequestration and blue carbon storage capacity. The role of environmental forcing and implications on blue carbon sink capacity are also discussed.

Measuring carbon sources and total sequestration by eelgrass meadows in Atlantic Canada

Tanya Prystay; Rachel E Sipler; Arnault LeBris

Quantifying carbon sequestration in local seagrass ecosystems improves estimates of the contribution of blue carbon to the global carbon cycle and can inform coastal management decisions. Similarly, identifying the source of the sequestered carbon is important for understanding where carbon release is being offset. Here, we present preliminary analyses of the carbon source and total carbon sequestration by eelgrass (*Zostera marina*) meadows in Newfoundland, Canada. We mapped three eelgrass meadows using a drone and collected 18 sediment cores from each site (N = 54). Sediment cores were used to measure the percent total organic carbon (C_{org}), N, $\delta^{13}C$, and $\delta^{15}N$ to determine the amount of carbon sequestered in each meadow and the likely carbon source. Preliminary results suggest that C_{org} from sediment collected within the meadow (i.e., edge and inside) was ~2% higher than in sediment collected outside the meadow. Stable isotopic compositions further suggest the C_{org} comes from a combination of terrestrial and plankton sources given a mean C:N of 13.9 and a mean $\delta^{13}C$ of -22 ‰ (range for marine bacteria and phytoplankton) irrespective of location. Using the drone derived maps, we aim to approximate the total carbon sequestered into sediments per eelgrass meadow and explore how differences could be related to meadow configuration, blade morphology, and water quality. Our findings will be the first known quantification of carbon sequestration by eelgrass meadows in Newfoundland, and help the process of contextualizing the contribution of Newfoundland eelgrass to the national carbon cycle and carbon budget.

Sedimentary carbon stocks of intertidal seagrass meadows in an impacted wetland: effects of coastal infrastructure constructions

Casal-Porras, Isabel; de los Santos, Carmen B.; Martins, Márcio; Santos, Rui; Pérez-Lloréns, J. Lucas; Brun, Fernando G.

Seagrass meadows, through their large capacity to sequester and store organic carbon in their soil, contribute to mitigate the impacts of climatic change. However, these ecosystems have experienced large losses and degradation worldwide due to anthropogenic pressures. At the local level, seagrass meadows are commonly impacted by coastal constructions either directly (replacement of the meadows by the structures) or indirectly (changes in the hydrodynamic driven by structures). When a meadow is impacted, the vegetation is partially or completely lost, and the sediment is exposed to the atmosphere or water column, resulting in the erosion and remineralisation of the stored carbon. Here we assessed how small coastal infrastructures in a coastal lagoon affected the sedimentary organic carbon stocks of seagrass meadows. Three intertidal areas colonised by seagrasses and impacted by the construction of a bridge and two pontoons were selected in the Ria Formosa (Portugal). At each site, the sedimentary blue carbon stock was assessed in the impacted area and in adjacent well-preserved seagrass meadows. We

observed that the sediment in the impacted areas was mainly sand, whereas that from the well-preserved meadows presented a higher percentage of mud. These differences are reflected in the organic carbon stock, which was, on average, 1.5 times lower in the impacted areas than in the well-preserved meadows. These results showed that, although the impacted areas were not large, coastal infrastructures caused a significant reduction of the blue carbon stocks and the total disappearance of the seagrass meadow.

Carbon stocks, carbon accumulation rates, and GHG flux dynamics of seagrass ecosystems: A systematic review

Clint Cameron, University of Queensland; Dan Friess, National University of Singapore; Núria Marbà, Universitat de les Illes Balears; Hilary Kennedy, Bangor University; Oscar Serrano, Edith Cowan University; *Mathew Oreska*, Virginia University ; Lynn Wong, National University of Singapore; Steve Crooks, Silvestrum Climate Associates; Siti Maryam Yaaku, DHI Group; Jim Fourquean, Florida International University; Emily Pigeon, Conservation International; Catherine Lovelock, University of Queensland

The first comprehensive review of blue carbon stocks in seagrass ecosystems (Fourqurean et al. 2012) was published a decade ago, and during the interim there has been a rapid expansion and acceleration of studies on all aspects of carbon cycling and storage within seagrass ecosystems. For example, analyses of GHG fluxes (e.g. exchange of CO2 between the sea-atmosphere and lateral export of respired CO2 from seagrass beds), carbon accumulation rates, and calcium carbonate cycling has now been reported in multiple studies. In particular, it is now recognized that calcium carbonate precipitation and dissolution by calcifying organisms associated with seagrass ecosystems (e.g. algae, seagrass epiphytes, and molluscs) is increasingly recognised as an important component in evaluating the net blue carbon sink capacity of seagrass ecosystems (Macreadie et al. 2017). This study presents preliminary results from an updated systematic review of almost 600 publications covering the full suite of carbon stocks, accumulation rates, GHG fluxes, and calcium carbonate cycling in seagrass ecosystems. Outcomes from the project are intended to give insights into the factors driving variability, describe geographic distributions, and reduce uncertainty in seagrass carbon stock and accumulation values. These values are essential to broadening the integration of seagrass ecosystems into carbon project development, carbon credit methodologies, national greenhouse gas accounting and other policy related applications and provide a stronger evidence base for conserving or restoring seagrass ecosystems.

Bahamas-wide Seagrass Blue Carbon Assessment leveraging Modern Earth Observation Advances

Alina Blume; Dimosthenis Traganos, German Aerospace Center (DLR); Avi Putri Pertiwi, German Aerospace Center (DLR); Benjamin Chengfa Lee, German Aerospace Center (DLR); Spyros Christofilakos, German Aerospace Center (DLR)

Seagrasses offer multiple ecosystem services and play an important role in carbon-related climate change mitigation and adaptation. Their carbon sequestration and storage potential can support a variety of Multilateral Environmental Agreements like the Nationally Determined Contributions of the Paris Agreement and the Sustainable Development Goals. Spatially explicit knowledge of seagrass distribution and site-specific in-situ carbon data are both crucial for the

assessment of the potential of seagrass blue carbon and its policy uptake in national climate agendas and investments.

Within the context of the Global Seagrass Watch project, we analysed open big Sentinel-2 satellite data within the open cloud computing platform of the Google Earth Engine to quantify the extent of Bahamian seagrass, and their associated carbon stocks (Tier 2 Assessment), and sequestration rates.

Preliminary assessments indicate that seagrasses cover about 10 to 25% of the country's shallow water area and may store up to 456 million Mg of carbon in their soils. of. The mapped seagrass extent is estimated to sequester 17 to 40 times more CO2 than the annual emissions of The Bahamas in 2018.

Our generated data inventories underline the importance of the seagrass ecosystem for The Bahamas and the necessity of recognizing their seagrass blue carbon into national climate agendas. In parallel, our preliminary assessment showcases the need for more cost-effective conservation and restoration efforts for seagrass meadows. Our remote sensing approach and data could support holistic efforts of scientists, managers, policy makers, and companies, from a national to a global climate action context.

Carbon provenance and coastal connectivity -implications for temperate seagrass carbon sequestration capacity

Emma A Ward; Federica Ragazzola; Sarah Reynolds; Marianna Cerasuolo; Joanne Preston

Seagrass has long been established as a coastal blue carbon habitat with near global presence. Their capacity to accumulate sedimentary organic carbon, poses them as a manageable resource to sequester carbon and reduce greenhouse gas emissions. Seagrasses accumulate carbon two-fold through *in situ* photosynthetic fixation of autochthonous carbon and sedimentation of allochthonous carbon from outside the ecosystem. This study collates an updated global synthesis of $\delta^{13}C$ analyses from seagrass sediments and leaves, enabling its categorisation into seagrass bioregions alongside grouping by seagrass species size. For paired $\delta^{13}C$ seagrass sediment and leaf values there was a difference in $\delta^{13}C$ of seagrass leaf tissue and seagrass sediment ($\Delta\delta^{13}C_{seagrass\text{-}sediment}$ median = 7.36‰), indicating regular presence of allochthonous carbon. Seagrass species composition was a significant factor in the $\Delta\delta^{13}C_{seagrass\text{-}sediment}$, with the highest $\Delta\delta^{13}C_{seagrass\text{-}sediment}$ found in monospecific meadows dominated by mid-range sized seagrass (e.g., *Zostera* spp., *Cymodocea* spp. and *Syringodium* spp). The temperate North Atlantic and North Pacific bioregions have significantly higher $\Delta\delta^{13}C_{seagrass\text{-}sediment}$ compared to all other seagrass bioregions (Temperate Southern Oceans, Mediterranean, Tropical Atlantic and Indo-Pacific). Seagrass meadows within the North Atlantic and North Pacific are dominated by mid-range sized seagrass. Therefore, these temperate seagrass meadow's affinity for allochthonous carbon from adjacent habitats, means their placement within the coastal landscape influences their carbon sequestration potential. This global review demonstrates that a meadow's seagrass species composition and placement within the seascape influences its carbon sequestration capacity; making them necessary forecasters of a meadow's carbon offset potential, particularly in the context of temperate seagrass meadows.

Megaherbivore exclusion at a long-term monitoring site led to more complex seagrass canopies and increased sediment accretion without an effect on sediment Corg

J. Samper-Villarreal, CIMAR, University of Costa Rica; J. Moya-Ramírez, School of Biology, University of Costa Rica; J. Cortés, CIMAR and School of Biology, University of Costa Rica

In some regions of the Caribbean Sea, seagrasses are threatened by sea turtle overgrazing. We deployed megaherbivore exclosures for 13 months at a long-term monitoring site where seagrass canopy complexity has declined in Costa Rica. During herbivore exclusion, seagrass cover and maximum canopy height increased in the exclosures (~ 75 % and 20 cm); while they remained steady in controls (< 25 % and ~ 5 cm). Following exclusion, above ground biomass was higher in exclosures (320 +- 60 g DW m^{-2}) compared to controls (170 +- 60g DW m^{-2}). Leaves were longer and wider in the exclosures (8 +- 5 cm and 0.8 +- 0.2 cm) compared to controls (2 +- 2 cm and 0.5 +- 0.1 cm). Above ground biomass C_{org} in exclosures (1.2 +- 0.2 Mg ha^{-1}) was two times higher than in controls (0.6 +- 0.2 Mg ha^{-1}). Meanwhile, there was no variation in seagrass shoot density (1,700 +- 800 shoots m^{-2}), below ground biomass (250 +- 100 g DW m^{-2}) and C_{org} (0.8 +- 0.4 Mg ha^{-1}), or in surficial sediment C_{org} (20 +- 3 Mg ha^{-1}). Canopy structural complexity increased within the exclosures compared to controls without an effect on sediment C_{org} content, yet sediment levels were higher in the exclosures. Current canopy complexity may be closer to levels prior to megaherbivore decline, yet overgrazing could lead to continued seagrass decline or loss. This could potentially impact sea turtle populations and inhibit seagrass restoration initiatives, with many other anthropogenic concurrent stressors on seagrasses.

Resilient consumers accelerate the plant decomposition in a naturally acidified seagrass ecosystem

Juhyung Lee; Maria Cristina Gambi; Kristy J. Kroeker; Marco Munari; Kabir Peay; Fiorenza Micheli

We used a naturally acidified seagrass ecosystem (Mediterranean seagrass *Posidonia oceanica*) as a model system to examine how ocean acidification (OA) modifies the community structure and functioning of plant detritivores, which play vital roles in the coastal food web, nutrient cycling, and carbon sequestration. In seagrass beds associated with volcanic CO_2 vents (Ischia, Italy), we quantified the effects of OA on seagrass decomposition by deploying litterbags in three distinct pH zones (i.e., ambient, low, and extreme low pH), which differed in the mean and variability of seawater pH. Acidification reduced seagrass detritivore richness and diversity through the loss of less abundant, pH-sensitive species but significantly increased the abundance of the dominant detritivore (amphipod *Gammarella fucicola*). Such compensatory shifts in species abundance caused more than a three-fold increase in the total detritivore abundance in lower pH zones. These community changes were associated with increased consumption (52-112%) and decay rate of seagrass detritus (up to 69% faster decomposition rate for the slow-decaying, refractory detrital pool) under acidification. Seagrass detritus deployed in acidified zones showed increased N content and decreased C:N ratio, indicating that altered microbial activities under OA may have affected the decay process. The findings suggest that OA could restructure consumer assemblages and modify plant decomposition in a globally important blue carbon ecosystem, which may have further implications for coastal nutrient cycling, carbon sequestration, and trophic transfer. Our study highlights the importance of within-community response variability and compensatory process in modulating ecosystem changes under global stressors.

