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The Ecological, Economic, and Climatic Importance of Seagrasses

Seagrasses are remarkable marine flowering plants that have adapted to life underwater, creating vast meadows that serve as the foundation for some of the most productive ecosystems on our planet. These underwater gardens provide critical habitat for countless marine species, sequester carbon at impressive rates, and deliver numerous ecosystem services that benefit human communities worldwide.

This presentation explores the unique biology of seagrasses, their global distribution, and the vital ecological, economic, and climatic services they provide - from supporting fisheries to protecting coastlines and mitigating climate change.

Şevki Danacıoğlu

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Definition of Seagrasses

Marine Angiosperms

Seagrasses are marine angiosperms adapted to exist fully submerged in brackish or salt water. Unlike algae, they are true flowering plants with specialized adaptations for underwater life.

Ecosystem Engineers

They promote sediment deposition, stabilize substrates, decrease water velocity, and function as part of the estuarine filtration system, removing contaminants from the water column.

Ecosystem Services

Seagrasses provide nutrient cycling, support commercially important fish species as nursery habitat, and serve as an important food source for mega-herbivores like green turtles, dugongs, and manatees.

Seagrasses vs. Algae: Key Differences

Vascular Plants

Like terrestrial plants, seagrasses have veins (lignified conducting tissue) that transport food, nutrients, and water throughout the plant. This vascular system is completely absent in algae.

Root Systems

Seagrasses possess true roots that bury into the substrate, anchoring the plant and absorbing nutrients. In contrast, algae attach to surfaces with holdfasts but cannot penetrate the substrate.

Reproduction

As flowering plants, seagrasses produce flowers, fruits, and seeds as part of their reproductive cycle. Algae reproduce through entirely different mechanisms and never produce flowers or seeds.

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Diversity in Seagrass Morphology

Paddle Shape

Some seagrass species feature oval or paddle-shaped leaves, creating distinctive meadow formations on the seafloor. These broader leaf structures capture sunlight efficiently in certain water conditions.

Fern Shape

Fern-shaped seagrass species display intricate, delicate fronds that create complex habitat structures. These elaborate leaf patterns maximize surface area for photosynthesis.

Ribbon Shape

The most recognizable seagrasses have long, ribbon-like leaves that can reach impressive lengths - some extending up to 7 meters. These flowing meadows create the classic "underwater prairie" appearance.

Seagrasses range dramatically in size, from tiny species with leaves the size of a fingernail to massive plants with leaves stretching several meters in length. This diversity allows them to thrive in various marine environments.

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Global Distribution of Seagrasses

1 Pan-Global Presence

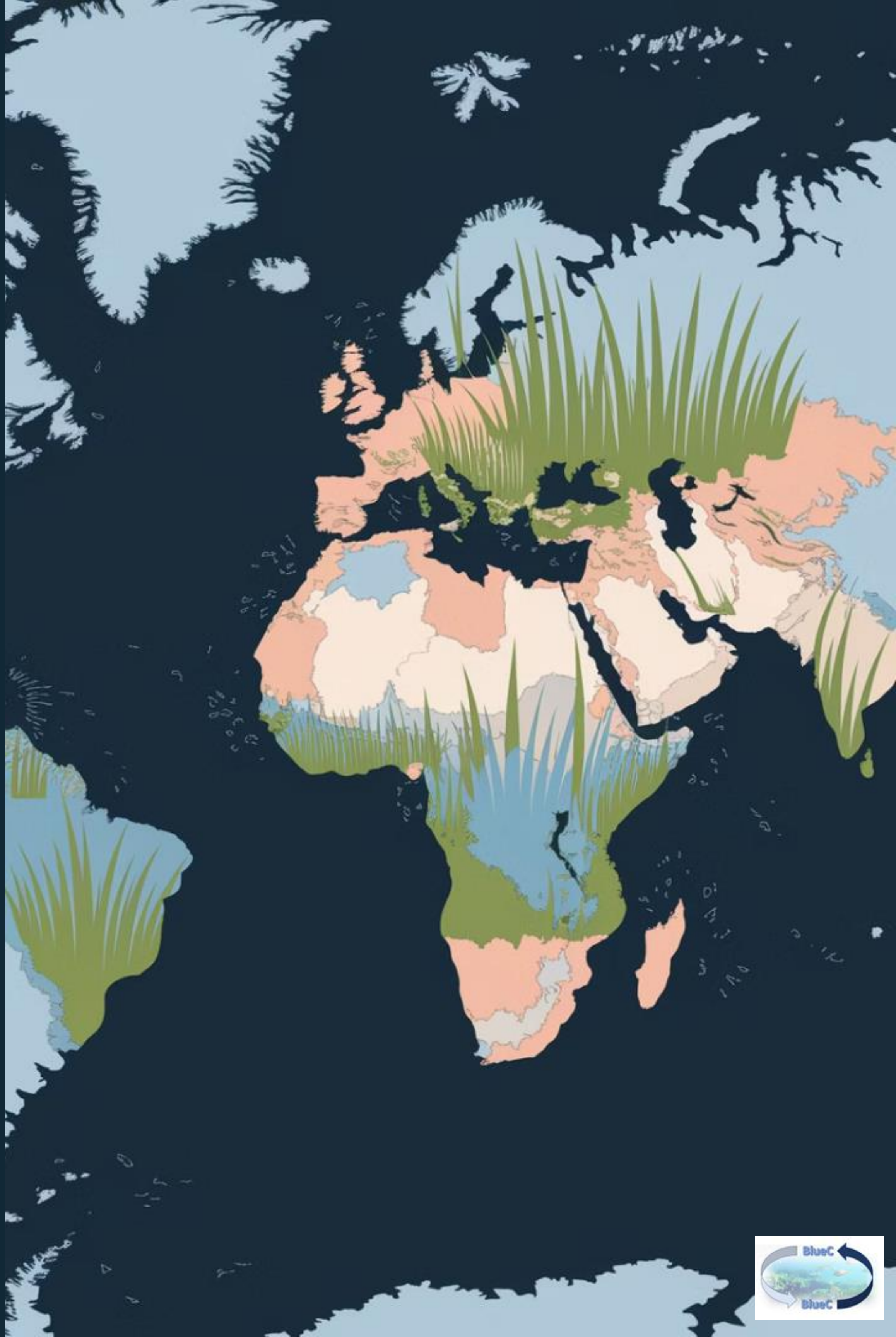
Seagrass meadows have a worldwide distribution, found in shallow coastal areas of all continents except Antarctica. Their ability to adapt to different conditions has allowed them to colonize diverse marine environments globally.

