ADDING A NEW DIMENSION TO THE UNDERSTANDING OF SEAGRASS ECOLOGY

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Abstract

The seagrasses which are facing a natural decline has come in the light for conservation and protection among the scientists working in the field of maritime issues. With the United Nations 2030 Agenda, we look forward to some of the Sustainable Development Goals, which not only focuses on "*Life Below Water*" but also on "*Zero Hunger*", "*Good health and Well Being*", "*Responsible Consumption and Production*" and "*Climate Action*". In this article we provide a new dimension in seagrass ecological research and the details of the perspective. With the reported ecological importance across the globe, we try to assess and review the importanceof seagrass ecosystem services and current scenario of the seagrass ecosystem through the published literature. We also try to focus on the fungus associated with the seagrasses research and present a review of published work from the past decade regarding the presence and association of seagrass and fungus across the globe. We present a comprehensive summary and documentation of the seagrass associated fungus research in this article.The article ignites the perspective of emerging fungal diseases in the seagrass and other ecosystem which would have global economic and social consequences in the backdrop of climate change.

Key Words: Seagrass, ecosystem services, vulnerability, fungal diseases, maritime issue

Introduction

Seagrasses popularly known as "*Umi-Kusa"* in Japanese are marine flowering plants with varied morphological attributes. Seagrasses occupy a variety of coastal habitats. They occur in intertidal and shallow subtidal soft bottom realms and can be found in marine inlets, bays, reefs, lagoons and channels that are sheltered from significant wave action. These meadows or patches could be monospecific or might comprise of multispecies communities. There are more than 70 species of seagrass around the world [1]. Similar to the terrestrial (land living) plants, seagrass can be classified into leaves (including veins), stem, roots (buried in the substrate) and reproductive parts such as flowers and fruits. Being recognized as priority subjects for conservation in International and National frameworks these seagrasses are facing widespread decline.

The compiled worldwide seagrass area combined to date has been estimated at *160,387* km^2across *103* countries/territories with moderate to high confidence, with an additional *106,175* km^2across another *33* countries with low confidence[2]. Studies have shown that seagrass beds have been found around the world, mostly limited to the temperate, subtropical and tropical latitude and most commonly occurs in the intertidal and subtidal regions.The global seagrass distribution highlights India as one of the four high species diversity centres across the globe[3]. Further, the Indian region highlight Andaman and Nicobar Islands (ANI) (*8.3* km^2) and Lakshadweep Islands regions (*1.12* km^2) as the most distributed seagrass regions[4]. However, a review study about status of seagrass ecosystem in India including Lakshadweep and ANI discussed the lack of research about seagrasses and their transformation towards management policy[5,6].

Ecosystem services of seagrasses

The ecosystem services provided by seagrass ecosystems make them a high conservation priority.The habitat complexity within seagrass meadows provides a plethora of highly productive and biologically rich habitats. They contribute to the human well-being by supporting tourism, recreational opportunities and valuable ecosystem services such as reducing coral related diseases, filtering water pollutants, stabilising sediment and absorbing nutrients thus helping in preventing the incidence of pathogenic marine bacteria and contamination in seafood. Certain seagrasses are the main diet of dugongs and green turtles and provide a habitat for many, smaller marine animals, some of which, like prawns and fish, are commercially important. They have also shown to acquire anti-bacterial properties. These seagrasses are acknowledged to prevent algal blooms by algicidal and growth-inhabiting activities against the microalgae causing the blooms. The leaves of seagrass support a host for epiphytes (algae, protozoans) and epizoa (encrusting animals) by providing a surface area on which they can grow. The seagrass beds act as green infrastructure and "*blue carbon*" habitats. It is vital to recognize the conservation, management and restoration of seagrass ecosystem around the world since they play an inevitable part of both biodiversity and human wellbeing.