Quantifying patterns and trends in thermal vulnerability and resilience of seagrass

Kylor Kerns, University of Virginia; Dr. Karen McGlathery, University of Virginia; Dr. Peter Berg, University of Virginia; Dr. Amelie Berger, University of Virginia

Seagrasses are widely regarded as carbon sinks that can sequester carbon and reduce greenhouse gas concentrations. At the same time, they are vulnerable to ocean warming and marine heatwaves, which can lead to the loss of sediment carbon stores. Understanding of how marine heatwaves vary spatially and temporally at a system-wide scale is important for determining the efficacy of carbon offset projects that exist under current policies for carbon markets. We are addressing this in the coastal bay system of the Virginia Coast Reserve (VCR), home to one of the most successful seagrass restoration projects in the world. We are using sensors to measure water column and sediment temperatures continuously from May – to September at 50 sites in the coastal lagoons (6 for sediment) to describe spatial and temporal variance of temperature and to link it to warming and marine heatwaves that may occur. Using two novel heating metrics: cumulative heat stress (as heating degree-hours) and thermal stress relief (as cooling degree-hours), I quantified in situ temperature data from four seagrass bays at the VCR. There is currently no risk assessment for heatwave vulnerabilities for seagrass carbon offset credits, yet this is arguably the greatest threat to carbon permanence. My research will make carbon accounting and restoration efforts more accurate for Virginia. It will provide critical information for the collaboration between TerraCarbon, The Nature Conservancy, the University of Virginia, and the Virginia Institute of Marine Science, which created the first verified blue carbon project and continues the VCR seagrass restoration.

Posters:

The role of seagrass-tidal marsh ecosystem connectivity in blue carbon sequestration

Carolyn J. Ewers Lewis, Department of Environmental Sciences, University of Virginia; Peter Berg, Department of Environmental Sciences, University of Virginia; Karen McGlathery, Department of Environmental Sciences, University of Virginia

Blue carbon (C) ecosystems – seagrass meadows, tidal marshes, and mangrove forests – are responsible for as much as 50% of the ocean's C burial. Estimates of the role of coastal ecosystems in global C capture have greatly improved over the past few years, but the influence of ecosystem connectivity and lateral transport on C capture is largely unknown, and has received little attention in C accounting schemes, despite the large capacity of blue C ecosystems, such as seagrasses, to export C-rich sediments and biomass. The barrier island system of the Virginia Coast Reserve Long Term Ecological Research site, USA, is home to one of the largest successful seagrass restorations in the world that is over 20 years old. Here, we sampled adjacent marsh sediments deposited before (10-15 cm depth interval) and after (0-5 cm depth interval) seagrass restoration along transects in back-barrier marshes. Sediments were analyzed for C and nitrogen, organic matter, particle size, C source (via bulk isotope analysis and Bayesian mixing models), and age (Pb-210 dating). Based on these results, we calculated C stocks and sequestration rates, and estimated the contribution of seagrass exports to marsh sediment C burial before and after seagrass restoration. The outcomes from this study can improve C accounting measures and benefit conservation and restoration of seagrass and other blue C ecosystems by providing quantitative evidence of C transfer and preservation between blue C ecosystems connected in the seascape.

Seagrass meadows as a significant carbon stock in islands of Tawi-Tawi, Southwestern Philippines

Sitti Zayda B. Halun, Institute of Oceanography and Environmental Science, Mindanao State University - Tawi-Tawi College of Technology and Oceanography, Bongao, Tawi-Tawi, Philippines; Dahlia P. Burias, Institute of Oceanography and Environmental Science, Mindanao State University - Tawi-Tawi College of Technology and Oceanography, Bongao, Tawi-Tawi, Philippines; Nurizna T. Jumaide, Research Office, Mindanao State University - Tawi-Tawi College of Technology and Oceanography, Bongao, Tawi-Tawi, Philippines; Fatima Faiza Amil, Mindanao State University - Tawi-Tawi College of Technology and Oceanography, Bongao, Tawi-Tawi, Philippines; Kimtang Mohammad, Mindanao State University - Tawi-Tawi College of Technology and Oceanography, Bongao, Tawi-Tawi, Philippines; Rosanda Tarabasa, Mindanao State University - Tawi-Tawi College of Technology and Oceanography, Bongao, Tawi-Tawi, Philippines; Alimar Sakilan, Mindanao State University - Tawi-Tawi College of Technology and Oceanography, Bongao, Tawi-Tawi, Philippines; Aldimar Bara, Mindanao State University - Tawi-Tawi College of Technology and Oceanography, Bongao, Tawi-Tawi, Philippines

Seagrass meadows are important carbon sinks so it is important to investigate their roles in climate change mitigation and adaptation. This study assessed the amount of organic carbon stored in the vegetation and sediments of mixed seagrass beds in four small island municipalities of Tawi-Tawi, SW Philippines (N5 01.878, E119 44.309). Abundance and species composition were determined in thirty 0.25 m^2 quadrats randomly placed along three 100-m parallel transects laid perpendicular to the shoreline at each sampling site. Above-ground and below-ground biomass, and sediment samples were obtained through coring. Sediment cores were sliced every 5 cm from surface to bottom. Plant samples and sediments were oven dried and organic carbon was determined through Loss on Ignition (LOI). The meadows were mixed stands of 8 seagrass species, namely *Enhalus acoroides*, *Thalassia hemprichii*, *Cymodocea rotundata*, *C. serrulata*, *Syringodium isoetifolium*, *Halodule pinifolia*, *H. uninervis* and *Halophila ovalis*. The organic carbon in belowground seagrass biomass was higher than aboveground seagrass biomass across species and sites. The vegetation carbon ranged from 24 to 40 Mg C ha^{-1} while sediment carbon ranged from 205 to 698 Mg C ha^{-1}. Sediment carbon accounted for ~90% of the carbon stock in the seagrass beds.This study illustrates the importance of seagrass beds as carbon sinks especially in low lying islands that are vulnerable to the impacts of climate such as sea level rise and storm surge.

Contribution of seagrass meadows to blue carbon stocks along the Southwest Atlantic coast

Joel Creed; Margareth Copertino, Instituto de Oceanografia, Universidade Federal do Rio Grande; Vinicius Patire, Centro Interdisciplinar de Energia e Ambiente, Universidade Federal da Bahia; Pere Masque, International Atomic Energy Agency; School of Natural Sciences, Centre for Marine Ecosystems Research, Edith Cowan University; Institute of Environmental Science and Technology and Physics Department, Universitat Autònoma de Barcelona; Hilary Kennedy, School of Ocean Sciences, Bangor University; Ximena Ovando, Museu de Malacologia Prof. Maury Pinto de Oliveira, Universidade Federal de Juiz de Fora; Vanessa Hatje, Centro Interdisciplinar de Energia e Ambiente & Dep. de Química Analítica, Universidade Federal da Bahia

Blue Carbon (BC) represents the carbon dioxide (CO2) captured from the atmosphere and stored by coastal and marine ecosystems. As seagrasses remain understudied in the southwest Atlantic

(SWA), seagrass cover is not well established and knowledge about seagrasses contribution to blue carbon is insipient. The aim of this study was to estimate the contribution of seagrass meadows to organic carbon (OC) stocks and assess accumulation rates compared to other vegetated coastal ecosystems. We reviewed the literature for data on seagrass distribution, biomass and soil OC from Guyana (08.28°N) to the Argentina (55.14°S), updated estimates of areal cover and calculated aboveground and soil carbon stocks. Quite some data were available on biomass but seagrass soil samples were highly localized (to the extreme north of the Northeastern Brazil, Southeastern Brazil and Rio Grande marine ecoregions). We estimated total seagrass cover in the SWA as 0.073 Mha. Almost 100% of seagrass OC stocks were along the Brazilian coast. The lowest aboveground biomass (0.14 ± 0.21 Mg C ha-1) and soil (51 Mg C ha-1) OC stocks per unit of area are in the subtropical Southeastern Brazil and Rio Grande ecoregions, respectively, whereas stocks are 4-times higher in Northeastern Brazil. Seagrass soils account for 99% of C stocks but there were large gaps in information and data on burial rates were limited. The region stores 12 Tg C in seagrasses biomass and soil which is less than in mangroves or saltmarshes and 3% of the total stock of OC in the SWA.

The role of a tropical seagrass ecosystem in allochthonous carbon burial

Riccardo Pieraccini, Ghent University; James Gitundo Kairo, Kenyan Marine Fisheries Institute; Steven Goderis, Vrije Universiteit Brussel; Nico Koedam, Vrije Universiteit Brus

Blue carbon ecosystems are highly productive habitats that strongly contribute to the storage of organic carbon in the seabed. In tropical environments, coastal ecosystems like mangroves provide high rates of carbon input to adjacent seagrass meadows, who in turn form a trap for this organic carbon. Using a spatial approach, we investigated the origin of the organic carbon present underneath seagrass meadows in the western creek of Gazi bay, Kenya. The study was conducted in an area surrounded by dense mangrove vegetation and inhabited by twelve seagrass species. By combining stable isotopes mixing models and carbon stock analysis, we found that a large fraction of sedimentary Corg associated with the seagrass meadows is indeed of allochthonous origin (37-69%). Remarkably, there was no clear spatial pattern of decreasing Corg with increasing distance from the mangrove vegetation – the amount of Corg stayed relatively constant throughout the creek. This pointed out the role of seagrass meadows in limiting the outwelling of organic carbon from the adjacent mangrove ecosystem. Indeed, the portion of mangrove-derived Corg represented approximately 22-51% of the allochthonous Corg present underneath the seagrass meadow. This highlighted that seagrass meadows in blue carbon ecosystems are indeed essential carbon sinks, limiting the exportation of mangrove derived organic carbon.

<u>Session 6B:</u> Next generation of technologies for improved seagrass restoration

Session Convener(s): Nicole Foster, University of Adelaide; Michelle Waycott, University of Adelaide

The advent of new technologies and a more sophisticated approach to applying them to solve environmental problems enables exciting opportunities for ecosystem recovery. Greater accuracy and application over larger spatial scales than has been possible previously can now be facilitated. We will explore the potential to reverse seagrass degradation through technological innovation in this symposium. These next generation technologies include molecular toolkits enabling analysis of environmental DNA to recover seagrass community composition over

millennia or advances in remote sensing imagery and evaluating risk and recovery options or even utilizing social media platforms and citizen science to activate on-ground works bringing together science and the community. We envisage and will seek out participants to present and explore results from projects taking an innovative technological approach. This represents a potential transdisciplinary symposium incorporating seagrass biology, restoration, conservation and management. Our expected outcomes will be to highlight the potential for step-change scale improvements to recovery of impacted seagrass ecosystems or to ongoing preservation of our amazing natural seagrass meadows around the world.

Talks:

Reversing the Course of Seagrass Loss through Seagrass Restoration in the Indian River Lagoon, Florida, an Estuary of National Significance

M. Dennis Hanisak, Harbor Branch Oceanographic Institute at Florida Atlantic University; Paul Wills, Harbor Branch Oceanographic Institute at Florida Atlantic University

The highly diverse Indian River Lagoon (IRL), one of the longest barrier-island estuaries in the U.S., harbors more seagrass species than any other North America estuary, with seven species total and five at their northern limits. Catastrophic loss of seagrass occurred in the IRL, due to two consecutive years (2011-2012) of unprecedented phytoplankton "super blooms" of nanochlorophytes and picocyanobacterial in 2011 and a subsequent brown tide (*Aureoumbra lagunensis*) in 2012. Shading resulted in widespread seagrass decline (up to 100% at many sites in the northern IRL; ~60% lagoon-wide). Limited recovery has occurred despite somewhat improved water quality. A feasibility study on seagrass restoration in partnership with St. Johns River Water Management District supported the hypothesis that the limited recovery is due to a lack of available recruits (vegetative fragments and seeds) rather than environmental factors. To address this bottleneck in recruitment, we have developed a land-based nursery to provide a supply of sustainable donor material. We have begun to successfully cultivate and transplant *Halodule wrightii* as part of collaborative seagrass restoration efforts. Our innovative seagrass nursery approach could play a significant role in the re-establishment of seagrass habitat, improve the management of this vital IRL resource, and contribute to the growing blue economy for mitigating carbon emissions and adapting to climate change.

