UNIVERSIDADE TÉCNICA DO ATLÂNTICO
INSTITUTO DE ENGENHARIA E CIÊNCIAS DO MAR

WEST AFRICAN SCIENCE SERVICE CENTRE ON CLIMATE CHANGE AND ADAPTED LAND USE

Master Thesis

ASSESSING THE ROLE OF SEAGRASSES AS A SOCIO-ECOLOGICAL SYSTEM:

A CASE STUDY FROM CAPE VERDE (GAMBOA BAY)

SEYDOUBA SOUMAH

Master Research Program on Climate Change and Marine Sciences

São Vicente
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Assessing the role of seagrasses as a socio-ecological system:

A case study from Cape Verde (Gamboa Bay)

Seydouba Soumah

Master's thesis presented to obtain the master's degree in Climate Change and Marine Sciences by the Institute of Engineering and Marine Sciences, Atlantic Technical University in the framework of the West African Science Service Centre on Climate Change and Adapted Land Use

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São Vicente
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Panel defense

President

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Examiner 1

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2021

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Dedication

I dedicate this work to the Almighty GOD who gave the strength and courage to accomplish this task, my wife, Mme SOUMAH Bintou Kaba, and my children Ousmane and Lancei SOUMAH. This work is also dedicated to my late mother, Madam SOUMAH Kadiatou Bangoura, who did all for my success; may her soul rest in perfect peace.

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I owe my wife and family; they were always a source of encouragement when all seemed lost. I also apologize to my children and my wife for being far away when they needed me. My sincere thanks go to my colleagues and all who contributed morally and materially towards realizing this work, and I am very grateful.

Resumo

Os ecossistemas marinhos são extremamente produtivos e altamente valiosos, com importância para a saúde global tanto do ambiente marinho como terrestre. No entanto, as alterações climáticas e a exploração intensiva dos recursos naturais têm impactos significativos nos ecossistemas oceânicos, incluindo as ervas marinhas. As ervas marinhas fornecem habitat e fontes alimentares essenciais para muitas espécies aquáticas. Embora cubram uma pequena porção da superfície do oceano, têm uma grande capacidade de sequestrar e armazenar carbono azul. A nível mundial, perderam-se áreas importantes dos ecossistemas de ervas marinhas, sem qualquer certeza para uma futura recuperação. Na África Ocidental, o conhecimento das ervas marinhas é ainda rudimentar, e a sua presença foi confirmada em apenas sete países. As alterações climáticas, combinadas com pressões antropogénicas directas, podem diminuir a resiliência das ervas marinhas para se adaptarem às condições em mudança, levando à sua degradação e subsequente perda de serviços ecossistémicos. O primeiro registo de ervas marinhas em Cabo Verde foi relatado em 2016 na baía de Gamboa, Praia, Ilha de Santiago; o único local documentado de um prado de ervas marinhas e conhecido como habitat e fonte alimentar para espécies marinhas. No entanto, o local está exposto à actividade humana, como o desenvolvimento costeiro, sem qualquer estudo que explore os impactos na saúde e estado das ervas marinhas. Este estudo visa avaliar e comparar o estado actual com o anterior dos prados de ervas marinhas em Gamboa e depois avaliar a percepção dos pescadores sobre as ervas marinhas. Foram utilizadas avaliações de campo para recolher e comparar parâmetros ecológicos, e foi utilizado um questionário para avaliar as percepções das partes interessadas. Os resultados do estudo mostram que parâmetros tais como cobertura total, biomassa, rizoma, e altura do dossel da espécie Halodule wrightii de ervas marinhas identificadas aumentaram, enquanto a densidade de rebentos diminuiu entre 2016 e 2021. A densidade real de rebentos é 5 vezes inferior à relatada em 2016, e a biomassa total é 1 vez mais do que a relatada em 2016. As dez (10) manchas de 20 m^2 registadas na altura alargaram-se a 6243 m^2. Os pescadores compreendem a importância do mar e estão conscientes da sua limpeza, mas não estão plenamente conscientes da existência de ervas marinhas, dos seus serviços ecossistémicos e não sabem como protegê-las. Se se pretende uma maior conservação e gestão das ervas marinhas, é necessário um ajustamento socioeconómico para fornecer orientações e informações que possam ter um impacto positivo nas actividades de conservação e gestão.

Plavras chaves: *Halodule wrightii*, Socio-ecologia, Percepções das partes interessadas

Abstract

The marine ecosystems are extremely productive and highly valuable, with importance for the overall health of both marine and terrestrial environments. However, climate change and intensive exploitation of natural resources have significant impacts on ocean ecosystems, including seagrasses. Seagrasses provide essential habitat and food sources for many aquatic species. Although they cover a small portion of the ocean's surface, they have a great ability to sequester and store blue carbon. Globally, important areas of seagrass ecosystems have been lost, with no certainty for future recovery. In West Africa, the knowledge of seagrasses is still rudimentary, and their presence has been confirmed in only seven countries. Climate change, combined with direct anthropogenic pressures, may decrease the resilience of seagrasses to adapt to changing conditions leading to their degradation and subsequent loss of ecosystem services. The first record of seagrass in Cape Verde was reported in 2016 at Gamboa bay, Praia, Santiago Island; the only documented site of a seagrass meadow and known as habitat and food source for marine species. However, the site is exposed to human activity such as coastal development, with no study exploring the impacts on seagrass health and status. This study aims to assess and compare the present to previous state of the seagrass meadows in Gamboa and then evaluate fishers' perception of seagrass. Field assessments were used to collect and compare ecological parameters, and a questionnaire was used to assess stakeholders' perceptions. The study results show that parameters such as total cover, biomass, rhizome, and canopy height of *Halodule wrightii* species of seagrass identified have increased, while the shoot density has decreased between 2016 and 2021. 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 ten (10) patches of 20 m^2 recorded then have extended to 6243 m^2. 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 how to protect them. If further conservation and management of seagrasses are intended, socio-economic adjustment is required to provide guidance and information that can positively impact conservation and management activities.