Factors affecting seagrass distribution

A number of environmental parameters are critical to whether seagrass will grow and persist. These include physical parameters that regulate the physiological activity of seagrasses: temperature, salinity, wave action, turbidity, currents, depth, tidal amplitude, substrate and day length, light, nutrients, epiphytes, diseases and anthropogenic inputs (nutrient and sediment loading). Various combinations of these parameters will permit, encourage or eliminate seagrass from a specific location.

Fungi as a factor of decline of seagrass

One of the key ecological factors that can make these seagrasses more vulnerable is the presence of fungi in the ecosystem.

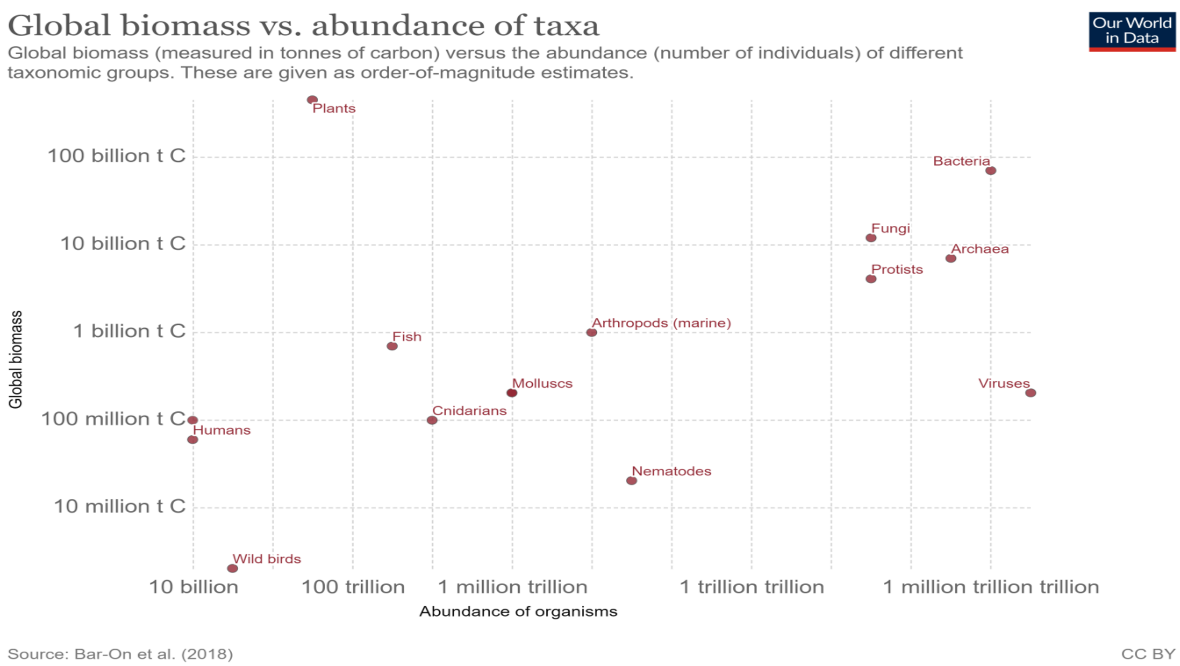

Figure 1: Global biomass versus the abundance of different taxonomic groups.

The Figure 1 has been adopted from "*Our World in Data*" [7] which clearly depicts the global biomass (measured in tonnes of carbon) versus the abundance (number of individuals) of different taxonomic groups in order of magnitude estimates. The significant occupancy of fungi in the natural environment (more than *10* trillion trillion) and a global biomass generation of more than *10* billion tonnes Carbon, can affect seagrasses and eventually human beings. These fungi occupying a peculiar niche in the environment, have fascinated mycologists for more than *70* years. Whilethere are estimated approximately *1.5* million fungal species on Earth [8]; the marine fungi have been estimated at about *10,000* species [9-11].S.P. Meyers first brought the attention of marine mycologists to fungi in seagrasses. All parts of seagrasses contain fungi. These fungi can also colonize internally in symptomless manner implying they cause no apparent damage to their host [12-14] and can be identified by culturing and metagenomics or through direct microscopy. Seagrass endophytes identified through culture methods using surface sterilization found fungi as the most common endophyte [15-17].