APPLYING MOLECULAR TOOLS FOR SEAGRASS RESTORATION

G. Procaccini, Stazione Zoologica Anton Dohrn, Naples, Italy; E. Dattolo, Stazione Zoologica Anton Dohrn, Naples, Italy; H.-M. Nguyen, Stazione Zoologica Anton Dohrn, Naples, Italy; J. Pazzaglia, Stazione Zoologica Anton Dohrn, Naples, Italy; I. Provera, Stazione Zoologica Anton Dohrn, Naples, Italy; M. Ruocco, Stazione Zoologica Anton Dohrn, Naples, Italy; A. Santillán-Sarmiento, Stazione Zoologica Anton Dohrn, Naples, Italy; L. Marín-Guirao, Stazione Zoologica Anton Dohrn, Naples, Italy; Seagrass Ecology Group, Oceanographic Center of Murcia, Spanish Institute of Oceanography, C/ Varadero, 30740 San Pedro del Pinatar, Spain.

Developing adequate strategies to manage, conserve and restore marine ecosystems biodiversity and services is a key target of environmental policies. Restoration of disturbed seagrass environments has become a worldwide priority to reverse ecosystem degradation and to recover ecosystem functionality and associated services. Seagrass resistance and resilience to environmental changes depend from plasticity of populations and single genotypes and from

adaptation to local environmental conditions. Despite the proven importance of genetic research to perform successful restoration projects, this aspects have often been overlooked. Molecular approaches can allow understanding meadows plasticity (i.e. potential meadows' resistance and resilience), through genetic and genotypic diversity metrics and to dissect acclimative/adaptive strategies, through gene expression approaches. The new information on the role of epigenetics in modulating gene expression and ensuring stress memory as well as the application of assisted evolution strategies have the potential to ope new directions for improving transplantation success. I will provide a comprehensive overview of genetic aspects related to seagrass restoration based on studies performed on Mediterranean seagrasses, including the genetic structure of both donor and target populations, dispersal, connectivity and local adaptation. I will also show the potential of new perspectives in assisted evolution, based on results obtained on Mediterranean seagrasses.

Storm detached fragments of the endangered seagrass *Posidonia australis* can be used to restore fragmented meadows

Giulia Ferretto, Centre for Marine Science and Innovation, School of Biological, Earth and Environmental Sciences, University of New South Wales, Sydney, NSW 2052, Australia; Tim M. Glasby, NSW Department of Primary Industries, Port Stephens Fisheries Institute, Port Stephens, NSW 2315, Australia; Alistair G. B. Poore, Centre for Marine Science and Innovation, School of Biological, Earth and Environmental Sciences, University of New South Wales, Sydney, NSW 2052, Australia AND Sydney Institute of Marine Science, Mosman NSW 2088, Australia; Corey T. Callaghan, German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, Leipzig 04103, Germany; Graham P. Housefield, NSW Department of Primary Industries, Port Stephens Fisheries Institute, Port Stephens, NSW 2315, Australia; Madelaine Langley, Centre for Marine Science and Innovation, School of Biological, Earth and Environmental Sciences, University of New South Wales, Sydney, NSW 2052, Australia; Elizabeth A. Sinclair, School of Biological Sciences & Oceans Institute, University of Western Australia, Perth, WA 6009, Australia; John Statton, School of Biological Sciences & Oceans Institute, University of Western Australia, Perth, WA 6009, Australia; Gary A. Kendrick, School of Biological Sciences & Oceans Institute, University of Western Australia, Perth, WA 6009, Australia; Adriana Vergés, Centre for Marine Science and Innovation, School of Biological, Earth and Environmental Sciences, University of New South Wales, Sydney, NSW 2052, Australia AND Sydney Institute of Marine Science, Mosman NSW 2088, Australia

Posidonia australis is an endemic habitat-forming seagrass in southern Australia that is prone to prolonged impacts because of its slow recovery rates. *P. australis* declines can impact ecosystem functioning, with cascading impacts to local economies. Traditional block-and-chain boat moorings are a major threat for *P. australis* as they remove seagrass, creating bare sand scars where natural recolonization is inhibited. New environmentally friendly moorings (EFMs) can limit damage to seagrasses, however, natural recolonization by *P. australis* can be very slow. We developed a novel restoration approach on old scars using naturally detached rhizome fragments collected by citizen-scientists. In 2019 we planted a total of 863 fragments into four bare scars (January and June) and into two scars with an EFM (November). Average survival of fragments after one year was significantly greater for those planted in June (54% ± 3.9SE) than in January (31% ± 4.2SE). The presence of an EFM did not influence survival. Many surviving fragments (36.3%) also had produced new shoots during the year. Morphometric traits of individually tagged fragments were also recorded. Storm detached fragments with originally more shoots and lower levels of leaf necrosis were more likely to survive. Our results show that naturally-

detached seagrass fragments can be used to effectively restore *P. australis* meadows. This is an important new approach for supplying propagules for restoration without damaging remaining populations of an endangered seagrass, and presents a compelling management approach that engages local communities and enhances conservation efforts.

Dispenser Injection Seeding (DIS) advances intertidal eelgrass restoration

Laura L. Govers, University of Groningen & Royal Netherlands Institute for Sea Research (NIOZ); Max Gräfnings, University of Groningen; Jannes H.T. Heusinkveld, the Fieldwork Company; Maarten Zwarts, the Fieldwork Company; Henk Wiersema, the Fieldwork Company; Dieuwke Hoeijmakers, the Fieldwork Company; Nadia Hijner, University of Groningen; Quirin Smeele, Natuurmonumenten; Tjisse van der Heide, University of Groningen & Royal Netherlands Institute for Sea Research (NIOZ)

Restoration of coastal wetlands, including seagrass beds, has been proven challenging and rapid advancements are needed to ensure future large-scale restoration successes. Intertidal seagrass restoration is especially difficult given the dynamic nature of intertidal areas that are subjected to a cycle of emergence. We here present how the development of a new seeding method has led to a strong improvement of intertidal annual eelgrass restoration in the Dutch Wadden Sea. From 2014 onwards, adaptive intertidal seagrass restoration has been conducted leading to the development of a novel seed-based restoration method: Dispenser Injection Seeding (DIS). For this method, measured seed densities in mud paste are injected into the sediment. Optimization of this method has resulted in a >50x increase in restored plant densities. In addition, DIS-seeding has been trialed up to a 1 hectare scale (250 seeding hours, 20 injections m^{-2}) between 2017-2021. Hence, this novel method is suitable for upscaling seed-based restoration efforts. Furthermore, repeated seeding on a suitable location has resulted in substantial population expansion from ~10,000 (2018) to 200,000 plants in 2021, spread across >250 ha. Surprisingly, the annual eelgrass population expansion is still ongoing and this population seems to be the first self-sustaining restored intertidal eelgrass population in the Netherlands. Thus, our newly developed next-generation seed-based restoration method (DIS) has provided a clear advancement in intertidal seagrass restoration. The method has been proven to be suitable for large-scale restoration efforts and may also be applied to subtidal restoration and to other seagrass species.

Assess the potential use of seagrass restoration support structures

M. Taphorn, Leibniz University Hannover, Ludwig-Franzius-Institute for Hydraulic, Estuarine and Coastal Engineering; L. Kamperdicks, Leibniz University Hannover, Ludwig-Franzius-Institute for Hydraulic, Estuarine and Coastal Engineering; R.-M. Bähre, Leibniz University Hannover, Institute of Plastics and Circular Economy; M. Paul, Leibniz University Hannover, Ludwig-Franzius-Institute for Hydraulic, Estuarine and Coastal Engineering; H. Behnsen, Leibniz University Hannover, Institute of Plastics and Circular Economy; T. Schlurmann, Leibniz University Hannover, Ludwig-Franzius-Institute for Hydraulic, Estuarine and Coastal Engineering

Seagrass meadows are important ecosystems which provide several ecosystem services as attenuation of hydrodynamic forces, stabilization of sediment and provision of habitat for fish. Being an ecosystem engineer, seagrass provides the required hydrodynamic conditions for its own growth. After the loss of a seagrass meadow, an alternative stable state of bare sandbed may

establish due to increased hydrodynamic forces and high turbidity impeding restoration attempts with established methods. In order to use artificial structures to regulate the hydrodynamics appropriately and thus enhance the success of seagrass restoration efforts, a good comprehension of the affected processes around the structures is needed.

Therefore, physical experiments were conducted in a 30 m long and 2 m wide wave flume to investigate the effects of different fully submerged porous structures on hydrodynamics and bathymetry under wave conditions. By the use of a series of wave gauges and an ADV-probe, we quantify wave heights and orbital velocities along the wave flume, in front of and behind the structures. The changes in bathymetry over the whole sandbed were measured by use of a 3D-Scanner, supplemented by echo sounder measurements underwater. All structures affect the hydrodynamics and the bathymetry dependent on wave frequency and height with varying extent and magnitude caused by their own form character. Following detailed analysis recommendations for the design of a restoration facilitating structure will be given.

How far can we restore seagrasses? The onset of a seagrass restoration initiative in West Africa

Omar Sanneh, Department of Parks and Wildlife Management, The Gambia; Salmoa Bandeira, University of Edwardo Mondalane, Maputo, Mozambique; Maria Potouroglou, Alma Charity Foundation, Uk

Seagrass of The Gambia and much of the West Africa sub-region were recently discovered thanks to a systematic seagrass research and monitoring program. Tens of hacters of seagrass were mapped in the Gambia, known from three major locations: Gunjur, Kartong-Karfaya and Bijol islands. Gambia seagrass (having two species, Halodule wrightii and Cymodocea nodosa), are threatened by erosion, fishing activity as well as low level of knowledge about their value and management.In West Africa, seagrasses are key marine habitats that sustain fisheries and charistmatic fauna such as sea turtle and manatees, provide coastal protection, sequester carbon therefore reducing climate change among other benefits. This manuscript present an ongoing seagrass restoration and conservation initiative founded on a multi-stakeholder network called Ba Nyamo Tanko (meaning "Conserving seagrasses" in Gambian language). This is centered on communities and envisages to build capacities in applying restoration techniques in management and conservation of local seagrass meadow as well as promoting best practices and appropriate advocacy for the wellbeing of seagrassses in the Gambia. Up to 7 ha are envisaged for restoration using mannual techniques, corresponding to around 5% of the estimated seagrasses in The Gambia. Seagrass restoration success, using standards is presented in this first western Africa seagrass restoration. This underpins a socio-ecological structure to foster learning on restoration techniques, strengthening of capacities and skills for appropriate seagrass governance. Gambia's, Ba Nyamo Tanko network entity, through existing discussion forum and ground actions, actively protect the seagrass and can be upscaled to other West Africa countries.

The relationship between genetic variation and resilience for seagrass: what do we really know for actionable science?

T. Erin Cox, University of New Orleans; Anastasia Konefal, University of New Orleans; Nicola Anthony, University of New Orleans; Amanda Kirkland, University of New Orleans; Kathryn Wyssmann, University of New Orleans; Rebecca Gilpin,Mississippi State University; Just Cebrian; Northern Gulf Institute, Mississippi State University

Seagrass beds are natural resource which have experienced historic declines in extent of global surface cover. These ecosystems are threatened by disturbances which act to remove plants and lower water quality leading to declines in production. Moreover, many disturbances, such as warming, are difficult to remove. Thus, there is a need by managers to increase the stress threshold of beds for longterm stability. One potential avenue for management is to assess the genotypic diversity of existing beds and their resiliency to environmental stress. Greater standing genetic diversity within a population is hypothesized to be beneficial for stability (i.e. diversity-resiliency hypothesis) because it increases the probability that resistant genotypes are present when faced with new stressors. Over the past decade, seagrass have been used as a model to test this hypothesis. Therefore, it is timely for a review to inform on using genetic varation in seagrass management. Specifically, we did a literature review on the relationship between genetic variation-resilience for coastal, foundation species. Key terms were entered into the Web of Science search engine to return 1,532 publications and a growing interest in the subject by year. Publications then had to meet three criteria for further review. The content had to include a focus on a coastal, foundation species, genetics, and a functional metric. Data summary is ongoing. A preliminary analysis indicates that the current understanding of the role of genetic variation in conferring resilience for seagrass is hindered by limitations in study design.