Keywords: *Halodule wrightii*, Socio-ecology, Stakeholders' perceptions

Abbreviations and acronyms

AGB	Above-Ground Biomass
BGB	Below-Ground Biomass
CBD	Convention on Biological Diversity
CFCs	Chlorofluorocarbons
CH4	Methane
CO2	Carbon dioxide
CO32-	Carbonate ion
EEZ	Exclusive Economic Zone
ESS	Ecosystem Services
EU	European Union
GDP	Gross Domestic Product
HCO3	bicarbonate
ITCZ	Intertropical Convergence Zone
IUCN	International Union for Conservation of Nature
N2O	Nitrous oxide
NDC	National Determined Contribution
OSCM	Ocean Science Centre Mindelo
S^2	Sulphate
SE	Standard error
SO_4^{2}-	Sulphide
SPSS	Statistical Package for the Social Sciences
USA	United States of America
UV	Ultraviolet
WAMER	Western African Marine Ecoregion

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1. Introduction

1.1 Background and context of the study

The marine ecosystems are extremely productive and highly valuable, with importance for the overall health of both marine and terrestrial environments. However, due to climate change and intensive exploitation of natural resources have significant impacts on ocean ecosystems, including seagrasses. Seagrasses are marine flowering plants found in all continents except Antarctica. They can be found from the intertidal to 90 m depth. They form habitats called seagrass beds or meadows and extend from a few square meters to hundreds of square kilometres. In general, 72 species of seagrasses in 6 families and 14 genera are widely distributed along temperate and tropical regions (Short et al., 2016).

Although they are relatively few compared to other marine or coastal organisms, their complex physical structure and high productivity can sustain significant diverse biomass of associated species. Their economic value is pretty significant and provides commercial subsistence catches such as prawns and fish (Short et al., 2016). Furthermore, seagrasses constitute a critical habitat and food source for many aquatic species, most often for breeding, and are also utilized as a part of their life cycle (Jones, 2001). They reduce the number of pathogenic bacteria that can cause disease in humans and marine organisms and can help improve the health of adjacent ecosystems, such as coral reefs (Hays et al., 2018). Seagrass can also be related to an extensive range of valuable ecosystem services that help mitigate and adapt to the effects of climate change, such as coastal protection, erosion control, and carbon sequestration. They can significantly influence the hydrodynamic environment by reducing current velocity, dissipating wave energy, and stabilizing the sediment (Ondiviela et al., 2014). There is now a growing awareness of seagrass blue carbon. Though they represent only a small area (0.2 % of the ocean's surface), it is estimated that seagrasses sequester and store 20 % of oceanic blue carbon (Short et al., 2016).

1.2 Problem statement

Seagrasses are of fundamental importance to human and are among the most valuable ecosystems on earth. Yet, the lack of data on their distribution for much of the globe has restricted scientists quantifying and understanding of their roles at global scales, but also regional and local (Hays et al., 2018). Despite recognizing the high ecological and socio-economic value of seagrass meadows, their biotopes are being lost globally at unprecedented rates (Hartog, 2014).

The global report of available seagrasses has found that 1.5 % of worldwide seagrass area was lost between 1980 and 2004, and the rate of loss has increased from 0.9 % to 7% per year before 1940 to 1990. Globally, about 29% of the earth's seagrass ecosystems have been lost (Waycott et al., 2009). In the past century, it was estimated that up to 50 % of all seagrass habitat had been lost along the developed east coast of the USA (Short et al., 2016). The possibility for future recovery in most areas is low due to loss of water clarity, severe coastal alterations, and unsustainable use (Short et al., 2016). Although there are still vast areas of seagrass in the world's nearshore environments, it has been revealed by Short et al. (2016) that they are among the world's most threatened ecosystems and are in accelerated decline due to coastal development, anthropogenic pressures of pollution, land cover change as well as direct physical impacts. A recent study has also revealed a global net loss of 5,602 km^2 of seagrass areas since 1880, with the most significant losses occurring in four bioregions, including tropical Atlantic, temperate Southern Ocean, temperate North Atlantic East, and tropical Indo-Pacific. Therefore, the decline was the slowest and most consistent in temperate Southern Oceans and Tropical Indo-Pacific (Dunic et al., 2021). They are the most threatened ecosystems on earth, with loss rates comparable to mangroves, coral reefs, and tropical rainforests (Waycott et al., 2009).