2 Depth Range

Seagrasses occupy soft-bottom sediments from the intertidal zone (areas exposed during low tide) to depths of up to 40 meters, depending on water clarity and light penetration.

3 Climate Adaptability

These remarkable plants thrive across climate zones, from tropical waters near the equator to temperate regions with seasonal temperature variations, demonstrating their evolutionary success and adaptability.



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Mapping Seagrass Distribution

17M

Minimum Hectares

The lowest global estimate of seagrass coverage, highlighting the significant area these ecosystems occupy worldwide.

60M

Maximum Hectares

The highest estimate of global seagrass coverage, showing the potential scale of these vital marine habitats.

25%

Mapped Coverage

Less than a quarter of the world's seagrasses have been properly mapped, indicating significant knowledge gaps.

↓

Declining Trend

Current knowledge suggests seagrasses are being lost at rates faster than documentation can capture.

The wide variation in estimated global coverage of seagrass meadows reflects our incomplete understanding of these ecosystems. In most countries, no generalized spatial mapping has been conducted, with seagrass locations known only from localized observations. Many areas remain completely unexplored for seagrass presence.

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Global Seagrass Bioregions

Temperate North Atlantic

Covering coastal areas of North America and Europe, this bioregion features species adapted to seasonal temperature variations and strong tidal influences.

Tropical Indo-Pacific

The most diverse bioregion, stretching from East Africa to Hawaii, containing the highest number of seagrass species in the world.

Tropical Atlantic

Encompassing the Caribbean, Gulf of Mexico, and tropical Atlantic coastlines with species adapted to warm, often hurricane-affected waters.

Temperate North Pacific

Spanning the coastlines of Asia and North America, this region hosts diverse seagrass communities adapted to the unique conditions of the Pacific Ocean.

Mediterranean

A distinct bioregion with endemic species like Posidonia oceanica, adapted to the Mediterranean's clear, warm waters and limited tidal range.

Temperate Southern Oceans

Including southern Australia, New Zealand, and South Africa, featuring unique species adapted to the Southern Hemisphere's oceanic conditions.

Globally, total seagrass area is estimated to be more than 177,000 km^2 based on mapped areas and inference of unmapped areas where seagrass occurrence has been documented. This distribution is organized into six distinct bioregions, each with characteristic species and ecological conditions.

European Seagrass Species

Zostera marina

Known as eelgrass, this widespread species can be found from arctic waters along the Norwegian coast to the Mediterranean. It can survive several months of ice cover in northern regions.

Zostera noltii

Dwarf eelgrass forms dense beds in muddy sand of intertidal areas. It has higher tolerance to desiccation than Zostera marina, allowing it to thrive in areas exposed during low tide.

Cymodocea nodosa

Sometimes called "seahorse grass" because its beds are characteristic habitats for seahorses. This warm-water species is widely distributed throughout the Mediterranean and Canary Islands.