Lessons learned from trialling methods for Zostera restoration in the intertidal zone

Lucy Coals, Deakin University, Swansea University and Project Seagrass; Richard Unsworth, Project Seagrass and Swansea University; Alison Evans, Project Seagrass and Swansea University; Benjamin Jones, Project Seagrass and Stockholm University; Marnie Cambell, Deakin University; Rhys Coleman, Melbourne Water; Laura Govers, University of Groningen; Max Grafnings, University of Groningen; Emma Jackson, Central Queensland University; Craig Sherman, Deakin University

Ongoing global seagrass decline presents challenges if we are to sustain the ecosystem functions and services they provide, and restoration provides us with the opportunities to ensure this. Restoration of seagrass in the intertidal zone is challenging due to the dynamic nature of this environment, and to date, many restoration attempts have been met with poor success and high variability. Successful seagrass restoration efforts are largely attributed to the planting techniques employed, site selection and the scale of planting. This study aims to provide insight into the effectiveness of different planting techniques used to restore seagrass via seeds in-situ. Using *Zostera marina* seeds, we trialled three planting techniques at six potential restoration locations across North Wales; biodegradable hessian bags, biodegradable coir pots, and Dispenser Injection Seeding. Circular split plots within the intertidal zone were planted to compare between planting techniques, whilst accounting for within site heterogeneity. Environmental and physical site characteristics were collected at each planting location to allow inter- and intra-site comparisons. Observations of shoot density, Pulse Amplitude Modulation of shoots and seed germination will be used to determine the effectiveness of each planting technique. These trials act as a first step in understanding the suitability of different planting methods for growing *Zostera marina* seeds intertidally, and how to optimise restoration through strategic selection of site dependent planting techniques. Results will directly contribute to the up-scaling and expansion of *Zostera* spp restoration.

Posters:

A novel approach for seagrass restoration through a fertilizing biodegradable substrate

Riccardo Pieraccini, Ghent University; Vicky Stratigaki, Ghent University; Thibaud Mascart, DEME group; Wouter Sciettecatte, Jan de Nul group; Aschwin Ellebrand, CCMAR; Marc Huyghens, DEME group; Jan Fordeyn, Jan de Nul group; Marleen De Troch, Ghent University

Habitat degradation, intensification of storms and floods, and coastal erosion are strongly threatening the resilience of coastlines worldwide. Seagrass meadows play a crucial role in maintaining high biodiversity and attenuating waves while their dense roots and rhizome systems reduce sediment resuspension and thus stabilize the seabed.

A set of restoration techniques for seagrass rewilding are currently being tested in a recently created marine reserve in Texel, a Dutch island in the Wadden Sea. The restoration site occupies an area of ~ 0.1 hectares and is characterized by both sheltered and exposed wave conditions. Specimens of Z. marina are introduced via both seed broadcasting and shoot transplantation. The seeds and shoots are introduced thanks to a natural, biodegradable substrate that acts as a carrier medium and supports the early establishment of the plant. This material also provides plant fertilization during the early settlement phase.

From early results on seed germination, we were able to identify a pattern of light-temperature-hormones that facilitate germination and overcome the seed dormancy bottleneck.
The monitoring strategy is evaluating the restoration action in all its components, assessing below and above ground growth, nutrient evolution, degradation rate of the substrate and its fertilizing effect, community composition assessment, and evolution over time. Wave and current sensors provide a data series to compare the attenuation effect between vegetated and unvegetated sites. Additionally, we will quantify the change in ecosystem services associated with the restored habitat over time.

Contribution to reversing the course of seagrass degradation by the capacity building of actors

Alioune FAYE; Assane GOUDIAB; Moctar BADJI; Bienvenu SAMBOU; Pr Cheikh DIOP; Fatima Niang DIOP; Adam CEESAY

Introduction—The stability of seagrass beds is is increasingly threatened. The 20th century has seen a major decrease in the distribution and abundance of seagrass beds around the world with an estimated annual decline rate of 7%.
New information and communication technologies, which play a decisive role in the development of environmental decision support systems, are increasingly used for the recovery of ecosystems. This is how the Institute of Environmental Sciences through the ResilienSEA project is developing online training modules on seagrass beds and sensitive West Africa coastal ecosystems by relying on these new technologies. The main objective is to strengthen the capacities of local communities, state agents in order to reverse the degradation of West Africa seagrass beds. Material and methods—Collectiong and synthesizing informations on seagrass beds in West Africa; Establishment of a list of oneline modules into which the modules on seagrass beds will be integrated; Validation, sharing and posting of the developed modules. Achieved Results—Currently, we are in the scripting and filming phase of the MOOCs. Scientific benefits—This community capacity-building activity will have provided human resources capable of reversing the degradation of seagrass beds in West Africa. Keywords: Seagrass, ecosystem, degradation

Changes in Halodule wrightii photo-physiology, metabolism, and gene expression after a major hurricane

Anastasia Konefal; Esra Ozturk-Yigit, Ege University; Just Cebrian, Northern Gulf Institute, Mississippi State University; T. Erin Cox, University of New Orleans

Seagrasses form productive ecosystems and are threatened by both chronic (e.g., ocean warming) and acute (e.g., major storm events) stressors. It is well known that seagrasses reallocate carbon and alter their photo-physiology to cope with these stressors, however it is unclear how quickly those responses are coordinated with molecular changes such as differential gene expression. Changes in expression of genes related to survival in harsh environments could be used as an early indicator of stress and provide insight into the potential for plants to acclimate to current and future conditions. In this study, we assess changes in *Halodule wrightii* photo-physiology, metabolism, and gene expression at hourly and diel intervals, between November 2019 and October 2020 including weeks before and after Hurricane Sally made landfall at our study site in Big Lagoon State Park, Florida. Despite reductions in salinity and irradiance, neither net primary productivity nor respiration of plants changed with hurricane passage. However, fluorescence measures indicated changes in photo-physiology that coincided with changes in water quality. Specifically, maximum quantum yield was higher while effective quantum yield was lower after than before hurricane landfall. Analysis of seven genes of interest from leaves are ongoing. Preliminary results from 9:30 and 16:30 in July and October, indicate a greater difference in seasonal regulation of photosynthesis related genes than diel. Deciphering linkages between gene expression and associated photo-physiological responses will increase our understanding of early indicators of seagrass health status, which may improve our ability for nimble adaptive management actions.

Landscape Genetics of Eelgrass Populations and Life History Types in the Pacific Northwest, USA

Bryan Briones Ortiz, University of Washington; Jennifer Ruesink, University of Washington; Kerry Naish, University of Washington

The application of modern genetic techniques to the study of diversity in seagrasses may significantly improve their conservation success. Restoration efforts in eelgrass (*Zostera marina*) are often hampered by a lack of information about the value of specific meadows to the population as a whole, because little is known about their population structure and potential for local adaptation. Most restoration efforts have approached success by evaluating transplant methods, timing of outplants, or comparing site conditions. However, less attention has been paid to matching phenotypes with environments, and maintaining population structure and diversity. Here, we aim to improve science-based decision-making by capitalizing on next-generation sequencing approaches to characterize patterns of eelgrass population structure across the landscape, and investigate evidence for divergence between phenotypes. Specifically, we use SNPs to describe genetic relatedness among 19 eelgrass populations distributed across the West Coast of the United States to provide insight about the relationship between population stratification and geography. In addition, we explore evidence for genetic divergence between different conspecific reproductive life history types. The outcomes of this work will inform the selection of populations that best serve as sources for successful transplants during restoration and mitigation, and predict how such transplants would influence existing population genetic structure and disrupt local adaptation.

Image analysis reveals environmental influences on the seagrass-epiphyte dynamic relationship

Chi Huang, Texas A&M University-Corpus Christi; Carissa Pinon, Texas A&M University-Corpus Christi; Ruby Mehrubeoglu, Texas A&M University-Corpus Christi; Kirk Cammarata, Texas A&M University-Corpus Christi

Seagrass restoration efforts require suitable environments. Conditions leading to excessive accumulation of algal epiphytes can limit seagrass productivity. Biomass measures widely used in understanding seagrass-epiphyte relationships provide limited insight into the dynamics of epiphyte colonization relative to leaf growth and senescence. Color scanning plus image analysis were developed to characterize epiphyte accumulation with seagrass growth in Thalassia testudinum collected monthly or bimonthly in Redfish Bay, Texas for nearly a year. Spectral Angle Mapper algorithms within ENVI Program distinguished the pixels of epiphyte-free leaf blades from many epiphytes. Misclassified pixels were < 10% in 94% of the analyzed images (n = 1822). Classification efficacy was evident by strong correlation of leaf biomass and morphology metrics vs. image-based metrics for seagrass collected across different seasons and environmental conditions (R2 = 0.86 to 0.98). However, linear regressions of epiphyte biomass vs. epiphyte area (pixels) and epiphyte load (epiphyte biomass/leaf biomass) vs. epiphyte coverage (epiphyte pixels/leaf pixels) were only moderate (R2 = 0.52 to 0.61) due to overgrowth of epiphytes on previously colonized leaf surface. Correlation of epiphyte biomass vs. epiphyte area improved significantly (R2 = 0.67 to 0.95) for data considered spatiotemporally. Patterns of epiphyte load vs. epiphyte coverage fitted linear models best in summer and fall but fitted exponential models in late summer and early spring. Data suggest a superimposition of linear colonization and exponential growth patterns of epiphyte accumulation which relates to seagrass leaf growth rate. Combining image-analysis with biomass reveals the dynamic epiphyte-seagrass relationship and the effects of changing environment.

The Global Seagrass Watch: Spatially-explicit seagrass ecosystem accounting enabled by contemporary remote sensing advances

D. Traganos, German Aerospace Center (DLR); A. Blume, German Aerospace Center (DLR); A. P. Pertiwi, German Aerospace Center (DLR); B. C. Lee, German Aerospace Center (DLR); S. Christofilakos, German Aerospace Center (DLR)

Seagrasses provide globally significant yet underestimated ecosystem services to humans, economies and ecosystems, the so-called natural climate solutions. Climate change, eutrophication, coastal development and uneven protection levels are impacting the health and services of seagrasses. Contemporary approaches are needed to reverse this loss of our coastal natural capital. Ecosystem Accounting (EA) presents a new holistic approach to streamline physical and monetary evaluation for natural ecosystems. The conceptualization of the System of Environmental-Economic Accounting (SEEA) EA by the United Nations signals a new era of comprehensive solutions for the conservation, restoration and protection of ecosystems like seagrasses. Here we present the Global Seagrass Watch coastal EA framework. Our framework harnesses powerful cloud computing, globally aggregated public satellite and reference datasets, and AI-guided big data analytics to map the ecosystem extent, condition, and services of seagrasses, including their accuracies and uncertainties. We showcase recent national seagrass EA applications across largely-uncharted underwater biomes in more than 30 countries and

300,000 sq. km. We targeted these coastal biomes due to their vast blue carbon and coastal biodiversity stocks, lack of spatially explicit information, and uneven uptake in global funding and policy strategies. Our introduced EA system yet concerns only baseline mapping of seagrass biophysical stocks. In the next phase, we aim to integrate ecological and economic modelling, and spaceborne change detection into our scalable framework. This amalgamation of legacy and modern mapping, modelling, and variables could support spatially-explicit blue carbon accounting, policy making, financing, and, ultimately, coastal resilience within and beyond the 21st century.

Evaluating multispectral UAV imagery for a multispecies intertidal seagrass environment

Eylem Elma, School of Natural and Environmental Sciences, Newcastle University, Newcastle upon Tyne, UK; Rachel Gaulton, School of Natural and Environmental Sciences, Newcastle University, Newcastle upon Tyne, UK; Catherine Scott, Natural England, Newcastle upon Tyne, UK; Tom Chudley, Byrd Polar and Climate Research Center, The Ohio State University, Columbus, OH, USA; Holly East, Department of Geography and Environmental Sciences, Faculty of Engineering and Environment, Northumbria University, Newcastle upon Tyne, UK; Hannah Westoby, Environment Agency, Newcastle upon Tyne, UK; Clare Fitzsimmons, School of Natural and Environmental Sciences, Newcastle University, Newcastle upon Tyne, UK

Zostera spp. around the UK are in poor condition and continue to decline, in large part due to anthropogenic activity. To better understand decline and support restoration or recovery efforts, accurate spatio-temporal monitoring of seagrass health and distribution is required. In recent years, UAV platforms have emerged as a tool for monitoring ecosystems at ultra-high spatial resolution, but their full potential for applications to seagrass habitats has yet to be evaluated. Here, we investigate the feasibility of UAV monitoring using a multispectral UAV platform and in-situ ground-truth surveys of an intertidal multi-species Zostera environment at Lindisfarne National Nature Reserve, UK. We conducted flights of two 400 × 400m plots at 120m altitude, capturing within these eight 100m long transects, also flown at 10m and 20m flight altitude. 20 x $1m^2$ quadrat photographs within each transect flight area were obtained as validation data. Pixel-based and object-based image analysis (OBIA) methods were applied to create classified habitat maps, and the accuracy of these methods was compared. Trade-offs between fine and coarse resolution drone imagery, relative accuracy and capacity to discriminate between Zostera spp. and from other surrounding species (e.g., opportunistic macroalgae) and field logistics are discussed, and optimal monitoring strategies proposed.