Anthropogenic pressures and natural threats at different spatial scales might be influencing their physiological, functional, and structural states. Climate change impacts, such as increased seawater warming, increasing storms, and sea-level rise, combined with the increasing population and unregulated coastal development, may result in such a fast rate of change that prevents seagrasses from adapting naturally and maintaining their status and consequently the provision of their services (Ondiviela et al., 2014).

The west coast of Africa is one of the least known areas for seagrasses in the world, and their distribution has not been extensively researched (Cunha et al., 2009). Their presence is confirmed in seven countries (ResilienSEA, 2019), where only three species are identified. The low level of awareness on their role and importance, threats to which seagrasses are subjected in the subregion are mostly human-induced, such as boat anchoring, some coastal bad finishing practices, and beach seining well as coastal development (Paulo et al., 2019). Therefore, to increase awareness, strengthen conservation strategies, and update the global seagrass map, there is a vital need for building local and regional research on seagrass ecosystems and then promote and incorporate their protection in local and regional policies.

1.3 Relevance and importance of the research

The knowledge of seagrasses in West Africa is generally limited. The latest research and awareness-raising activities occur in seven countries, including Mauritania, Senegal, Guinea Bissau, Cape Verde, Guinea Gambia, and Sierra Leone (Potouroglou, 2018; ResilisienSEA, 2019). The lack of information on seagrasses and their importance in the region have been cited in the literature and considered one of the key factors hindering the management of their ecosystem (Dewsbury et al., 2016; Ruiz-frau et al., 2017; Potouroglou, 2018).

The archipelago of Cape Verde comprises ten volcanic islands along with some islets in the eastern Atlantic Ocean. Lying within the Western African Marine Ecoregion (WAMER), the island is situated 570 km off the coast of Senegal. Cape Verde hosts one of the most critical nesting populations of the loggerhead turtle (*Caretta caretta*) globally, and is especially crucial for marine turtle conservation since five species live and feed in local waters (Marco et al., 2011). The first record of seagrass in Cape Verde was reported in 2016 by Creed et al (2016) in a wave-protected site between Gamboa and Ilheu Santa Maria, Praia, Santiago Island. The authors suggested that systematic surveys of the soft bottoms of the islands would result in further new records.

Gamboa Bay is the only documented site with seagrass meadow in Cape Verde constituting both habitat and food source for marine turtles and regarded appropriate to conduct applied research related to both climate change adaptation and mitigation. The area is prone to many anthropogenic activities, with no comprehensive assessment of how seagrass ecosystem services are perceived to vary among locals and no study exploring the actual state of seagrasses. For these reasons, it is therefore imperative to conduct research that explores the seagrass meadow's exact condition, help understand drivers that might influence the whole ecosystem, and the perceived knowledge of local communities about seagrass meadows in Gamboa Bay.

1.4 Research questions

1. What is the actual state of the seagrass meadow in Gamboa; species, coverage, above and below-ground biomass, shoot density, and canopy height?
2. What are the perceptions of fishers about seagrasses?
3. What are the pressures and threats that influence the health of seagrass meadows in Gamboa?

1.5 Aim of the research

The aim of the study is to characterize and compare the actual to the previous state of the seagrass meadows, assess local communities' perception, and identify the attributed impact to the seagrass meadows in Gamboa.

1.6 Specific objectives

1. Evaluate the actual state of seagrass found in Gamboa, their coverage, biomass, and shoot density.
2. Assess stakeholder’s (fishers) perceptions about seagrasses and their importance.
3. Identify the natural and anthropogenic impact on seagrasses and evaluate the implication of the impacts on sectors of economic importance, such as fisheries.

1.7 Structure of the work

The subsequent sections of this thesis are structured as follows:

The first section provides the background, problem, and relevance of this study. It also highlights the aim and objectives of this study as well as research questions. The second section reviews literature that describes the key concepts about seagrasses, debates, controversies, and gaps in existing knowledge. The third section describes the detailed methods used for the collection of data to achieve the objectives of the present study; the fourth section presents the results of the study and discusses them in the fifth section. The last one (sixth section) summarizes the findings, concludes, and suggests recommendations based on the results.

2. Literature review

This section gives a synthesized overview of seagrass distribution, environment, structure, growth and reproduction, services and benefits to humans, threats and resilience, and management and conservation practices.

2.1 Overview

The marine ecosystems are extremely productive and highly valuable, with importance for the overall health of both marine and terrestrial environments. However, global environmental modification due to climate change and intensive exploitation of natural resources have significant impacts on ocean ecosystems, including seagrasses. Seagrasses are marine flowering plants found in all continents except Antarctica, from the intertidal to 90 m depth. They form habitats called seagrass beds or meadows and extend from a few square meters to hundreds of square kilometers (Short et al., 2016). Its name is wholly descriptive, as is the name seaweed for marine algae (Newmaster et al., 2011). Their habitat can be patchy or composed of continuous vegetation (Cornelis den Hartog, 2016). Seagrasses are closely related to plants on land and probably evolved from land-living angiosperms (flowering plants) millions of years ago. They are not true grasses but rooted vascular (flowering) plants of terrestrial origin that have successfully returned to the sea (Björk et al., 2008). This return needed several adaptations that allowed them to live in submerged ocean regions. Their ecosystems are highly productive and dynamic (Björk et al., 2008).