Seagrass: Current Scenario

Seagrasses, coral reefs and mangroves are often interconnected and interdependent, supporting coastal communities around the world. Almost *30* per cent of global seagrass area has been lost since the late nineteenth century and at least *22* of the world's *72* seagrass species are declining worldwide because of coastal development, nutrient loading that leads to poor light conditions on the sea floor, climate change, and cascading impacts of fishing, dredging and boating activities [18].Further, disease such as white pox disease, white plague, white band, white syndrome, pink spot, dark spot, pink line syndrome, polychaete infestation and crown of thorn grazing have been reported to be prevalent in the scleractinian corals of ANI [19]. This validates the necessity to monitor and asses the seagrass as well for any emerging disease. Ensuring a sustainable future for seagrasses by aligning with policies implemented at the national, regional or global levels can help countries achieve multiple economic, societal and nutritional objectives.

Seagrass Monitoring

Seagrass monitoring shall help policy makers with data to know whether resource status and conditions are stable, improving or declining which shall aid in making evidenced-based decisions, policy framing and its implementation. The seagrass monitoring would enable us to examine, quantify and assess the acceptable range of stressors. The seagrass monitoring can be done keeping into consideration various environmental stressors including climate (e.g. cyclones, seasonal temperature),local and short-term weather (e.g. wind and tides),water quality (e.g. river discharge, plume exposure, nutrient concentrations, suspended sediments, herbicides),biological (e.g. epiphytes and macroalgae),substrate (e.g. grain size composition),seagrass environmental integrators (e.g. tissue nutrients).In rapid changing environment and marine extreme events, the environmental stressors change rapidly (minutes/days/weeks/months) but can also undergo chronic shifts (years) which necessitates the need of seagrass monitoring. The seagrass monitoring shall not only be beneficial to the angiosperms but also other organisms that use those habitats. Regular seagrass monitoring shall help in knowing fungal diversity and pathogenic fungi before they become intractable. A timely rapid response will help us identify and prioritize future requirements and initiatives. Recent notable studies conducted emphasised the monitoring of seagrasses ecosystems as an expedient tool for surveillance of marine biodiversity and conservation.

The engrossing study on how a microscopic organism can affect an entire ecosystem has fascinated many scientists and researchers since decades. Many of them have studied the fungus diversification present either on leaves, roots, tissues or plant as a whole. These studies have been majorly conducted individually at endophytic or epiphytic level associated with seagrass. The Figure 2 and Table 1 presents a summarized documentation of the seagrass associated fungus research from the past decade.