Exploring priming strategies to improve stress-tolerance and resilience of Posidonia oceanica seedlings

I. Provera, Stazione Zoologica Anton Dohrn, Naples (Italy); F. Badalamenti, CNR-IAS, Palermo (Italy) - Stazione Zoologica Anton Dohrn, Naples (Italy); G. D'Anna, CNR-IAS, Castellammare del Golfo (Italy); V.M. Giacalone, CNR-IAS, Torretta Granitola (Italy); L. Marín-Guirao, Centro Oceanográfico de Murcia (IEO-CSIC), San Pedro del Pinatar (Spain) - Stazione Zoologica Anton Dohrn, Naples (Italy); M. Martinez, CNR-IAS, Palermo (Italy); A. Zenone, Stazione Zoologica Anton Dohrn, Palermo (Italy); G. Procaccini, Stazione Zoologica Anton Dohrn, Naples (Italy)

Posidonia oceanica is endemic to the Mediterranean basin, where it forms extensive monospecific meadows. Rapid environmental changes are causing irreversible regression of

these valuable ecosystems, making it extremely important to develop strategies to increase their resilience to current and future stressors. Based on plant's ability to store information after exposure to stress (i.e. stress memory), many works on terrestrial species have focused on developing priming techniques that prepare plants to respond better and faster when the stress recurs. Priming and stress memory have only recently been observed in a few seagrasses species, although the temporal persistence of the memory and mechanisms for priming induction remain to be defined. In this study, we explored different priming strategies in *P. oceanica* seedlings with potential for enhancing their stress tolerance and their overall resilience. We tested three different priming strategies, each including a different level of stress, for two environmental stressors, temperature and salinity. In mesocosms, seedlings were exposed to short-term nonlethal stress induced by the selected thermal and saline priming strategies for stress memory activation. After a recovery phase during which samples were returned to non-stress conditions, thermal- and saline-primed seedlings were respectively exposed to heat and hypersaline stress to asses the onset of stress memory. The overall results indicated that defining optimal conditions for priming is still at early stage in seagrasses, highlighting the issues that need to be addressed to standardize priming approaches for improving seagrasses restoration in the face of climate change.

Rewilding the sea with domesticated seagrass

van Katwijk MM; van Tussenbroek BI; Hanssen SV; Hendriks AJ; Hanssen L

Large-scale restoration of lost seagrass meadows is urgently needed to revive these planetary ecosystem services, but sourcing donor material from natural meadows would further decline them. Therefore, we advocate the partial domestication and mariculture of seagrasses in order to produce the large quantities of seed needed for successful rewilding of the sea with seagrass meadows. We provide a roadmap for our proposed solution and show that 44% of seagrass species have promising reproductive traits for domestication and rewilding by seeds. The proposed domestication of seagrass to enable rewilding may likely exceed budgets traditionally assigned to nature restoration projects by orders of magnitude but will also be more profitable. Rather, investments should be part of budgets required for climate change mitigation, agricultural innovations, and land and sea use transitions in the future era.

<u>Session 7A:</u> Seagrasses into the 21st century: Insights from global coordination and a way forward

Session Convener(s): Jonathan Lefcheck, Smithsonian Environmental Research Center; Emmett Duffy, Smithsonian Environmental Research Center

Large-scale coordination of ecological observing is both more feasible and more valuable than ever before. The growth and interconnection of coordinated networks has provided new insights into changing seascapes worldwide and new opportunities for conservation and management. In this session, we convene scientists cooperating in their exploration of seagrass ecosystems, their patterns and drivers, and the diverse and abundant communities they support. We will report on the first insights from the 2020 Global Seagrass Survey led by Smithsonian's MarineGEO Network, which includes dozens of partners from all six continents. The project's aim is to understand the fluxes of energy through seagrass food webs, and how these fluxes are mediated by environmental gradients and the diverse community of organisms that live in seagrass

habitats. In doing so, partners will highlight the exciting ongoing work at their sites that aligns with the network themes of biodiversity, habitat use, and food webs and fits into this global picture. We will also synthesize twenty years of data from SeagrassNET, the largest and longest-running coordinated seagrass monitoring program on the planet. We will present the long-term trends in local seagrass abundance and diversity from SeagrassNET sites, link these trends with environmental pressures (such as warming climate), and discuss the future of globally coordinated science, including SeagrassNET.

Talks:

Seagrass habitat shapes faunal communities: A global food-web perspective

Jonathan S. Lefcheck, Smithsonian MarineGEO; J. Emmett Duffy, Smithsonian MarineGEO

Seagrasses are essential habitats for many fishes and invertebrates, and healthy meadows can significantly enhance the biodiversity and biomass of associated organisms. A systematic survey of seagrass-associated animal communities, however, is lagging behind coordinated surveys of vegetation cover and density. Here, we present insights from a large-scale contemporary study of seagrass ecosystems organized by the Smithsonian Institution's MarineGEO program from 2019-2021, encompassing 35 locations in 20 countries on six continents. At each location, partners applied standardized methods to quantify seagrass cover and composition, shoot density, macroalgae, epifaunal invertebrates, and local fish assemblages. We first use structural equation modeling to examine the cascading effects of seagrass condition on invertebrate and fish diversity and biomass. We show that higher seagrass percent cover and shoot density provides more habitat for a diverse array of benthic invertebrates, and in turn, this increases the diversity and abundance of their fish predators. We further apply a metabolic-based framework to estimate energy (carbon) flux through simplified food webs and how this is affected by local biodiversity. This study validates the value of seagrasses in providing habitat and sustaining coastal food webs, and further provides a blueprint for collecting coordinated observations across the wide range of seagrass species and ecosystems worldwide.

An empirical and predictive framework to understand eelgrass (*Zostera marina*) responses to multiple pressures

Jillian Dunic, Department of Biological Sciences, Simon Fraser University; Isabelle Côté, Department of Biological Sciences, Simon Fraser University

As human activities increase in frequency, intensity, and spatial extent, seagrass ecosystems face growing threats from multiple pressures. Although managers recognize that accounting for cumulative impacts is critical for the preservation of ecosystem function and services, they are rarely included in seagrass management plans. Successful management requires identifying measurable management targets but lack of data, non-linear ecosystem responses, and shifting targets under multiple pressures complicate the identification of these targets. To develop an empirical and predictive framework that can identify critical management values and predict how these values change under multiple pressures, we performed a quantitative review of over 25 studies that measured the effects of temperature and light on eelgrass (*Zostera marina*) performance. Our dataset included results from laboratory, mesocosm, and field studies. We modelled the interactive effect of temperature and light on the performance (i.e., lateral shoot production rates) of eelgrass using a hierarchical generalised additive model. This allowed us to predict eelgrass growth responses across a range of light and temperature. We then generated

thermal performance curves across a range of light values from complete darkness to saturating light and found that the shape of these curves changed with light level. Thus, two critical performance values, zero-growth rate and optimal growth rate, shifted across the combination of light and temperature values. Our modelling framework aims to bridge the gap between data from laboratory and field studies, can be expanded to include more pressures and species, and has the potential to be developed into an interactive management tool.

A Pleistocene legacy structures global variation in modern eelgrass ecosystems

J. Emmett Duffy, Smithsonian MarineGEO and SERC; John J. Stachowicz, University of California Davis; Pamela L. Reynolds, University of California Davis; Erik E. Sotka, College of Charleston; Kevin A. Hovel, San Diego State University; Christoffer Boström, Åbo Akademi University; Katharyn E. Boyer, San Francisco State University; Mathieu Cusson (Université du Québec à Chicoutimi; Johan Eklöf, Stockholm University; Aschwin H. Engelen, Universidade do Algarve; Britas Klemens Eriksson, University of Groningen; F. Joel Fodrie, University of North Carolina at Chapel Hill; John N. Griffin, Swansea University; Clara M. Hereu, Universidad Autónoma de Baja California; Masakazu Hori, Fisheries Research and Education Agency; A. Randall Hughes, Northeastern University; Mikhail V. Ivanov, Saint-Petersburg State University; Marlene Jahnke, University of Gothenburg; Pablo Jorgensen, Universidad Nacional de Tierra del Fuego; Claudia Kruschel, University of Zadar; Kun-Seop Lee, Pusan National University; Jonathan S. Lefcheck, Smithsonian MarineGEO and SERC;Per-Olav Moksnes, University of Gothenburg; Masahiro Nakaoka, Hokkaido University; Mary I. O'Connor, University of British Columbia; Nessa E. O'Connor, Trinity College Dublin; Robert J. Orth, Virginia Institute of Marine Science; Bradley J. Peterson, Stony Brook University; Henning Reiss, Nord University; Katrin Reiss, Nord University; J. Paul Richardson, Virginia Institute of Marine Science; Francesca Rossi, University of Cote d'azur-CNRS; Jennifer L. Ruesink, University of Washington; Stewart T. Schultz, University of Zadar; Jonas Thormar, Institute of Marine Research Norway; Fiona Tomas, IMEDEA - CSIC; Richard Unsworth, Swansea University; Erin Voigt, San Diego State University; Matthew A. Whalen, University of British Columbia; Shelby L. Ziegler, Moss Landing Marine Lab; Jeanine L. Olsen, University of Groningen

Distribution of Earth’s biomes is structured by the match between climate and plant traits, which in turn shape associated communities and ecosystem processes and services. But that climate-trait match can be disrupted by historical events, with lasting ecosystem impacts. As Earth’s environment changes faster than at any time in human history, a critical question is whether and how organismal traits and ecosystems can adjust to altered conditions. The ZEN network quantified the relative importance of current environmental forcing versus evolutionary history in shaping the growth form and associated community of eelgrass (*Zostera marina*), a widespread foundation plant of ecosystems along northern hemisphere coastlines, which experienced major shifts in distribution and genetic composition during the Pleistocene. We found that eelgrass growth form and biomass retain a legacy of the Pleistocene colonization of the Atlantic from the ancestral Pacific range and of more recent within-basin bottlenecks and genetic differentiation. This evolutionary legacy in turn influences the biomass of associated algae and invertebrates that fuel coastal food webs, with effects comparable to or stronger than effects of current environmental forcing. Such long-term lags in phenotypic adaptation and acclimatization among foundation species represent a potential choke point for ecosystems adjusting to rapid climate change.

A Climate Vulnerability index for World Heritage seagrass habitats

Riccardo Losciale; Jon Day; Scott Heron

Climate change is the greatest and fastest-growing threat to UNESCO World Heritage (WH) properties. Seagrass habitats within WH properties are a key blue carbon asset, the protection of which can help mitigate climate change. WH seagrass habitats play a key role in enhancing the health of the surrounding environment and provide a range of ecosystem services to the human communities associated with those properties. However, assessment of climate risks to WH seagrass habitats is needed. The Climate Vulnerability Index (CVI) is a rapid and systematic risk assessment tool to assess the vulnerability of WH values and associated communities to climate change. We developed a CVI thematic group framework and applied it to WH seagrass habitats. Through the analysis of UNESCO documents and scientific literature, we reviewed the conditions of, threats to and protection for WH seagrass habitats. Seagrass vulnerability was assessed using survey data collected from 36 seagrass scientists and 17 WH managers across the globe. We found that 53.8% of the assessed WH seagrass habitats have high vulnerability to climate change. This study seeks to inform managers about the vulnerability of their WH seagrass habitats to climate change, and to inspire collaboration between scientists and managers in developing strategies to improve the protection of WH seagrass habitats from the impacts of climate change.