The services provided by global coastal ecosystems are affected by a wide variety of anthropogenic activities. Particularly, seagrasses are adversely affected by impacts resulting from billions of people living within 50 km of a seagrass meadow. In the form of nutrient cycling, fish productivity enhancement, habitat provision for fish, waterbirds, and invertebrate species, and being and a significant food source for endangered species, such as dugong, manatee, and green turtle, the ecosystem services provided by seagrasses are estimated as $1.9 trillion per year. They are crucial for marine species, ecology, and the geomorphology of coastal ecosystems. Currently, they are facing many threats, mainly induced by humans (Björk et al., 2008). Three (3) of the 72 total seagrass species are considered to be endangered, and ten (10) other species are at elevated risk of extinction (Cornelis den Hartog, 2016).

2.3 Seagrasses distribution

2.3.1 Global distribution and extent of seagrasses

Seagrasses are widely distributed along temperate and tropical coastlines of the world, and they have vital ecological roles in coastal ecosystems and can form extensive meadows supporting high biodiversity. Based on tropical and temperate influences, species assemblages, and distributional ranges, seagrasses are found in six bioregions, including two tropical regions and four temperate (Fig. 1) (Short et al., 2007). The tropical bioregions include the Tropical Atlantic and the Tropical Indo-Pacific. In contrast, temperate bioregions include the Temperate North Atlantic, the Temperate North Pacific, the Temperate Southern Oceans, and the Mediterranean. Both of the two tropical bioregions support mega-herbivore grazers, including sea turtles and sirenian (sea-cows) (Short et al., 2007).

In terms of seagrasses' global extent, extrapolation is sometimes used to quantify the global dimension of seagrasses in the areas limited by seagrass mapping efforts in turbid water systems and some geographic regions with less attention from the scientific community. Based on recorded sites and considering additional unmapped meadows in Waycott et al. (2009), the total area of seagrasses was 177,000 km^2. This estimate of the total seagrass area is deemed to be poorly resolved. Seagrasses occur in 159 countries and cover over 300,000 km^2, making them one of Earth's most widespread coastal habitats (UNEP, 2020).

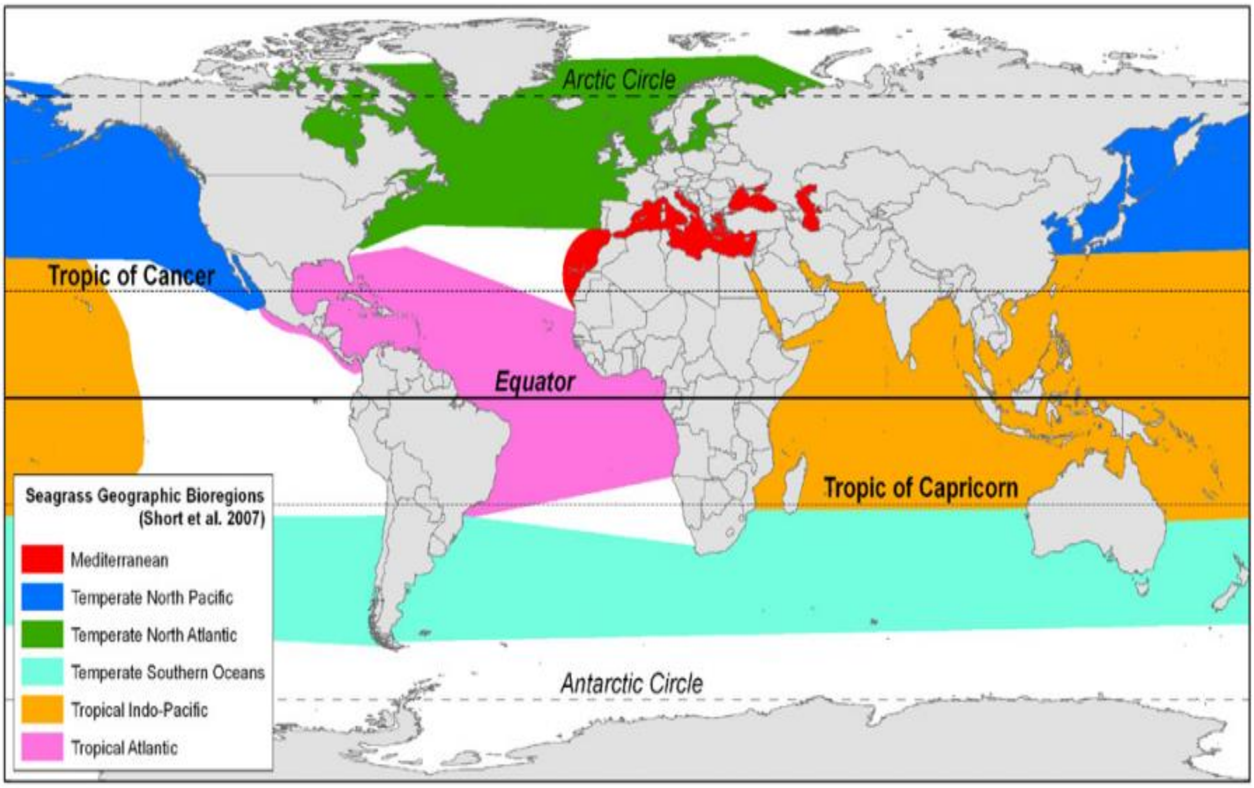

Figure 1: The six-seagrass specific geographic bioregions from Short et al (2007)