Posidonia oceanica

Restricted to the Mediterranean Sea, this endemic species forms extensive meadows from shallow waters to depths of 50-60 meters in areas with very clear water.

Despite their terrestrial origins, seagrasses are well adapted to the marine environment and can be found from the intertidal zone at the shore to depths down to 50-60 meters in European waters. The four European species are easily identifiable and their geographical distribution is well documented.

Common Characteristics of European Seagrasses

1

Leaf Structure

The visible part consists of shoots or leaf bundles with 3-10 linear leaves, creating the meadow canopy that provides habitat and performs photosynthesis.

2

Rhizome Network

Shoots attach to horizontal and/or vertical rhizomes that creep within or atop the sediment, forming an interconnected underground network.

3

Root System

Roots penetrate into deeper layers of the seafloor, anchoring the plant and absorbing nutrients from the sediment.

4

Clonal Growth

Rhizomes divide to form new leaf bundles, creating genetically identical shoots that function as a single interconnected individual.

European seagrass species share several morphological characteristics despite their visual differences. This common structure allows them to perform similar ecological functions across different habitats and regions, from the cold waters of the North Sea to the warm Mediterranean.

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Zostera marina (Eelgrass)

1 Distribution

Found from arctic waters along the northern Norwegian coast to the Mediterranean. Very abundant in the Baltic Sea, the North Sea, and along the Atlantic coasts down to northern Spain. In the Mediterranean, it appears mostly as small isolated stands.

2 Habitat

Predominantly subtidal, growing down to 10-15 meters depth depending on water clarity. Most often perennial, though annual stands are found intertidally in the Wadden Sea.

3 Morphology

Shoots have 3-7 leaves with width varying between 2mm for young plants and up to 10mm for large individuals. Leaves are usually 30-60cm long but may reach up to 1.5m in beds on soft sediments at intermediate depths.

4 Identification

Easily identified by terminal shoots growing only on horizontal rhizomes, creating distinctive meadow patterns on the seafloor.

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Zostera noltii (Dwarf Eelgrass)

1

Distribution

Distributed from the southern coasts of Norway to the Mediterranean Sea, the Black Sea, the Canary Islands, and recorded as far south as the Mauritanian coast, showing its adaptability to different water conditions.

2

Habitat

Forms dense beds in the muddy sand of intertidal areas where Zostera marina is sparse due to its lower tolerance to desiccation. This habitat specialization allows the two species to coexist in the same regions.

3

Morphology

Features small leaf bundles with 2-5 narrow leaves attached to a horizontal rhizome. Each rhizome holds many shoots on short branches separated by rhizome segments. The leaves are 0.5-2mm wide and 5-25cm long.

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Cymodocea nodosa (Seahorse Grass)

Cymodocea nodosa, proposed to be called 'seahorse grass' due to its characteristic habitat for seahorses, is a warm water species widely distributed throughout the Mediterranean, around the Canary Islands, and down the North African coast. The species does not extend further north than the southern coasts of Portugal.

It can be found from shallow subtidal areas to very deep waters (50-60m). Cymodocea nodosa has leaf bundles consisting of 2 to 5 leaves. The leaves are 2 to 4mm wide and from 10 to 45cm long. The species is best identified by its vertical rhizomes and the long, white or pink segments of the horizontal rhizomes.

Posidonia oceanica

Mediterranean Endemic

Posidonia oceanica is restricted to the Mediterranean Sea, with its distribution stopping at the border where Mediterranean and Atlantic waters mix in the western part of the Mediterranean Sea. It's the most widespread higher plant in the Mediterranean.

Depth Range

This remarkable species grows from shallow subtidal waters to depths of 50-60m in areas with very clear waters, demonstrating its exceptional adaptation to low-light conditions at greater depths.

Distinctive Morphology

Posidonia oceanica has leaf bundles consisting of 5 to 10 leaves attached to vertical rhizomes. The leaves are broad (5 to 12mm) with length usually varying from 20 to 40cm but may reach up to 1m in favorable conditions.

Identification Features

The species is easily identified by its dense, broad leaves and the hairy remains around the rhizomes and lower parts of the shoots, giving it a distinctive appearance compared to other Mediterranean seagrasses.

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Ecosystem Services of Seagrasses

1. **Human Well-being**
   Supporting communities worldwide
2. **Ecosystem Services**
   Provisioning, regulating, cultural
3. **Global Impact**
   Food security, climate, biodiversity
4. **Environmental Protection**
   Water purification, coastal defense
5. **Health Benefits**
   Disease control, pathogen removal

Seagrass ecosystems provide a wide variety of services that support human well-being around the world. It is estimated that more than 1 billion people live within 100km of a coast with seagrass meadows, potentially benefiting from their provisioning, regulating and cultural services.