Genomic approaches to understanding the role of local adaptation of seagrasses in a changing world

John J. Stachowicz, University of California Davis; Rachael Bay, University of California Davis Deanna Beatty, University of California Davis; Brooke Benson, University of California Davis Katie DuBois, University of California Davis; Richard Grosberg, University of California Davis; Lauren Scheibelhut, University of California Merced; Karolina Zabinski, University of California Davis; ZEN Partners, Zostera Experimental Network

Genetically-based phenotypic variation within species and spatial and temporal variation in microbial partners are thought to play an important role in explaining adaptation of seagrasses to local conditions and to a changing environment. We have used global and local scale surveys and whole-genome sequencing to describe the genomic and microbial landscape of Zostera marina, finding strong evidence of local adaptation of plants on scales as small as a few kilometers and as large as entire coastlines. For example, along a local thermal gradient of 10C spanning 30km, we find strong signals of selection that are supported by results from common garden mesocosm experiments. Parallel geographic gradients in plant morphology occur independently in different ocean basins with different evolutionary histories and we are using large-scale genomic surveys to assess the role of various forces in driving these differences. Genomic tools also offer potential for better understanding the relationships between seagrasses and their microbial associates. We surveyed eelgrass microbiome along 23 degrees of latitude and correlated it with the presence and intensity of seagrass wasting disease to identify several microbial taxa that may either promote or exploit infection by the wasting disease pathogen. The strong variability in leaf microbiomes contrast with greater consistency in root microbial communities across locations, suggesting perhaps a more consistent functional role for leaves over roots. We close with a discussion of future directions to merge eelgrass genomics with ecology and microbiology to develop a more holistic view of the ecology of seagrasses in a changing world.

Creating community. Efforts of the SAV Community of Practice.

Dottie Byron, Dauphin Island Sea Lab & University of South Alabama; Mark Finkbeiner, NOAA Office for Coastal Management; David J. Wilcox, Virginia Institute of Marine Science Robert J. Orth, Virginia Institute of Marine Science; Kris Kaufman, NOAA Office of Habitat Conservation

What is "community"? Defined as "a feeling of fellowship with others, as a result of sharing common attitudes, interests, and goals", communities come in all shapes and sizes. However, community depends on those that are involved. Knowledge transfer within communities is often limited to direct nodes occurring through person to person private conversations (emails, phone calls, conferences, coffee breaks, etc.). While valuable to those within the node, that knowledge remains in a "black box" to those outside the node who may also benefit from the information.

Here we will present on efforts started during the bi-annual 2019 CERF conference to engage and expand interactions between submerged aquatic vegetation (SAV) mapping and monitoring practitioners using the open-source platform Discourse. Using Discourse, the SAV Community of Practice(SAV-COP) is attempting to open those conversations and create a searchable more permanent legacy to pass knowledge from the older generations to the up and coming ones. We will cover who we are, what our mission is, and how everyone can get involved, including a live demonstration of the forum and its power. We invite all to join the discussions (at https://forum.cerf.science/), engaging with others from around the world to share our personal experiences and knowledge in and around seagrass (currently just) mapping and monitoring.

Citizen science and local ecological knowledge reveal local opportunities for seagrass conservation

Benjamin Jones, Project Seagrass & Stockholm University; Bethan Thomas, Project Seagrass; Leanne Cullen-Unsworth, Project Seagrass; Richard Unsworth, Project Seagrass & Swansea University

In comparison to other habitats, the number of scientists studying seagrass meadows remains few, albeit rising. Despite increasing knowledge of their importance, global analysis of threats to seagrass have remained stagnant, more so now that interest is growing in other areas of seagrass related research. Given the estimated scale of global seagrass decline, and the risk of further loss from large-scale and widespread anthropogenic activity, this study sought to explore the variability in threats to seagrass across the globe. We examine threats identified at the local scale using a global citizen science database and place these in the context of a series of case studies that draw upon local ecological knowledge. Citizen scientists overwhelmingly report boating activities as the most persistent local threat to seagrass, whereas LEK identifies fishing as the most persistent threat. While traditional science provides us with information on large scale threats requiring complex solutions (e.g.m widespread nutrient pollution), the local threats identifies through citizen science and LEK provide opportunities to develop targeted local solutions that can increase seagrass resilience (e.g., reducing anchoring and mooring, sustainable fisheries). To conserve seagrass, we must harness citizen science and local ecological knowledge and pair it with conventional scientific knowledge to reveal opportunities for action at the local scale.

Indo-Pacific Seagrass Network (IPSN): Collaborative research to advance the understanding of seagrass fisheries

Lina Mtwana Nordlund, Uppsala University, Sweden; Leanne C. Cullen-Unsworth, Project seagrass, UK; Narriman S. Jiddawi, Institute of Fisheries Research Zanzibar, Tanzania; Richard K.F. Unsworth, Swansea University & Project seagrass, UK; Johann Stiepani, Uppsala University, Sweden; Benjamin Jones, Stockholm University, Sweden; Johan Eklöf, Stockholm University, Sweden

The Indo-Pacific Seagrass Network (IPSN) started in 2018 and has 25 locations across the Indo-Pacific, from southern Mozambique in the west to Micronesia in the east. Over the last couple of years, data has been collected using four research protocols specifically developed to investigate linkages between seagrass ecosystems, biodiversity, and fisheries. The methods used were 1) survey of the intertidal zone focusing on seagrass and barren areas and the associated fauna; 2) gleaning landing surveys, incl catch assessment; 3) a socio-economic survey of the location; 4) mapping of the intertidal zone. Not all data has been collected at all locations. The data is now curated and output on the Indo-Pacific level is in preparation, along with local stakeholder communication. One of the focus areas has been on gleaning, fishing by walking with basic gear. Initial data analysis from the IPSN gleaning landing surveys shows that the gleaning landing composition differs across the Indo-Pacific, ranging from landing different species from one class (e.g. bivalves) to a high diversity of species belonging to eight different classes/taxa (e.g. shrimps, sea cucumbers, sea urchins). The most commonly used gear while gleaning is hands or knife. The landed catch is foremost for home consumption and /or to be sold at the local market. Gleaning is common and often practised in seagrass, but seldom even considered in policy and management. With this collaborative research, we want among other things to increase the understanding of the importance of seagrass in fisheries.

Posters:

Notes from the Other Gulf: Tropical Seagrasses More Common in The Gulf of California than Previously Indicated in Published Literature

Abigail Libbin Cannon, Karla Pedraza, Sula Vanderplank, Fabio Favoretto, Magali Ramirez-Zuñiga, and Juan Manuel López Vivas

While tropical seagrasses have been noted in the Gulf of California since 1979, they are understudied in this region and on much of Latin America's tropical Pacific Coast. Four seagrass genera, *Zostera, Ruppia, Halodule,* and *Halophila* are present in the Gulf of California, although only the latter two genera are primarily tropical. *Ruppia, Halodule,* and *Halophila* are also present south of the Gulf of California on Latin America's tropical Pacific coast, but *Zostera* is not found south of the Gulf of California. Seagrasses are understudied in the Gulf of California and most of the Tropical Eastern Pacific and their known distribution is limited. Recent efforts, however, have found multiple populations of *Halophila, Halodule,* and *Ruppia* around La Paz and Loreto that are not noted in previously published literature. Ongoing attempts to find additional seagrass beds in the Gulf of California, as well as the Pacific Coast of mainland Mexico will be reviewed. Efforts to study the ecology of Gulf of California tropical seagrass beds, their degree of genetic connectivity to other seagrass beds in the Americas, and their utility as Blue Carbon sinks will also be discussed.

Eelgrass declines and potential drivers of change in the South Slough estuary, Oregon, USA

Alicia Helms, South Slough NERR;Caitlin L. Magel, University of Washington, Oregon State University; Sally D. Hacker, Oregon State University; Francis Chan, Oregon State University; María José Marín Jarrín, University of Oregon; David A. Sutherland, University of Oregon; Lu Wang, Ocean Associates Inc., Oregon State University; Ryan S. Mueller, Oregon State University; John Schaefer, Confederated Tribes of the Coos, Lower Umpqua, and Siuslaw Indians

Eelgrass (*Zostera marina)* was historically abundant in the South Slough arm of the Coos estuary, Oregon. The South Slough NERR conducts quarterly to annual intertidal eelgrass surveys at four sites along the salinity gradient. In 2015, eelgrass abundance declined at the mid estuary, polyhaline site (SeagrassNet, OR25.1) followed by declines at the marine site with absence of eelgrass at two upstream, mesohaline sites by 2017. Using time-series of eelgrass abundance and System-Wide Monitoring Program water quality and weather data along with other data collected by SSNERR and collaborators, modeling analyses were conducted to determine environmental drivers that may be contributing to eelgrass declines. Principal component analysis and linear mixed effects modeling were used to determine summer eelgrass biomass was negatively associated with water and air temperature, water column turbidity, and watershed disturbance. Daily climatology of oceanographic conditions, including wind stress, water and air temperature, and river discharge were adjusted for event driven variability and compared before eelgrass declines (2004-14) and after declines, during marine heat wave and El Niño events (2013-17). Increased air and water temperature, lower river discharge, and longer residence time of warmer waters in the shallow South Slough compared to the Coos estuary were correlated to eelgrass declines. Maximum Entropy species distribution modeling found elevation was the strongest factor determining eelgrass distribution with water temperature and chlorophyll-a as secondary factors. Analyses indicated that increasing water/air temperature were primary stressors contributing to intertidal eelgrass population declines. Results are important for informing protection, management, and restoration of eelgrass habitat.

Threatened seagrass beds in the French Antilles (Caribbean Sea): feedback from 15 years of regional monitoring in the framework of adaptive management

Fanny Kerninon; Amandine Vaslet; Christelle Batailler; Claire Bissery; Julien Chalifour; Sébastien Gréaux; Simone Mège; Claire Hellio

Seagrass beds are very important ecosystems that still suffer from a lack of recognition despite their current worldwide decline under multiples pressures. In French Antilles (Caribbean Sea), a regional monitoring of benthic communities, including seagrass beds, was established in 2007 in four marine protected areas, across Guadeloupe, Saint-Martin (French part) and Saint-Barthélemy islands. Temporal changes in the morphological and structural characteristics of seagrass beds were assessed over a 15-year period of adaptive management. Long-term data provide information on occurrence of decline (both abrupt and gradual) in native seagrass species abundance (mainly *Thalassia testudinum* and *Syringodium filiforme* in some cases). These trends indicate a change in seagrass communities, historically dominated by the climactic species *T. testudinum*, in favour of opportunistic, colonising and invasive seagrasses. The associated benthic fauna data reveal significant heterogeneity between stations and across islands. At the stage of the project, we can analyse the effectiveness of the sampling strategy

and discuss the potential improvement based on current management and conservation issues. This study also highlights the urgent need for better support of the seagrass beds management and implements concretes and adapted interventions to reverse loss and sustain their essential services. Finally, these monitoring actions would benefit from being integrated into broader regional and global approaches in order to increase cooperation between seagrass beds managers and scientists.

Local thermal variation modulates resilience to warming in a marine foundation species: evidence from seagrass seedlings.

Laura Pereda-Briones, IMEDEA (UIB-CSIC), Spain; Fernando Tuya, Universidad de las Palmas de Gran Canaria, Spain; Laura Royo, IMEDEA (UIB-CSIC), Spain; Vincent Combes, Oregon State University, USA; Enric Ballesteros, CEAB (CSIC), Spain; Sabrina Clemente, Universidad de La Laguna, Spain; Gal·la Edery, IMEDEA (UIB-CSIC), Spain; Fernando Espino, Universidad de las Palmas de Gran Canaria, Spain; Simone Farina, International Marine Centre, Sardinia, Italy; Yolanda Fernandez-Torquemada, Universidad de Alicante, Spain; Vasilis Gerovasileiou, Hellenic Centre for Marine Research, Crete, Grece; Ivan Guala, International Marine Centre, Sardinia, Italy; Ljiljana Ivesa, Ruđer Bošković Institute, Croatia; Maria Sini, University of the Aegean, Greece; Gabriele Procaccini, Stazione Zoologica Anton Dohrn, Italy; Jorge Terrados, IMEDEA (UIB-CSIC), Spain; Lázaro Marín-Guirao, IEO Murcia, Spain; *Fiona Tomas*, IMEDEA (UIB-CSIC), Spain

Disturbances associated with climate change may push organisms beyond their resilience limits, and strong ecological consequences are expected when “foundation” species are affected. When predicting species’ responses to warming, species are typically considered as physiologically homogeneous. Yet, the specific response to extreme events may vary according to differences in phenotypic plasticity and local adaptation across the range of a species. Using a common-garden mesocosm experiment, we compared the resilience (i.e., response to and recovery from) to two warming events of different intensity on Cymodocea nodosa seagrass seedlings germinated from seeds collected at eight regions across the species’ distribution range. We show a positive relationship between resilience to warming and local thermal variability, suggesting seagrass evolutionary adaptation to local thermal conditions. Our results highlight the critical importance of incorporating intra-specific variability when making predictions and when developing conservation and restoration strategies about species vulnerability to climate change. Furthermore, strong negative lag-effects on seedlings performance were observed after the warming phase had already stopped, highlighting the importance of following species’ responses after a disturbance has finished, particularly because most experimental studies have only examined immediate, short-term, responses to stressors. Given the long-term common-garden approach used, we expected that differences in seedling responses would be mainly the result of genetic changes leading to local adaptation.