The Tropical Atlantic: has ten (10) seagrass species, including one recent invasive species (Table 1), and is occupied mainly by three species such as *Thalassia testudinum, Syringodium filiforme,* and *H. wrightii* predominant in the western tropical Atlantic such as the

Gulf of Mexico and the Caribbean Sea. These species often occur intermixed or sequentially in ecological succession and can also be in single-species stands (Green et al., 2004). Several species of Halodule, such as *Halodule bermudensis,* are also revealed for this region, but the taxonomy description is still unclear (Short et al., 2007). The region is predominantly a carbonate environment and has clear water with a high diversity of seagrasses on reefs and shallow banks dominated by *Thalassia testudinum* (Short et al., 2007). The west coast of Africa has only *H. wrightii* which extends from the Mediterranean Bioregion and *C. nodosa* and *Z. noltii* (Short et al., 2007).

The Tropical Indo-Pacific: is a vast tropical region extending from the east coast of Africa to the eastern Pacific Ocean. This region inhabits more seagrass species than any other region. In this region, 24 species of seagrasses have been identified, of which three (3) species have their center of distribution in an adjacent region (Table 1)) (Short et al., 2007). Seagrasses are found on coral reef flats in many parts of the region between the reef break and shore. Species such as *Thalassia hemprichii*, *Syringodium isoetifolium,* and *Halodule unnerves* dominate reef platforms (Short et al., 2007). These species are found throughout two-thirds of the western region, with *Cymodocea rotundata* and *Cymodocea serrulata* common in the same area. Most tropical seagrasses species are found in water less than 10 m deep (Green et al., 2004). Species of the genus Halophila are found in a range of habitat types, from shallow estuarine environments to very deep clear water. They are shared throughout the Tropical Indo-Pacific, with *H. decipiens* reaching 58 m in the Great Barrier Reef (Chin, 2005). Seagrasses such as Halophila *spinulosa, H. ovalis, Halophila tricostata*, and *Halophila Capricorn* are below 35 m depth (Coles et al., 2015). At the western edge of the Tropical Indo-Pacific bioregion, H. stipulacea has been reported to exist at 70 m depth in the Red Sea. The western Tropical Indo-Pacific is characterized by high seagrass diversity, including the currently identified 12–14 species for the tropical areas of the Indian Ocean. Most of them are known to exist on the southeast coast of India, the Red Sea, and eastern Africa, with some species in the Persian Gulf (Jagtap, 1996).

Temperate North Atlantic: in the Atlantic, this bioregion extends from USA North Carolina to Norway, Greenland, and along the coastlines of Europe south to Portugal. This bioregion inhabits *Z. marina* found in vast intertidal areas to depths of 12 m in clear ocean water (Short et al., 2007). This species occurs in most marine soft-bottom environments, including lagoons, estuaries, and shallow coastal areas with good water clarity (Short et al., 2007).

Seagrass species assemblage in this region is not always clearly differentiated between temperate and tropical regions because two of the region's five species are found in the southern boundaries (Table 1) (Short et al., 2007). For example, *Z. marina* occurs intermixed with *Halodule wrightii*, a tropical species, at the southern end of its temperate range on the east coast of the USA in North Carolina (Fonseca, 1984). While the species tends to form broad mono-specific stands in the north temperate oceans, and *C. nodosa* grows intermixed with temperate seagrasses in Portugal (Short et al., 2007). In this region, Eelgrass was severely impacted in the 1930s by the wasting disease, with a sporadic, localized recurrence observed again in the 1980s. Most of these affected areas are now repopulated except regions of poor water clarity (Burdick et al., 1993).

Temperate North Pacific: This Bioregion has 15 species of seagrass, of which four (4) species occur only at the region boundary. Three temperate genera of seagrasses dominate this region and include *Zostera*, *Ruppia*, and *Phyllospadix* (Table 1) (Short et al., 2007). Species of *Zostera* are centered in east Asia, and *Zostera caulescens* was reported to have reproductive shoots reaching 7.8 m in length in Japan and 8 m in Korea (Green et al., 2004). *Z. marina (*Eelgrass*)* is known to occur throughout the Pacific Rim from Japan, Korea, and China to the northern Bering Sea as well as down to the Gulf of California. It is also reported to occur in Alaska nearby the Arctic Circle and is known to grow under the ice (McRoy et al., 1969). In this bioregion, Eelgrass grows to approximately 10 m depth, with other species of *Zostera* found at more limited or deeper depth ranges. For example, Z. *caulescens* and *Zostera caespitose* are respectively found at the depth reaching 17 and 20m deep. Species such as *Phyllospadix* are found at both west and eastern sides of the Pacific. Two species occur in Asia and three (3) species in North America, all having a modified rhizome that allows them to grow exposed coasts and attached to rocks in the high-energy surf zone (Short et al., 2007).