Seagrasses play a significant global role in supporting food security, mitigating climate change, enriching biodiversity, purifying water, protecting coastlines, and controlling diseases. These ecosystem services translate to direct economic and social benefits for coastal communities and beyond.

Seagrasses Support Marine Biodiversity

Megafauna Habitat

Seagrass meadows provide critical feeding grounds for threatened marine megafauna like green sea turtles, which graze directly on seagrass blades. These endangered species depend on healthy seagrass ecosystems for their survival.

Nursery Grounds

The complex structure of seagrass meadows creates perfect nursery habitat for countless fish species, including many commercially important ones. Juvenile fish find both food and protection from predators within the seagrass canopy.

Invertebrate Diversity

A rich community of invertebrates thrives within seagrass meadows, from tiny crustaceans to mollusks and echinoderms. These organisms form the base of complex food webs that support higher trophic levels.

The provision of shelter, feeding and nursery grounds are critical ecosystem services delivered by seagrasses worldwide, as evidenced by the high diversity and abundance of fauna within seagrass meadows. Many of these animals are of special interest and include threatened, endangered or charismatic species.

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athogen Removal

Seagrasses can remove microbiological contamination from the water, reducing exposure to bacterial pathogens for fish, humans, and invertebrates. This natural filtration process helps maintain healthier marine environments.

Bioactive Compounds

Seagrasses produce bioactive secondary metabolites with antibacterial and antifungal activity. Extracts from tropical species like Halophila stipulacea, Cymodocea serrulata, and Halodule pinifolia have shown activity against human pathogens.

Coral Protection

Coral reefs benefit from adjacent seagrass meadows, with coral disease levels halved when seagrasses are present. This protective relationship highlights the importance of maintaining diverse coastal ecosystems.

Algal Bloom Control

Seagrass meadows can control harmful algal blooms through algicidal and growth-inhibiting activities against the microalgae causing the blooms, helping maintain ecosystem balance.

Seagrasses Mitigate Climate Change

19.9Pg

Carbon Storage

Global estimate of organic carbon stored in seagrass ecosystems, making them significant carbon sinks.

2

Carbon Sources

Carbon is sequestered both as seagrass biomass and through trapping organic particles from adjacent ecosystems.

1000s

Years of Storage

Carbon deposits in seagrass sediments can remain for millennia if left undisturbed.

↑O_2

Oxygen Production

Seagrasses produce oxygen through photosynthesis, benefiting the marine environment.

Seagrass meadows are significant carbon sinks at the global scale with high capacity for taking and storing carbon in the sediment, also known as 'blue' carbon. For this service, seagrass ecosystems have great potential in combating climate change, with benefits for the entire planet.

The anoxic conditions of seagrass sediments enhance the preservation of the sedimentary carbon, leading in some cases to the formation of large carbon deposits that can remain for millennia if left undisturbed.

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Carbon Storage in Seagrass Ecosystems

1

Above-ground Biomass

The carbon stored in leaves and stems is considered a short-term carbon sink, as this material is more prone to grazing, export, or decomposition. However, it still plays an important role in the overall carbon cycle.

2

Below-ground Biomass

Rhizomes and roots store carbon in more stable forms, protected from rapid decomposition by the low-oxygen conditions in the sediment. This represents a medium-term carbon storage mechanism.

3

Sediment Carbon

The largest and most stable carbon reservoir is in the sediment itself, where organic matter from both the seagrass and other sources becomes buried and preserved for centuries to millennia under anoxic conditions.

4

Allochthonous Carbon

Seagrass meadows trap and store organic particles derived from adjacent ecosystems, acting as a "carbon vacuum" that removes carbon from the broader marine environment.

The capacity of seagrasses to sequester carbon varies among species, meadow characteristics, and environmental conditions. Generally, the largest organic carbon deposits occur in undisturbed meadows formed by large, persistent species with complex canopies in sheltered, shallow environments with moderate nutrient inputs.