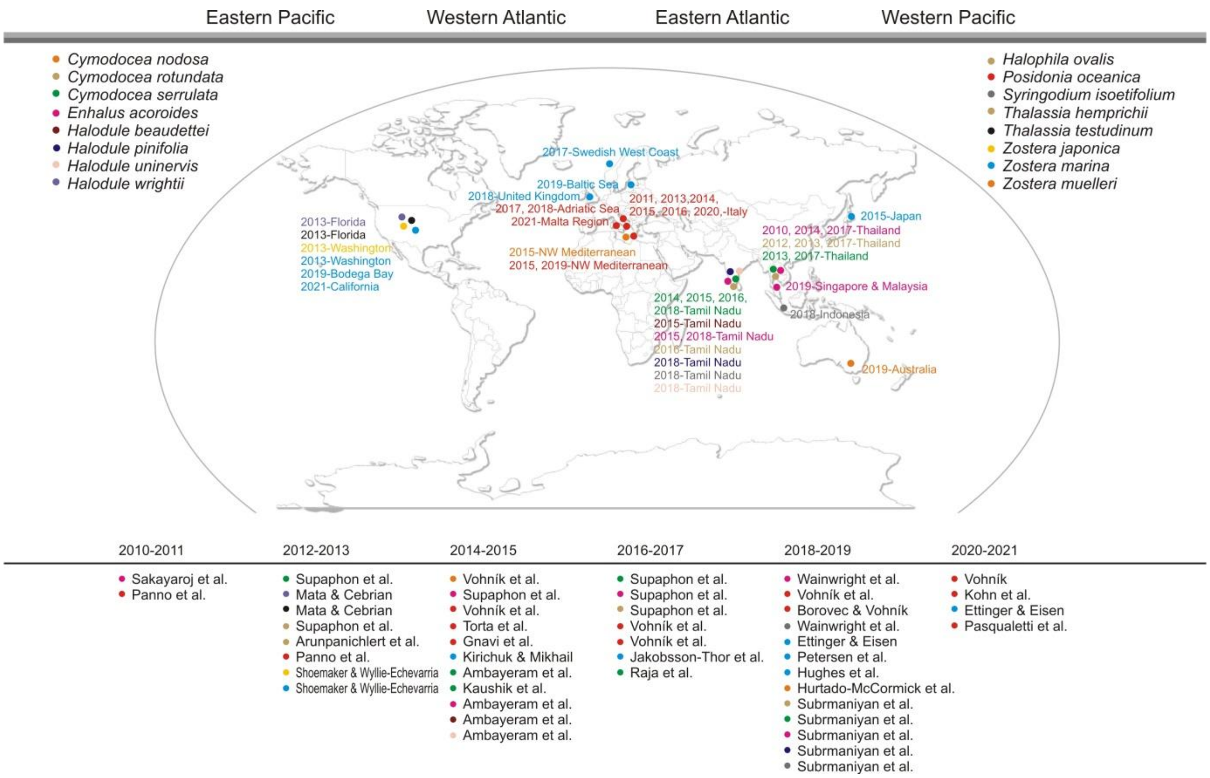

Figure 2: Atlas and timeline of major fungus and seagrass related research over the last decade (2020-2011)

Table 1: Summary of the seagrass associated fungus research from the past decade.