Mediterranean: this bioregion has nine (9) seagrass species, with two species occurring only at the boundary of the region (Table 1). Species such as *P. oceanica, Z. marina*, *Z. noltii*, and *C. nodosa* form single species meadows as well as *H. stipulacea*, known as an invasive species to the region (Short et al., 2007). This region is characterized by deep beds of *P. oceanica* reaching up to 45 m and 30–40 m depth for *C. nodosa* (Green et al., 2004). Although *H. stipulacea* is known to be rare below 50 m, the species was reported to be collected from 145m depth by dredge off Cyprus and is the known deepest documented seagrass in the world(Ruı, 2009). On the open coast of France, Italy, Spain, and also in the Adriatic Sea in the Mediterranean, *Z. marina* is present frequently grows in coastal lagoons of the western Mediterranean (Laugier et al., 1999), where it often occurs with *Z. noltii*. The association of, both temperate–tropical mix species, makes the bioregion unique with endemic species such as *P. oceanica* mostly known in the temperate, and *C. nodosa* from Tropical Indo-Pacific bioregion both occurring around the entire Mediterranean. These species as well as *H. wrightii* and *H. decipiens* are found on the northwest coast of Africa within and out of the Mediterranean Sea. The Canary Island also inhabits *C. nodosa and H. decipiens* (Short et al., 2007)

Temperate Southern Oceans: This bioregion accounts for a total of 18 species, from which four (4) species only occur at the region's boundaries (Table 1). Seagrasses exhibit a wide range of biotopes in this region, including surf zones. In this circumpolar region, species such as *Zostera* and *Ruppia* occurs on all continent including South America, Africa, and Australia. *R. maritima* collected from Straits of Magellan by Lucia Mazzella is reported to be the southernmost seagrass in the world. Across the Indian Ocean part of South Africa, tropical species such as *H. ovalis* and *T. ciliatum* occur, while species such as *Zostera capensis* and *Ruppia spp.* Populate temperate southern Africa (Short et al., 2007). The temperate–tropical distinction is helpful in considering seagrass species distribution, and the exceptions of species emigrating into neighboring regions are likely driven by thermal anomalies or propagule dispersal resulting from ocean circulation patterns (Short et al., 2007).

The same number of temperate and tropical seagrass genera as well as species are revealed to exist, and the global distribution of seagrasses genera is reported to be coherent between the two hemispheres. The north and south hemispheres share the seagrasses genera and have each one unique seagrass genus. According to F. Short et al. (2007), some genera are more species than others, and the *Halophil*a genus is known to be the most species of seagrass. The identification of seagrasses bioregions around the ocean is established under the species distribution sustained by the diversity of their genetic pattern. This bioregion establishes a foundation that helps in interpreting ecological, physiological, and genetic results collected in specific locations or from particular species. The difference between temperate–tropical is very important to consider when dealing with seagrass species distribution. The fact of some species migrating into neighboring regions is reported to be driven by temperature anomalies or propagule dispersal due to ocean circulation patterns. Since the Paris agreement has required National Determined Contribution (NDC's) to reduce emissions, this has attracted increased global concern on the spatial extent, loss, and restoration of seagrass meadows. The recent global extent of seagrass meadows estimated by McKenzie *et al.* 2020 extends with Moderate to high confidence to 160,387 km^2 across 103 countries with a separate estimate of 106,175 km^2 mapped with low across another 33 countries (Mckenzie et al., 2020).

Table 1: global seagrasses bioregion, description, and species in temperate and tropical areas from Short et al. (2007)

Bioregion	Description	Species
1-**Temperate North Atlantic** (North Carolina, USA, to Portugal	Low diversity temperate seagrasses (5 species) primarily in estuaries and lagoons	*Ruppia maritima, Zostera marina, Zostera noltii, Cymodocea nodosa+, Halodule wrightii+*
2-Tropical Atlantic (including the Caribbean Sea, Gulf of Mexico, Bermuda, The Bahamas, and both tropical coasts of the Atlantic)	High diversity tropical seagrasses (10 species) growing on back reefs and shallow banks in clear water.	*Halodule beaudettei, H. wrightii (H. bermudensis, H. emarginata), Halophila baillonii, Halophila decipiens, Halophila engelmanni, Halophila johnsonii, R. maritima, Syringodium filiforme, Thalassia testudinum, Halophila stipulacea+*
3-Mediterranean (including the The Mediterranean Sea, the Black, Caspian and Aral Seas and northwest Africa)	Vast deep meadows of moderate diversity and a temperate/tropical mix of seagrasses (9 species) growing in clear water.	*C. nodosa, Posidonia oceanica, Ruppia cirrhosa, R. maritima, Z. marina, Z. noltii, H. wrightii+, H. decipiens+, H. stipulacea+*
4- Temperate North Pacific (Korea to Baja, Mexico)	High diversity of temperate seagrasses (15 species) in estuaries, lagoons, and coastal surf zones.	*Phyllospadix iwatensis, Phyllospadix japonicus, Phyllospadix scouleri, Phyllospadix serrulatus, Phyllospadix torreyi, R. maritima, Zostera asiatica, Zostera caespitosa, Zostera caulescens, Zostera japonica, Z. marina, H. wrightii+, H. decipiens+, Halophila euphlebia+, Halophila ovalis+*