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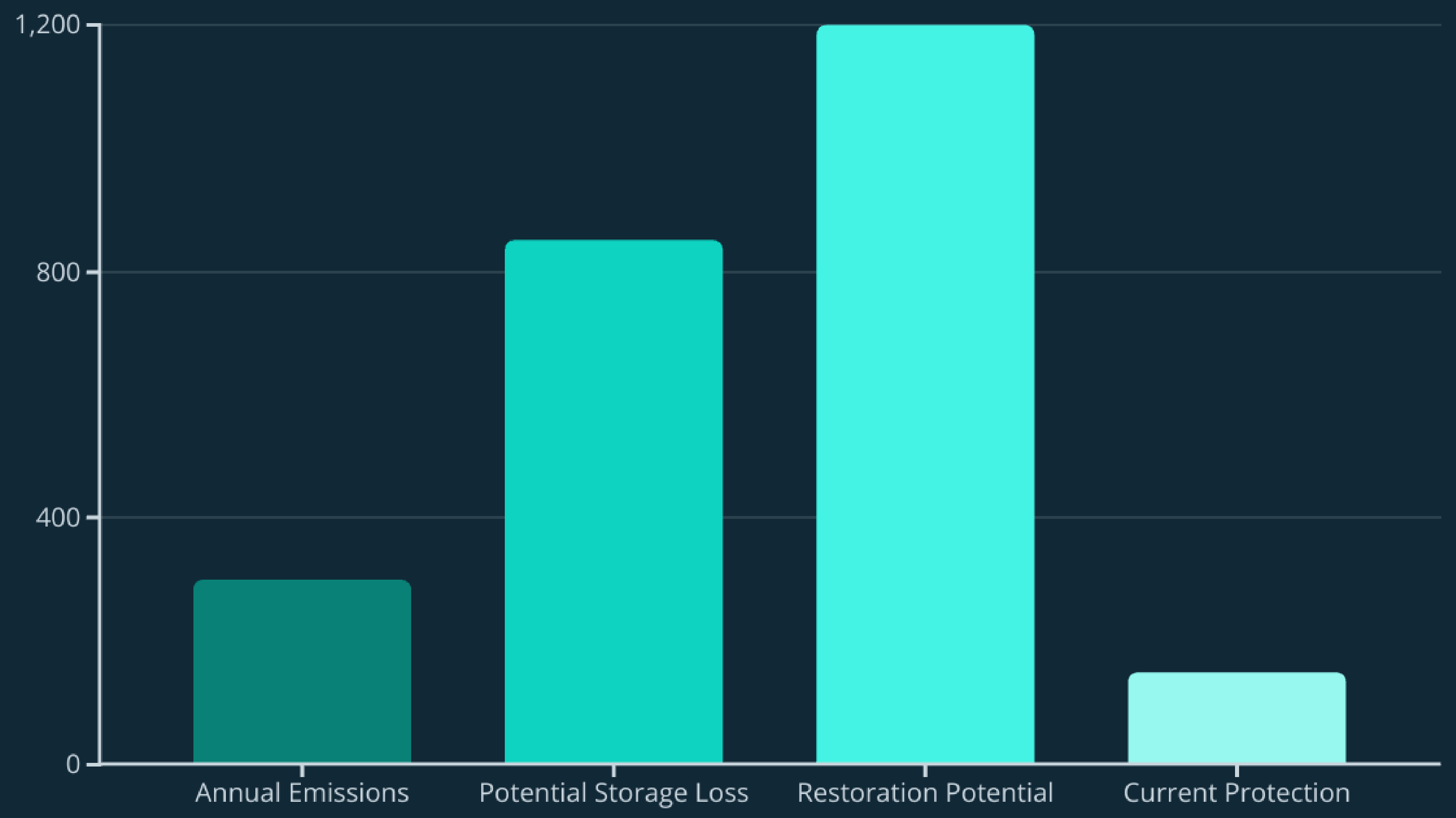
Seagrass Loss and Carbon Emissions



The loss of seagrass meadows leads to reduced carbon sequestration and storage capacity and to more CO_2 emissions derived from the remineralization of the soil carbon deposits. With present rates of loss, seagrasses are estimated to release up to 299 Tg carbon per year.

Similar to what happens with the degradation of terrestrial carbon sinks, the loss of seagrass ecosystems may significantly contribute to anthropogenic CO_2 emissions and to the acceleration of climate change. Despite their significant role as carbon sinks, seagrasses have been traditionally overlooked in greenhouse gas emission accounting inventories.

Blue Carbon Strategies

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2009 Seminal Reports

Publications by Nellemann et al. and Laffoley & Grimsditch highlighted the potential of restoring and conserving seagrass meadows as a climate change mitigation approach within a novel framework termed "blue carbon strategies."

1

IPCC Guidelines

2

The Intergovernmental Panel on Climate Change developed guidelines supporting the reporting of greenhouse gas emissions or sequestration derived from the conversion and restoration of seagrass meadows within countries' national inventories.

Carbon Standards

3

Development of carbon standards like the Verified Carbon Standard allows restoration projects to benefit from carbon credits, creating financial incentives for seagrass conservation.

Future Implementation

4

Although no projects have used seagrass as a tool for emissions reduction to date, the markets and methods are currently being developed and likely to be tested and applied soon.

Since the initial reports, significant advances in science and policy have been made towards implementing blue carbon strategies. However, challenges remain, including the lack of carbon sequestration data for some regions, incomplete seagrass mapping, spatial variability in greenhouse gas emissions, and uncertainties related to legal aspects such as land tenure and tidal boundaries.