ResilienSEA Project and Seagrass Protection in Cabo Verde

Lisdalia Moreira, National Environment Directorate / Ministry of Agriculture and Environment; Zofia Radwan, National Environment Directorate / Ministry of Agriculture and Environment; Aliny Tavares, National Environment Directorate / Ministry of Agriculture and Environment; Denis Dias, ONG Lantuna; Nivaldo Ramos, University of Cabo Verde

Cape Verde is an archipelagic country formed by 10 islands and 13 islets, an extensive coastline of 2000 km and Exclusive Economic Zone (EEZ) with approximately 734,265 km², located in

the Atlantic Ocean about 570 km from the West African coast. The existence of seagrass was recorded for the first time in 2015, according to a survey conducted, within the island of Santiago Cape Verde's marine biodiversity is considered globally to have an enormous scientific value due to its geomorphological characteristics, as many endemic and native species are threatened, which, in turn, makes conservation of the archipelago's biodiversity a global concern. The natural heritage is unique and the physical environment of these islands produces several habitats with a great specific wealth of fauna and flora. Nevertheless, its biodiversity is naturally restricted to the geographical limits of the islands and is extremely vulnerable to human activity, the rapidly expanding of coastal development and climate change. As part of the national implementation of the ResilienSEA project, aiming to conserve and make seagrass resilient in West Africa, Cape Verde identified Praia da Gamboa, as a pilot site, aiming at scientific research and promotion of appropriate instruments for its management and conservation. The species identified is *Halodule wrightii*, in an area of approximately 4000 m^2 with the possibility of extension to 6000 m^2 according to the monitoring carried out in July 2021.The ResilienSEA project is implemented in partnership with national institutions in charge of the marine environment, universities and NGOs. Cape Verde is an archipelagic country formed by 10 islands and 13 islets, an extensive coastline of 2000 km and Exclusive Economic Zone (EEZ) with approximately 734,265 km^2, located in the Atlantic Ocean about 570 km from the West African coast. The existence of seagrass was recorded for the first time in 2015, according to a survey conducted, within the island of Santiago Cape Verde's marine biodiversity is considered globally to have an enormous scientific value due to its geomorphological characteristics, as many endemic and native species are threatened, which, in turn, makes conservation of the archipelago's biodiversity a global concern. The natural heritage is unique and the physical environment of these islands produces several habitats with a great specific wealth of fauna and flora. Nevertheless, its biodiversity is naturally restricted to the geographical limits of the islands and is extremely vulnerable to human activity, the rapidly expanding of coastal development and climate change. As part of the national implementation of the ResilienSEA project, aiming to conserve and make seagrass resilient in West Africa, Cape Verde identified Praia da Gamboa, as a pilot site, aiming at scientific research and promotion of appropriate instruments for its management and conservation. The species identified is *Halodule wrightii*, in an area of approximately 4000 m^2 with the possibility of extension to 6000 m^2 according to the monitoring carried out in July 2021.The ResilienSEA project is implemented in partnership with national institutions in charge of the marine environment, universities and NGOs.

Identifying cues that promote flowering in eelgrass (Zostera marina).

Marlene Jahnke, University of Gothenburg (Department of Marine Sciences); María Eugenia Bernal Gómez, Stockholm-Uppsala-SLU-Gothenburg University

Genetic diversity and connectivity have been shown to be key factors for seagrass meadows persistence. Despite the effectiveness of clonal reproduction in terms of colonization, genetic diversity and connectivity are mainly supported by sexual reproduction. However, the ambiguous connection between cues and mechanisms that trigger flower induction in seagrasses has hindered us from understanding flowering phenology in detail, which in turn has obstructed the incorporation of strategies that enhance sexual reproduction in management programs.

One of the obstacles to studying sexual reproduction in seagrasses is the intricacy of finding reproductive structures or anticipating the flowering season at the sites of study. In an effort to contribute to overcome this challenge, we use linear mixed models (LMMs) to assess whether

clonality patterns correlate with physical parameters that may influence sexual reproduction. We here focus on eelgrass (*Zostera marina*) and address, in a first step, spatial scales over 100s of kilometres along the Swedish Bohuslän coast. Furthermore, ongoing work with these models is aimed at assessing broad-scale drivers of sexual reproduction. To achieve this, we present local.scale preliminary results as an open request to collaborate with data that could enrich the large-scale analysis.

The outcomes of this work will enable further research on the adaptation potential of seagrass ecosystems and their capacity to persist under climate change scenarios as well as on the reinforcement of management programs in seagrass meadows.

Dynamics and Operation of the Seagrass in the Islands of Unhocomo and Unhocomozinho (BOLAMA BIJAGÓS BIOSPHERE RESERVE - GUINEA-BISSAU)

Noelo Cardoso, Centre for Applied Fisheries Research / Minister of fisheries; Jeremias Francisco Intchama, Centre for Applied Fisheries Research / Minister of fisheries; Emanuel Dias, Biodiversity Institute and Protected Areas / Minister of environment; Amadeu D'Almeida, Centre for Applied Fisheries Research / Minister of fisheries

At the interface of the intertidal and subtidal zone, seagrass provides many ecosystem services such as coastal protection and form biodiversity hotspots in addition to being important nursery areas. Seagrass habitats contribute indirectly to Guinea-Bissau's economy by creating a favourable environment for economically important specie. However, neither the authorities nor Scientifics or the general public have sufficient knowledge about seagrass habitats. Historically, Guinea-Bissau focuses more of its attention on the conservation of mangroves. Banks of macro algae and marine phaters monospecific to Halodule wrightii are present and occupy a vast region in the Bolama Bijagós Biosphere Reserve. The main objective of this study was to provide the first data on the ecology of these marine plants and encourage their conservation at the national level. A focus was on the study of the spatial and seasonal dynamics of seagrass in the islands of Unhocomo and Unhocomozinho (2019-2021) and on the identification of other seagrasses in the Bolama region. The second focus was on the analysis of the productivity of the seagrass habitat in maintaining the climate, on the conservation of coastal areas, on sustaining biodiversity and on sustaining the country's economy. It should be noted that underwater banks play roles in maintaining the herbivorous population of fish, molluscs, reptiles and marine mammals. Dives were performed that allowed the mapping the spatial distribution and understanding the life cycle of Halodule wrightii. Public surveys revealed a lack of awareness of this ecosystem despite its ecological and economic potential. Scientific surveys expose the role seagrass plays as nurseries and in sustaining marine biodiversity, and diving surveys documents the distribution of seagrass. This ecosystem, because of the multiple functions it performs, should be better taken into account in the management of Guinea-Bissau's marine environment, especially included in the management plans of MPAs.

Integrating seagrass conservation in the management of marine protected areas – Sherbro River Estuary, Sierra Leone a case study

Paul A. Lamin, Environnent Protection Agency

The absence of information on the most fundamental characteristics of seagrass distribution and health has posed a major problem for seagrass conservation in Sierra Leone. At the Sherbro

River Estuary in the Bonthe District, an assessment led to the discovery of seagrass. The *Cymodoceaceae* family's *Halodule wrightii* was discovered as a single species.

The Sherbro River estuary is a designated Marine Protected Area (MPA). A monitoring program in 2022 indicated that seagrass coverage was poor, with most regions having less than 50% coverage. The plants are tiny, with leaves varying in length from 4 to 9 cm.

Whilst the seagrass meadows are frequently found in shallow nearshore locations, they are at high risk of being destroyed by fishing activities. Given that the focus was not on seagrass, the MPA management plans are far from reducing the impact of fishing on seagrass.

The study's main aim is to see how effective it is to incorporate seagrass conservation and protection into the Sherbro River Estuary's MPA management plan. Analysis of the influence of significant stakeholders' involvement in the formulation of management strategies, as well as stakeholder analysis to understand their various responsibilities, are part of the study methodologies.

As a result, incorporating seagrass conservation within the MPA management plan will encourage local stakeholders to actively participate in decision-making processes related to seagrass protection and conservation.

Session 7B: Microbial ecology in seagrass ecosystems: Uniting the microscale and macroscale perspectives

Session Convener(s): Belinda C. Martin, University of Western Australia; Matthew W. Fraser, University of Western Australia; Sairah Y. Malkin, Horn Point Lab, University of Maryland Center for Environmental Sciences; Stacey M. Trevathan-Tackett, Deakin University

Rooted plants form intimate relationships with sediment and soil microorganisms. In terrestrial ecosystems, plant-mycorrhizal and plant-bacterial relationships are ubiquitous and widely understood to affect plant fitness and can affect local and system-level biogeochemical cycling. Plant-microbial interactions in aquatic systems have so far received less attention. Studies of the microbiome – incorporating the collective genomes of the microbes (composed of bacteria, bacteriophage, fungi, protozoa and viruses) that live in a particular ecosystem (e.g. sediment, human gut, surface of a leaf) – have enhanced our understanding of ecosystem functioning, and a recent surge in microbiome research is enabling a deeper understanding of seagrass ecology. Relationships between microbes and plants may take many forms, ranging from mutualistic to parasitic, and may affect a myriad of ecological processes. For example, microbes may promote the supply of nutrients to seagrasses by fixing nitrogen and mobilizing phosphorus. Plant-microbial interactions may also affect competitive outcomes between native and invasive seagrasses through their influence on sediment sulfur cycling. Additionally, as rapid responders to environmental change, seagrass microbiomes may be useful biosensors, serving as early sentinels for detecting change to seagrass health. There is a wealth of opportunity to better understand how the seagrass microbiome and micro-scale interactions may further our understanding of seagrass fitness and be used as a tool for conservation and restoration management.

In this session, we aim to bring together research that furthers our understanding of microbial processes that affect seagrass ecology, restoration, and management. Research that addresses seagrass-microbial associations and/or micro-scale processes are encouraged.

Talks:

Can microorganisms influence germination of seagrass seeds?

Anne Brauer, University of Greifswald; Eduardo Infantes, University of Gothenburg; Mia Bengtsson, University of Greifswald

Seagrasses are the only plants flowering and producing seeds in the marine realm. They form vast meadows in coastal areas that fulfill important ecosystem services. During the past decades, seagrass cover declined in many places and re-colonization is slow. Despite clonal growth, the recruitment of seagrasses from seeds is essential for expansion and the formation of new meadows and thus seagrass restoration. While the microbiome of terrestrial flowering plants and their seeds is well studied, the microbiome of seagrass seeds has received limited attention. First studies indicate that high proportions of *Zostera marina* seeds can carry potential pathogens that inhibit seedling development, while for *Posidonia oceanica* seedling leaf growth was enhanced by certain microorganisms.

Here, we present a comparative study on the microbiome of eelgrass (*Z. marina*) seeds along the salinity gradient of the German Baltic Sea to establish a community baseline, followed by an experiment to assess the influence of microorganisms on germination and seedling development. We could show that *Z. marina* seeds carry distinct prokaryotic and eukaryotic microbial communities compared to those on leaves and roots. Despite the geographical distance and changing conditions, we could define a seed core microbiome. By then manipulating eelgrass seed and sediment microbiomes, we show how microorganisms affect eelgrass seed germination and seedling development.

Thus, we highlight the importance microorganisms can have for germination and establishment of healthy seagrass seedlings, a prerequisite for recovery and restoration of seagrass ecosystems worldwide.