5-Tropical Indo-Pacific (East Africa, south Asia and tropical Australia to the eastern Pacific)	Most extensive and highest diversity bioregion; tropical seagrasses (24 species) predominantly on reef flats but also in deep waters, many commonly grazed by mega-herbivores.	*Cymodocea angustata*, *Cymodocea rotundata, Cymodocea serrulata*, *Enhalus acoroides, Halodule pinifolia, Halodule uninervis, H. wrightii, Halophila beccarii, Halophila capricorni, H. decipiens, Halophila hawaiiana*, *Halophila minor, H. ovalis, Halophila ovata, Halophila spinulosa, H. stipulacea, Halophila tricostata, R. maritima, Syringodium isoetifolium, Thalassia hemprichii, Thalassodendron ciliatum, Zostera capensis+, Z. japonica+, Zostera muelleri+ [Zostera capricorni]*
6-Temperate Southern Oceans (New Zealand and temperate Australia, South America, and South Africa)	Extensive meadows of low-to-high diversity temperate seagrasses (18 species) often growing under extreme conditions.	*Amphibolis antarctica, Amphibolis griffithii, Halophila australis, Posidonia angustifolia, Posidonia australis, Posidonia ostenfeldii complex*, *Posidonia sinuosa, R. maritima, Ruppia megacarpa, Ruppia tuberosa, Thalassodendron pachyrhizum, Z. capensis, Z. muelleri [Z. capricorni], Zostera tasmanica [Heterozostera tasmanica], H. decipiens+, H. ovalis+, S. isoetifolium+, T. ciliatum+*

Notes: *species of seagrass that center of distribution is in an adjacent bioregion or invasive to a bioregion are marked with a "+." These in brackets are conspecific with the preceding species. Species listed in parentheses require further genetic and morphometric investigation and may be conspecific with the preceding species.*

2.3.2 Seagrasses distribution in West Africa

West Africa has been reported as one of the least known regions for the occurrence of seagrasses in the world. The publications about seagrasses in the region are only available for Mauritania (Cunha, 2009). The knowledge of seagrasses meadows is still rudimentary on the west coast of Africa. Now, their presence is confirmed in seven countries, Mauritania, Senegal, Guinea Bissau, Guinea, Sierra Leone, Gambia, and Cabo Verde, with the occurrence of three species such as *Halodule wrightii*, *Cymodocea nodosa,* and *Zostera noltii* (Potouroglou,2018; ResilisienSEA, 2019)**;** and this lack of information on seagrasses and their importance in the region have been cited in the literature and considered as one of the key factors hindering the management of their ecosystem (Dewsbury et al., 2016; Ruiz-frau et al., 2017).

2.4 Structure of seagrasses

Seagrasses have similar organs and tissues as the other flowering plants. As most of the mature flowering plants, seagrasses have distinctive above and below-ground parts. Above ground, parts are mainly made up of shoots bearing leaves. A leaf most often has a basal sheath that protects the apical meristem and develops leaves and a distal blade to produce food by photosynthesis and release water vapor through transpiration. Below ground parts, however, consist of roots to anchor and rhizomes/stems to mechanically support seagrass (Antony et al., 2007). Seagrasses' complex physical structure and high productivity of ecosystems permit them to support considerable biomass and diversity of associated species. According to Short et al. (2016), there are 72 seagrass species in 6 families and 14 genera. Most of them have flattened leaf blades except the genus Syringodium in the family of *Cymodoceaceae* (Fig 2A) and some *Phyllospadix* in family *Zosteraceae* (Fig 2B), which both have cylindrical leaves and elongated or strap-like leaves except the genus *Halophila* in the family *Hydrocharitaceae* (Fig 2C). They all have an extensive system of roots and rhizomes. The only and unique lineage of seagrass species with small paddle-shaped blades and most often in pairs is the genus *Halophila*.

Even though they are similar in terms of structure, seagrasses widely vary in size and productivity. Some may have their canopies extended to several meters into the water column and others to only a few centimeters above the sediment surface. The below-ground part, such as roots and rhizomes, may also penetrate at different depths in the sediments depending on the genera (Nordlund et al., 2016). Therefore, this difference in its structure, especially its productivity and size, may influence important ecosystem services such as sediment accretion and stabilization, coastal protection, and nursery habitats.

Figure 2:photographs showing seagrasses genius, Syringodium (A), Phyllospadix (B), and Halophila (C)

2.5 Seagrass environment

Even though life in the aquatic environment largely differs from the terrestrial environment, the basic requirements for seagrass growth are similar to that of terrestrial plants. Seagrasses' habitats or ecosystems are made up of both biotic and abiotic components. Biotic components consist of all living things in an ecosystem, while biotic factors are inorganic things that affect the living organisms of an ecosystem. The biochemical and physical properties of the environment in which seagrasses live control their growth and distribution. However, inorganic carbon, sufficient light, and nutrients are of a fundamental need for development. Moderate exposure to waves, temperature, salinity, substratum, and several biological factors affect seagrasses distribution. The interaction of these factors, which is said to be complicated, makes it difficult to predict the presence or distribution of seagrasses at a given time and place by separating only the effects of single elements (Greve et al., 2004).

2.6 Biotic and abiotic factors controlling seagrass growth

Several environmental parameters determine the distribution of seagrass meadows. These parameters include conditions that regulate the morphology and physiological activity of seagrasses known as biophysical conditions. Conditions that retard available plant resources, such as excess nutrients and sediment loading, are often driven by human-induced influences. In addition, biologically managed parameters are seeds availability and vegetative fragments. Therefore, the combined effect of these parameters allows, encourages, or puts an end to seagrass in a given location (Hartog, 2014).