Seagrasses Mitigate Ocean Acidification

1 Photosynthetic Carbon Uptake

The high productivity of seagrasses affects the carbonate chemistry of surrounding seawater due to the large quantities of dissolved inorganic carbon taken up during photosynthesis. This metabolic activity helps counteract acidification locally.

2 pH Buffering

Seagrasses tend to increase seawater pH during the daytime, potentially offsetting the deleterious effects of increasing anthropogenic CO_2 in the seawater. This creates localized zones of higher pH within and around seagrass meadows.

3 Refuge for Calcifying Organisms

Marine organisms, particularly calcifying species such as corals and shellfish living within or adjacent to seagrasses, may benefit from this service by finding a local refugium from ocean acidification effects.

Although their role in buffering ocean acidification depends on environmental conditions, healthy seagrass meadows can contribute to enhancing the resilience of vulnerable species to ocean acidification in the short-term. This ecosystem service becomes increasingly valuable as ocean pH continues to decrease due to rising atmospheric CO_2 levels.

Coastal Protection Services

Wave Energy Reduction

Seagrass leaves reduce flow velocity and decrease wave energy as water moves through the meadow. Studies have shown wave energy reductions of up to 40% in areas with dense seagrass coverage, providing significant protection to shorelines.

Sediment Stabilization

The complex root and rhizome systems of seagrasses prevent erosion and stabilize the sediment. This anchoring effect helps maintain coastline integrity even during storm events and prevents valuable land from being washed away.

Beach and Dune Formation

Seagrass litter that accumulates on beaches contributes to stable dune formation. In the case of large species like Posidonia, thick piles of beach-cast material called banquettes can reach up to 3m in height, creating natural barriers.

Sedimentation Enhancement

Seagrass meadows enhance vertical accretion of sediments and seabed elevation through the accumulation of below-ground biomass and particles trapped from the water column, helping coastlines keep pace with sea level rise.

Seagrass meadows play an important role in protecting coastal areas from erosion, flooding, and storm surges. This natural coastal defense system becomes increasingly valuable as climate change intensifies storm events and accelerates sea level rise.

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Natural Infrastructure for Climate Adaptation

Self-Repairing Systems

Unlike engineered "grey" infrastructure that requires constant maintenance, seagrass meadows are living systems capable of self-repair and natural regeneration after disturbances. This makes them more sustainable long-term solutions for coastal protection.

Healthy seagrass ecosystems can adapt to changing conditions, including gradual sea level rise, by either increasing soil elevation through sediment accumulation or migrating inland if space allows.

Grey vs. Green Infrastructure

Traditional engineering solutions based on building "grey" infrastructures (dykes, seawalls) involve direct loss of coastal habitats. Such infrastructures need to be maintained and upgraded to ensure their efficiency in future climate change scenarios, making them economically unsustainable.

In contrast, natural barriers from ecosystems such as seagrasses have the capacity to self-repair and adapt while also providing multiple other ecosystem services, creating a more holistic and sustainable approach to coastal management.

In tropical areas, seagrasses together with sediment-producing calcifying algae have been shown to be effective natural solutions for nourishing beaches, offering a self-sustainable alternative to traditional engineering approaches and increasing coastal resilience to climate change. This highlights seagrasses as one of the best ecosystems for eco-engineering, nature-based solutions.

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Seagrasses Support World Fisheries

Commercial Fisheries

Seagrass meadows provide valuable nursery habitat to over one-fifth of the world's largest 25 fisheries, including walleye pollock, the most landed species on the planet. This nursery function directly supports commercial fishing industries worth billions of dollars annually.

Subsistence Fishing

In cases where seagrass meadows are in close proximity to communities, they often serve as important fishing grounds for local food supply. Invertebrate gleaning in seagrass meadows is an accessible fishing activity due to the shallow nearshore environment.

Recreational Fishing

Seagrass fisheries around the world have recreational value, attracting anglers who target prized sport fish that depend on these habitats. This recreational fishing generates significant tourism revenue for coastal communities.

Seagrass meadows are of fundamental importance to world fisheries production of both vertebrates and invertebrates in various ways. The benefits often extend beyond local communities, providing "extralocal" benefits to people who may live far from the seagrass meadows themselves.

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Invertebrate Fisheries in Seagrass Meadows

Invertebrate gleaning fisheries occurring within seagrass meadows are considered to be an accessible fishing activity mainly due to their shallow nearshore environment and the ease of collecting such fauna. In many parts of the Indo-Pacific region, these gleaning fisheries are vital for maintaining daily protein needs and alleviating poverty.

Seagrasses also have a range of indirect roles in enhancing fisheries, such as providing a trophic subsidy to offshore or deeper water fisheries or filtering terrestrial run-off. These ecosystem services connect seagrass habitats to broader marine food webs and fisheries productivity beyond their immediate boundaries.