Year	Seagrass	Sample	Fungi	Region	Cross-Reference
2021	*Posidonia oceanica*	Rhizosphere substrate and Roots	Epiphytic and Endophytic	Malta Region	Vohník,2021
2021	*Zostera marina*	Seagrass as a whole	#	California	Ettinger&Eisen,2021
2020	*Posidonia oceanica*	Leaves	#	Giglio Island near Italy	Pasqualetti *et al.*,2020
2020	*Posidonia oceanica*	Leaves	#	Corsica region of France	Kohn *et al*.,2020
2019	*Posidonia oceanica*	Roots	#	NW Mediterranean	Vohník *et al*.,2019
2019	*Zostera marina*	Tissues	#	Bodega Bay	Ettinger&Eisen,2019
2019	*Zostera marina*	Living specimen	#	Baltic Sea, Germany	Petersen *et al*.,2019
2019	*Zostera muelleri*	Upper and lower parts of the leaf, the sheath, roots and rhizomes, surrounding sediment, and seawater	#	New South Wales (NSW), Australia	Hurtado-McCormick *et al*.,2019
2018	*Enhalus acoroides*	Leaves, roots and rhizomes	Endophytes	Singapore and Malaysia	Wainwright *et al*.,2018
2018	*Posidonia oceanica*	Roots	#	Southern Adriatic Sea of Montenegro	Borovec&Vohník,2018
2018	*Syringodium isoetifolium*	Blades	#	Indonesian	Wainwright *et al.*,2018
2018	*Zostera marina*	Shoots with 4–6 leaves	#	Thames Estuary, United Kingdom	Hughes *et al*.,2018
2018	*Cymodocea rotundata*	Leaves	Endophtic	Palk Bay from Tamil Nadu	Submaniyan *et al*.,2018
2018	*Cymodocea serrulata*	#	Endophtic	Eastern Coast Of Tamil Nadu	Submaniyan *et al.*,2018
2018	*Enhalus acoroides*	Leaves	Endophtic	Tamil Nadu Coast, India.	Submaniyan *et al.*,2018
2018	*Halodule pinifolia*	#	Endophtic	Tamil Nadu Coast, India.	Submaniyan *et al*.,2018
2018	*Syringodium isoetifolium*	#	Endophtic	Tamil Nadu Coast, India.	Submaniyan *et al*.,2018
2018	*Halophila ovalis*	#	Endophtic	Tamil Nadu Coast, India.	Submaniyan *et al*.,2018
2017	*Cymodocea serrulata*	Leaves, roots and rhizomes	Endophytes	Trang Province, Thailand	Supaphon *et al.*,2017
2017	*Enhalus acoroides*	Leaves, roots and rhizomes	Endophytic	Trang Province, Thailand	Supaphon *et al.*,2017
2017	*Halophila ovalis and Thalassia hemprichii*	Leaves, roots and rhizomes	Endophytic	Trang Province, Thailand	Supaphon *et al.*,2017
2017	*Posidonia oceanica*	Roots	#	Adriatic Sea	Vohník *et al*.,2017
2017	*Zostera marina*	Shoots	#	Swedish West Coast	Jakobsson-Thor *et al*.,2017
2016	*Posidonia oceanica*	Roots	#	Croatia, Italy, France, And Spain	Vohník *et al*.,2016
2016	*Cymodocea serrulata*	#	Endophtic	Eastern Coast Of Tamil Nadu	Raja *et al*.,2016
2015	*Cymodocea nodosa*	Root	Endophytic	North West Mediterranean Sea	Vohník *et al*.,2015
2015	*Posidonia oceanica*	Roots	#	NW Mediterranean	Vohník *et al*.,2015
2015	*Posidonia oceanica*	Shoot, root, rhizome and leaf bundle	#	Sicily (Italy)	Torta *et al.*,2015
2015	*Zostera marina*	Rhizosphere	#	Great Bay, Sea Of Japan	Kirichuk & Mikhail,2015
2015	*Cymodocea serrulata*	#	Endophtic	Eastern Coast Of Tamil Nadu	Ambayeram *et al*.,2015
2015	*Enhalus acoroides*	Leaves	Endophtic	Tamil Nadu Coast, India.	Ambayeram *et al.*,2015

2015	*Halodule beaudettei*	#	Endophtic	Tamil Nadu Coast, India.	Ambayeram *et al.*,2015
2015	*Halodule uninervis*	#	Endophtic	Tamil Nadu Coast, India.	Ambayeram *et al.*,2015
2014	*Enhalus acoroides*	Leaves, roots and rhizomes	Endophytic	Trang Province, Thailand	Supaphon *et al.*,2014
2014	*Posidonia oceanica*	Rhizomes	#	Liguria (Italy)	Gnavi *et al.*,2014
2014	*Cymodocea serrulata*	#	Endophtic	Eastern Coast Of Tamil Nadu	Kaushik *et al*.,2014
2013	*Cymodocea serrulata*	Leaves, roots and rhizomes	Endophytes	Trang Province, Thailand	Supaphon *et al.*,2013
2013	*Halodule wrightii*	Living leaves	Endophytic	Big Lagoon State Park, Florida	Mata&Cebrian,2013
2013	*Thalassia testudinum*	Living leaves	Endophytic	Big Lagoon State Park, Florida	Mata&Cebrian,2013
2013	*Halophila ovalis and Thalassia hemprichii*	Leaves, roots and rhizomes	Endophytic	Trang Province, Thailand	Supaphon *et al*.,2013
2013	*Posidonia oceanica*	Leaves, rhizomes, roots and matte	#	Liguria, Italy	Panno *et al*.,2013
2013	*Zostera japonica*	Rhizomes	Endophytes	San Juan archipelago region Washington	Shoemaker&Wyllie-Echeverria,2013
2013	*Zostera marina*	Rhizomes	Endophytes	San Juan archipelago Washington	Shoemaker&Wyllie-Echeverria,2013
2012	*Halophila ovalis and Thalassia hemprichii*	Leaf	#	Trang Province, Thailand	Arunpanichlert *et al.*,2012
2011	*Posidonia oceanica*	Leaves, rhizomes, roots and matte	#	Liguria, Italy	Panno *et al*.,2011
2010	*Enhalus acoroides*	Leaf	Endophyte	Southern Thailand	Sakayaroj *et al*.,2010