Investigating the feasibility of nursery cultivation of the intertidal seagrass, Zostera muelleri, for use in restoration

Yi Mei Tan, Deakin University; Jack Dewhurst, University of Melbourne; Edel Lheureux, Université de Pau et des Pays de l'Adour; Elizabeth Keehner, Deakin University; Rhys Coleman, Melbourne Water; Emma Jackson, Central Queensland University; Peter Macreadie, Deakin University; Craig Sherman, Deakin University

Ambitious restoration targets set globally present a unique challenge – the provision of sufficient restoration material to meet them. In the coastal restoration sphere, the need for seagrass nurseries is clear yet there are currently few existing studies. Mesocosm experiments were carried out in Victoria, Australia, to assess the feasibility of a seagrass nursery by examining the impacts of the source of seagrass cultivated, the source of sediment used as growing substrate, and the presence/absence of sediment-associated microbial communities manipulated via autoclaving of sediments on survival and growth of Zostera muelleri. Seagrasses were cultivated successfully, with overall high survival and growth. Of the three experimental treatments, sediment source and the presence/absence of microbial communities did not affect cultivation success. In contrast, seagrass source was important, but this was mostly limited to a single source that performed poorly. The microbial communities were subsequently profiled to assess community composition in the different sediment treatment combinations. While the short-term

survival of seagrasses was not affected by cultivation within autoclaved or non-autoclaved sediment, the microbial communities found in these different sediment types had clear structuring. Interestingly, functional group analysis found higher percentages of bacteria involved in the C, S, and N cycles in autoclaved sediments. Further studies are required to assess if such microbial communities structuring is detrimental to seagrass health in the long-term, which would in turn affect nursery cultivation success. Overall, these results indicate that a Z. muelleri nursery is highly feasible and should be further explored as a tool for seagrass restoration.

Shifts in sediment and Zostera marina microbiomes at early stages of seagrass restoration in the German Baltic Sea

Katharina Kesy, Aquatic Microbiomes, Institute of Microbiology, University of Greifswald, Greifswald, Germany; Tadhg Ó Corcora, Marine Evolutionary Ecology, GEOMAR Helmholtz Centre for Ocean Research Kiel, Kiel, Germany; Anne Brauer, Aquatic Microbiomes, Institute of Microbiology, University of Greifswald, Greifswald, Germany; Matteo Lattuada, Landscape Ecology and Environmental Systems Analysis, Institute of Geoecology, TU Braunschweig, Braunschweig, Germany; Angela Stevenson, Marine Evolutionary Ecology, GEOMAR Helmholtz Centre for Ocean Research Kiel, Kiel, Germany; Thorsten B. H. Reusch, Marine Evolutionary Ecology, GEOMAR Helmholtz Centre for Ocean Research Kiel, Kiel, Germany; Maike Paul, Leibniz University Hannover, Ludwig Franzius Institute of Hydraulic, Estuarine and Coastal Engineering, Hannover, Germany; Boris Schröder, Landscape Ecology and Environmental Systems Analysis, Institute of Geoecology, TU Braunschweig, Braunschweig, Germany; Mia M. Bengtsson, Aquatic Microbiomes, Institute of Microbiology, University of Greifswald, Greifswald, Germany

Seagrasses are important ecosystem engineers that provide many ecosystem services, such as nursery grounds for commercial fish stocks, or carbon storage. To halt the ongoing global decline in seagrass area, diverse attempts have been undertaken to restore lost meadows in various regions, with variable results. One aspect that has received limited attention, both for initial restoration success (e.g. plant survival), and the return of ecosystem services (e.g. carbon storage), is the role of the microbiome of the seagrass itself and of the sediment it inhabits. Here, we report on initial shifts in sediment and eelgrass (*Zostera marina*) microbiomes, one and three months after transplanting shoots at two newly restored sites in the German Baltic Sea. By comparing the data to those from a nearby natural seagrass meadow and an unvegetated control, we aim at detecting the onset of the eelgrass influence on the sediment microbial community and its potential functions. Simultaneously, we track changes in the eelgrass root and leaf microbiomes after transplantation from a donor meadow to both a nearby and more distant site, to investigate the stability of the microbial community and its potential importance for eelgrass establishment.

We hypothesize that sediment microbiome data can serve as an early proxy for ecosystem service recovery in seagrass restoration and that knowledge about the seagrass microbiome could help identify suitable restoration sites. We hope that this will inform and aid future seagrass restoration initiatives, as well as decision makers to evaluate the feasibility and benefits of seagrass restoration.

Effects of depth gradients and plant-soil interactions on trait divergence and local advantage within seagrass meadows

Torrance C. Hanley, Northeastern University; Cynthia G. Hays, Keene State College; Forest R. Schenck, Massachusetts Division of Marine Fisheries; A. Randall Hughes, Northeastern University

Intraspecific trait divergence within foundation species is common and attributable to both abiotic conditions and biotic interactions. Environmental gradients often underlie phenotypic differentiation within populations. Plant-soil interactions can also influence community properties and ecosystem functions. To examine the effects of environmental gradients and plant-microbial interactions on trait divergence within seagrass meadows, we first conducted a greenhouse experiment manipulating seed source depth (seeds from shallow and deep reproductive shoots) and soil conditioning treatment (soil conditioned by shallow and deep vegetative shoots) to determine whether there was a local advantage to being planted in soil conditioned by plants from the same versus a different depth. We found significant effects of source depth: deep seeds germinated earlier and deep seedlings were taller and had more leaves than shallow seeds/seedlings. In addition, we found significant effects of soil depth: seedlings planted in deep-conditioned soil were taller than seedlings planted in shallow-conditioned soil. At the end of the experiment, we also found a significant source depth*soil depth interaction, with seedlings performing better when planted in soil conditioned by plants from a *different* depth. Second, we used these seedlings to conduct a fully-crossed field reciprocal transplant experiment. Outplant depth had strong effects on seedling performance (shallow > deep). However, there were no effects of source depth on seedling performance. But the effects of soil conditioning persisted in the field, with seedlings in deep-conditioned soil being taller and having more leaves, suggesting that both environmental gradients and plant-microbial interactions contribute to trait divergence within seagrass meadows.

Ocean acidification alters the composition and functional potential of Posidonia oceanica phyllobiome

Lu Wang, Oregon State University, USA; Fiona Tomas, IMEDEA (CSIC-UIB), Spain; Gema Hernan, IMEDEA (CSIC-UIB), Spain; Jorge Terrads, IMEDEA (CSIC-UIB), Spain; *Ryan Mueller*, Oregon State University, USA

The oceans act as a sink for anthropogenic carbon emissions, and consequently significant changes in inorganic carbon concentrations and in pH are projected to occur within the next century, leading to important ecological consequences for marine organisms. Seagrasses are projected to potentially benefit from this phenomenon, because of increasing CO_2 , the preferred source of inorganic carbon for photosynthesis. As seagrasses and their microbiota are metabolically linked, this increased carbon availability may yield changes in the seagrass microbiome. We sampled *Posidonia oceanica* leaves from sites off of the coast of Ischia, Italy, where naturally occurring volcanic CO_2 vents acidify surrounding ocean waters. We analyzed both 16S rRNA amplicon and metagenome sequencing to investigate differences between *P. oceanica* phyllobiomes at vent and ambient sites. Results showed distinct community differences based on site variables, which was not seen in the water column microbiota. Representative metagenomes of vent and ambient sites provided evidence for enrichment of autotrophic microbes in ambient sites and heterotrophic microbes in vent sites. Genes enriched in ambient sites include those involved in carbon fixation and ABC transporters, whereas genes enriched in vent sites include those involved in sucrose and starch metabolism and biofilm formation. These

results highlight that ocean acidification can have strong ecological effects on seagrass microbiomes, likely being indirectly influenced by vent conditions through enhanced plant productivity that increases the bioavailability of carbon, supporting diverse, heterotrophic, and potentially pathogenic microbes that may have implications for marine biogeochemical cycling as well as host fitness and adaptability.

Epiphyte Biofilms: Connecting Micro to Mini Scale Indicators of Environment

Chi Huang, TX A&M University-Corpus Christi, College of Science; Carissa Pinon, TX A&M University-Corpus Christi, College of Science; Mehrube Mehrubeoglu, TX A&M University-Corpus Christi, College of Engineering; Hua Zhang, TX A&M University-Corpus Christi, College of Engineering

Studies are needed to integrate molecular taxonomic and functional information of seagrasses and their biofilm communities to morphological observations made as environmental conditions change. Epiphyte imaging is sensitive to community differences with changing environments, and thus complementary to molecular taxonomic studies of community composition. *Thalassia testudinum* was studied at 3 sites differently impacted by decades of wastewater treatment effluent. There were no consistent differences in seagrass biomass, despite a consistently increased level of epiphyte biomass and imaging-derived leaf coverage, at the site (CI) that was least-impacted by WWTP effluent. However, this site was uniquely situated near an oyster reef and the Intracoastal Waterway, and it had the highest level of porewater DIN compared to the site most-impacted by WWTP effluent (W), which had significantly highest porewater PO4-P. No significant differences were observed between sites for the δ15N values of seagrass or epiphytes. In contrast, δ13C values of seagrass were most negative at CI, and for epiphytes, most negative at W and highest at CI. Molecular taxonomy (16S, 18S) of the epiphytes revealed differences in community composition, with W being most enriched in diatoms, green algae, cyanobacteria deltaproteobacteria and bacteroidia, while depleted of red algae, nematodes, most other animal taxa, gammaproteobacteria and alphaproteobacteria. The imaging and molecular technologies are complementary regarding epiphyte community change in response to environmental conditions, and they can expand knowledge of how communities coordinate to produce ecosystem phenotypes.

Effects of epiphytes on the seagrass phyllosphere

Kasper Elgetti Brodersen; Michael Kühl

Eutrophication is a major threat to seagrasses worldwide, as it leads to increased epiphyte overgrowth of leaves. Yet, little is known about how epiphytes affect key biogeochemical processes and chemical conditions in the seagrass phyllosphere. We used microsensors to measure microgradients of O_2, temperature, pH, nitric oxide and CO_2 at the bare and epiphyte-covered leaf surface of *Zostera marina*. Epiphytes result in extreme daily fluctuations in pH, O_2 and inorganic carbon concentrations at the leaf surface, severely hampering the seagrass' performance. In light, the presence of epiphytes resulted in strong phyllosphere basification, which reduced the CO_2 and HCO_3^- availability at the leaf surface and reduced photosynthetic efficiency due to carbon limitation and enhanced photorespiration, which increases the risk for plant starvation. With epiphytes, leaf surface pH increased to >10, thereby exceeding final pH levels of ~9.6 and CO_2 compensation points for photosynthesis. Epiphytes also impeded heat transfer between the leaf surface and the surrounding water, leading to the establishment of

thermal boundary layers (TBLs) and leaf warming. The TBL imposes an insulating barrier impeding heat dissipation from the leaf, potentially aggravating negative responses to elevated temperatures, when seagrasses are living close to their thermal stress threshold. In darkness, epiphytes resulted in increased CO_2 and hypoxia at the leaf surface – increasing the risk of plant/tissue asphyxiation. Moreover, anoxic conditions in the leaf epiphytic biofilm at night can also enable anaerobic microbial processes leading to harmful nitric oxide production via denitrification. Epiphytes can thus represent a severe threat to seagrass health.

Does the seagrass microbiome mediate risk of disease?

Olivia J. Graham; Emily M. Adamczyk; Siobhan Schenk; Phoebe Dawkins; Samantha Burke; Emily Chei; Kaite Cisz; Sukanya Dayal; Jack Elstner; Arjun Lev Pillai Hausner; Taylor Hughes; Omisha Manglani; Miles McDonald; Chloe Mikles; Anna Poslednik; Audrey Vinton; Laura Wegener Parfrey; C. Drew Harvell

Microbial communities strongly influence the health and functions of their hosts and can be a first line of defense against infections. While research increasingly shows a role of the microbiome in terrestrial plant disease resistance, this has yet to be demonstrated with the diversity of pathogens infecting marine plants. Here, we test the hypothesis that the host-associated microbiome increases host resistance to seagrass wasting disease. We experimentallt manipulated the eelgrass (*Zostera marina*) microbiome with antibiotics, mechanical removal by vortexing, and dilute bleach, then inoculated plants with *Labyrinthula zosterae* (Lz), the causative agent of seagrass wasting disease. Our experiments using different microbiome methods consistently showed significantly higher disease severity in eelgrass wrrith an unmanipulated microbiome. Indeed, our results did not support a protective role of the eelgrass microbiome against Lz. We paired these experiments with 16S rRNA gene sequencing of field-collected eelgrass to determine how microbial communities may change in different disease states. Microbial composition and richness between diseased and healthy (completely asymptomatic) tissue varied markedly in one of three sampling years, suggesting diseased eelgrass could have a degredation community under certain conditions. This work enhances our understanding of plant-microbe-pathogen interactions in a valuable marine foundation species.