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Future of Seagrass Fisheries

Climate Resilience

Seagrass meadows may be less vulnerable to climate change than other habitats like coral reefs.

Increased Fishing Pressure

As other habitats degrade, fishers may increasingly target seagrass-associated species.

Sustainability Concerns

Higher fishing pressure raises questions about long-term sustainability of seagrass fisheries.

Management Needs

Integrated approaches connecting habitat conservation with fisheries management are essential.

In the context of a changing global environment where many marine habitats such as coral reefs are increasingly becoming degraded, fishers may need to compensate by exploiting different habitats and locations. As potentially more climate-resilient habitats, many seagrass meadows are likely to become more highly targeted for their fish assemblages, placing their sustainability in doubt.

In many areas (for example, the United Kingdom) extensive seagrass loss has occurred outside the realm of recent recorded history, with the loss overshadowed by wholesale overexploitation of fisheries. This "shifting baseline" has led to habitat conservation being disconnected from fisheries management.

Documenting Seagrass-Fishery Connections

Limited Documentation

Although there is widespread recognition that seagrasses support fisheries, there are limited documented examples of the consequences of seagrass loss on associated fisheries. This knowledge gap hinders effective management and conservation efforts.

Historical Context

In many areas, extensive seagrass loss occurred before modern scientific monitoring began. This historical loss has been overshadowed by the wholesale overexploitation of fisheries, creating a "shifting baseline" in our understanding of marine ecosystems.

Management Disconnect

The role of habitat in supporting fisheries has been poorly recognized, causing biodiversity and habitat conservation in the coastal seascape to be disconnected from fisheries management approaches and policies.

Research Needs

More studies quantifying the specific contributions of seagrass habitats to fisheries productivity are needed to inform integrated management approaches that protect both the habitat and the fisheries it supports.

Bridging the gap between seagrass conservation and fisheries management requires better documentation of the ecological and economic connections between healthy seagrass ecosystems and productive fisheries. This integrated approach is essential for sustainable management of coastal resources.

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Cultural Services: Traditional Uses

Packing Material

The leaves of Posidonia oceanica were traditionally used as packing material to transport fragile items like glassware and pottery throughout Mediterranean countries. They were also used to ship fresh fish from coastal areas to inland cities, preserving the catch.

Agricultural Uses

As parasites thrived less in P. oceanica leaves than in straw, they were used as cattle bedding in stables. When straw was scarce, dry P. oceanica leaves were also used to make adobes and as roof insulation in southeastern Spain and the Balearic islands.

Bedding Material

Seagrass leaves were widely used as filling material for mattresses and cushions, a practice popularized throughout Italy by Pope Julius III in the 16th century. Respiratory infections seemed to be prevented when sleeping on this type of bedding.

Although seagrasses might not be widely known by the public today, they were familiar and valuable resources for coastal communities throughout history. Their medicinal uses included the alleviation of skin diseases like acne and pain in legs caused by varicose veins.

Cultural Services: Building Materials




In the Netherlands, eelgrass leaves have been used as constituents of dikes ("wierdyken"), providing natural reinforcement to these critical coastal protection structures. Zostera marina was the preferable stuffing of baby mattresses until the 1950's, and the leaves are still used today in traditional chair seats.

Across Europe, Zostera marina leaves have been used as roof covering for farm houses, providing excellent natural insulation and weather protection. The durability of these materials speaks to the remarkable properties of seagrass as a building material, with some structures lasting for generations.

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Economic Value of Seagrass Ecosystems

15837

€/ha/year

Minimum estimated value of services provided by seagrass ecosystems.

100x

Value Comparison

Seagrass ecosystems are two orders of magnitude more valuable than croplands.

1980s

Valuation Beginning

Economic assessment of seagrass value began in the late 20th century.

↑

Growing Recognition

Awareness of seagrass economic value continues to increase.

The large knowledge about the biology and ecology of seagrasses gained during the last third of the 20th century has driven increased awareness of the economic value of seagrasses to humans. The biological resources and ecological services provided by seagrasses are based on the physical structure of the plants themselves and the underwater meadows they form, their biological activity, and that of the associated fauna and flora.

Even with limitations and caveats in these economic estimates, they highlight the extraordinary importance of seagrass ecosystems compared to other habitats and land uses. This economic valuation helps justify conservation efforts and policy decisions that protect these valuable marine resources.

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Tourism and Recreation Value

1

2

3

4

Sport Fishing

The Quintana Roo region in Mexico is famous for its sport fish populations of tarpon, bonefish, snook and permit, with much of the recreational fishing activity occurring in the seagrass lagoons of the peninsula, generating significant tourism revenue.