Conclusion and Discussion

The coastal ecosystem is one of the most significant interfaces as it lies between the land and the sea. These areas are not only ecologically significant but are crucial for the development of civilisation. The communities living around these coastal ecosystems are dependent on these ecosystem services for their food security and livelihood. The dependence of growing coastal population, amplified by the impact of climate change have put these ecosystem services under immense stress leading to more scarcity of the natural resources produced through these ecosystem services. These natural resources such as fishery breeding ground, fishery production and stocks are one of the significant pillars of the survival of coastal communities whose sole dependencies for their nutritional and livelihood requirement are obtained through them. The loss of ecosystem services through degradation in varied form would lead to overall imbalance of global carbon cycle leading to disrupted monsoon, changed storm pattern, nutrient cycle imbalance to name a few. While these disruptions would be challenging for a healthy ecosystem, ultimately this degradation would affect global fishery resource productivity leading to disruption in food security followed by effect on global economies and eventually leading to social instability globally.

These disruptions can be minimised by understanding the already established factors and new emerging factors which can cause these disruptions. The article highlights a new emerging factor that might disrupt not only seagrass ecosystem but eventually other ecosystem in the light of rising sea surface temperature and extended high heat days. The fungi which can proliferate in warmer areas need to be acknowledged for their potential as a future threat in harming the efficiency of ecosystem services provided by such ecosystems. Through this article it is understood that the fungi are present in the marine environment, however their action in influencing the ecosystem services through pathogenic form is still unknown and a point of concern.

Coming to the ecosystem services as discussed earlier which are supported by key ecosystems such as mangroves, coral reefs, seagrasses and seaweeds collectively, which are present at varied depths either as monospecific or with another ecosystem as multi-ecosystem, becomes the centre of concern. The vulnerability of these ecosystemshas been assessed for varying factors but have not been assessed for the vulnerability from the fungal disease outbreak. Taking example of mangroves which have more timber content and coral reefs with high calcareous content are assumed to be more resilient from fungal infections. Seagrasses and certain species of seaweeds which have more of edible components are prone to the microbial and fungal diseases. In this regard, researchers have acknowledged the role of vertical spreading of fungal disease in crustose coralline algae due to major global stressors: ocean warming and acidification at Palymara Atoll. Such research has prompted in making monitoring of these interconnected components a paramount necessity for sustaining the integrity of the marine ecosystem. The seagrasses are more prominent in occurrence and perform vital ecological functions as discussed earlier but have still under recognised functions that deals with promoting resilience of the ecosystem and associated organisms from the microbial and especially fungal pathogens. Overall, the seagrasses have experienced decline in abundance due to innumerable causes which require committed studies and research. The impact of climate change and physico-chemical properties in causing decline is comprehensively known, the role of fungal disease from associated myco-biota in global seagrass declines is largely unknown. Therefore, a rapid response involving comprehensive and appropriate actions in monitoring ought to be taken to prevent, significantly reduce or eliminate the factors causing loss to the seagrass ecosystem or any other interconnected ecosystem in this regard.

Data Availability

No new data were generated or analysed in support of this research.

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Author Contribution

Parth Arora did the data collection and analysis of the findings, writing initial manuscript, created figures. Dr Gadi Padmavati drafted, conceptualised and revised the manuscript.

Conflict of interest statement

The authors have no conflicts of interest to declare

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