Wildlife Viewing

Many tourists flock to seagrass areas in Akumal, Mexico to swim with green turtles, and to Marsa Alam in Egypt to snorkel and dive with dugongs. These charismatic megafauna depend on healthy seagrass habitats for their survival.

Birdwatching

In temperate areas, brant geese and numerous other birds attract birdwatchers to locations with seagrass meadows, such as the Solent in the United Kingdom and Puget Sound in the United States of America.

Coastal Tourism

The clear waters and biodiversity associated with healthy seagrass meadows enhance the overall appeal of coastal destinations, contributing to the broader tourism economy even when visitors aren't specifically aware of the seagrass itself.

The value of seagrasses for tourism and recreation is often not acknowledged, despite the vast indirect income they provide to such industries. Tourists may not realize they're benefiting from seagrass ecosystems when they enjoy activities in coastal areas, creating a disconnect between the economic value and public awareness.

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Cultural Identity and Heritage

1 Traditional Livelihoods

In many regions of the world, seagrass meadows represent a traditional way of life and identity for fishers and communities. They are directly associated with food and livelihoods that have sustained coastal populations for generations.

2 Spiritual Significance

From a religious perspective, the opercula of molluscs collected in seagrass meadows have been used to produce ceremonial incense. These cultural practices connect communities to the marine environment through spiritual traditions.

3 Archaeological Preservation

Seagrass deposits play a key role in preserving valuable underwater archaeological and historical heritage across the world, such as Roman and Phoenician shipwrecks, prehistoric settlement sites, and submerged ancient cities.

4 Historical Archives

Seagrass meadows constitute historical archives of human cultural development over time, with sediment layers containing artifacts and environmental information that help scientists reconstruct past human-environment relationships.

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Seagrass in the Fermentation Industry

Research Beginnings

Research in bioethanol production has been on the rise since 2000, with scientists exploring various aquatic plants as potential feedstocks. This includes freshwater species like water hyacinth and marine macroalgae such as Saccharina japonica and Ulva species.

Japanese Innovation

In 2014, scientists from Japan studied the possibility of using Zostera marina seeds to obtain fermented products containing ethanol at high concentrations. They processed eelgrass seeds following methods similar to those used in the manufacture of Japanese sake or rice wine.

Impressive Results

This innovative process allowed the production of 16.5 percent ethanol, which is stronger than most wines. The high starch content of seagrass seeds makes them particularly suitable for fermentation processes.

Future Potential

As Zostera marina is widespread in the northern hemisphere, it has potential to be utilized not only for biofuel but also by food and beverage industries. It could potentially be harvested as a sustainable crop, allowing for the development of a new marine fermentation industry.

Seagrass as Biochar

Seagrass Wrack Utilization

Seagrass wrack (washed up seagrass on coastal areas) can be beneficial for both terrestrial and marine ecosystems, as well as for humans. Rather than treating this material as waste, it can be transformed into valuable biochar with multiple applications.

The collection and processing of seagrass wrack provides a sustainable way to utilize material that might otherwise be removed from beaches as "waste," turning it into a resource with environmental benefits.

Biocharring Process

Biocharring is the process of converting biomass through thermochemical processes in an oxygen-limited environment to create a solid material with high carbon content. This process effectively locks carbon into a stable form that resists decomposition.

Seagrasses were found to have high conversion efficiency, which was comparable to high-quality terrestrial biochar products. This makes them an excellent candidate for biochar production, with potential applications in agriculture, water filtration, and carbon sequestration.

Biochar has recently gained recognition as a tool to enhance the sequestration of atmospheric carbon, thereby helping to mitigate climate change. The high carbon content and stable structure of biochar allows it to persist in soils for hundreds to thousands of years, effectively removing that carbon from the atmospheric cycle.

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Seagrass in Medicine

1. **Therapeutic Applications**
   Targeted treatments for diseases like lung cancer
2. **Nanoparticle Production**
   Green synthesis of bioactive compounds
3. **Eco-friendly Approach**
   Sustainable alternative to chemical synthesis
4. **Seagrass Extracts**
   Source of unique bioactive compounds
5. **Medical Need**
   Addressing cancer and infectious diseases

Despite promising achievements in pharmaceutical biotechnology and the development of new drugs, cancer and infectious diseases remain the main causes of mortality and morbidity worldwide. Green synthesis has been introduced as a simple, economically viable, and environmentally friendly alternative approach for the synthesis of nanoparticles.

In a typical green synthesis, biological compounds (such as plant extracts) act as both reducing and stabilizing agents, leading to the production of desirable nanoparticles with predefined features. The seagrass Cymodocea serrulata has proven to be a valuable bioresource for generating rapid and eco-friendly bioactive nanoparticles specifically for lung cancer therapy, opening new frontiers in marine-based medicine.