2.6.1 Abiotic factors controlling seagrasses growth

Light availability

For many seagrasses species, light is one of the critical factors that regulate their maximum depth distribution. This is why seagrasses are often found in shallow coastal waters where sunlight is available enough to support their growth. The quantity and quality of light available for photosynthesis are directly related to seagrass growth and survival (Greve et al., 2004). Compared to marine phytoplankton, seagrasses have a high minimal light requirement because the light compensation point of the plants differs from one species to another and also depends on factors such as temperature and sediment chemistry. Seagrasses minimum light requirement does not fit all seagrasses species at all times, and also, these found in turbid waters have higher light requirements than those found in more transparent waters. Some species' minimum average light requirement is about 10% of surface irradiance. For example, species such as *Z. marina*, *C. nodosa*, and *P. oceanica* have specific morphologic acclimatization within the range of irradiance seagrasses can exist to capture light for photosynthesis. Seagrasses prolong their leaves and thin their shoots when light levels reduce to capture light in the acclimatization process. While, species such as *Z. noltii*, which inhabit the intertidal area where sufficient is provided, rarely show this acclimatization (Greve et al., 2004). The range and productivity of seagrasses are restricted by both the depth and clarity of the water column since they are typically light-limited plants (Reidenbach et al., 2018).

Factors affecting water column and sediment can affect the amount of light reaching the water bottom and decrease plant photosynthetic efficiency. Reduced photosynthetic activity diminishes oxygen translocation to underground tissues and the rhizosphere. This declines seagrass abundance because belowground tissues undergo anaerobic conditions and deplete carbohydrate reserves. Several studies have shown that an increase in nutrient loading increases the loading of chlorophyll-a concentration which in turn reduces light availability for seagrasses and affects their growth (Congdon et al., 2003). According to Choice et al. (2014), light requirements for *Halophila engelmannii* range from 8% to 10% of surface irradiance and 25–27% of surface irradiance for *Halodule wrightii*. The relationship between increased nutrients loading, eutrophication, reduced light availability have detrimental impacts on seagrasses. Therefore, understanding the light requirements of seagrasses improved the management of seagrass ecosystems for managers of coastal systems.

Temperature

Temperature is one of the important abiotic factors that influence seagrass productivity. All biological processes are affected primarily by increasing reaction rates of the biochemical pathways due to temperature. Processes such as photosynthesis and respiration are slow at very low temperatures and increase when the temperature increase. A negative energy balance within the plant occurs when respiration exceeds photosynthesis due to high temperatures. Although some adaptation to the local temperature regime is possible, temperature determines the geographical boundaries for growth. Seagrass species have different temperature tolerance; for example, *Z. marina* is generally adapted to relatively cold habitats with temperatures ranging between -1ºC in winter and approximately 25ºC in summer. *C. nodosa* and *P. oceanica* grow in warmer environments with temperatures ranging from approximately 10ºC to about 30ºC (Congdon et al., 2003).

The distribution and abundance of seagrasses are controlled by physiological tolerances, which result in fluctuations in species density and composition (Congdon et al., 2003).In general, temperatures exceeding 25°C adversely impact temperate seagrasses, and those above 43°C may affect tropical seagrasses. The predicted increase in global temperature is said to impact the Earth's oceans significantly. A direct effect of increased global temperature on seagrasses will be the impact on growth rates and other physiological functions, making seagrasses shift in terms of distribution due to increased stress of temperature and changes in the patterns of sexual reproduction. Another effect of temperature may include the changes in plant community due to increased changes in the frequency and intensity of extreme weather events and eutrophication (Frederick T Short et al., 1999).

Salinity

Salinity is part of causative agents that affect the growth and distribution of seagrasses, and it can affect the osmotic pressure in the cells. However, many seagrasses are well used to sudden changes in salinity. They are known to grow at salinities ranging between 5 ‰ and 45 ‰. For example, they can grow in the estuarine habitats, where salinity rapidly changes and varies significantly with time. Seagrasses species have different salinity tolerance, and some are tolerant to changes in salinity than others. *Z. marina* and *Z. noltii* are often observed in estuaries, and *Z. noltii* also occurs in intertidal areas, the zone where, within a few hours, changes in salinity can vary from only a few ‰ to more than 30 ‰. Species such as *C. nodosa* inhabits more saline water varies from 26 - 44‰, and P. oceanica is only found in areas with high salinities.

The unusual increase in salinity above the mean values (33-36 ‰) is due to desalinization or intense evaporation from shallow areas. Therefore, the increased salinity value up to 60 ‰ is said to severely affect seagrasses in shallow areas (Greve et al., 2004). The seagrass model developed by Fong and Harwell (1994) and modified by Bay et al. (2003) indicated that freshwater inputs and related decreases in nearshore areas salinity influence the distribution and growth of single species and limit competitive interactions to allow species replacements. High tolerance of *H. wrightii* to salinities (5–80‰) is reported in several studies that documented the correlations between salinity and seagrass distribution, concluding *Halodule wrightii* high tolerance to low salinities. For that reason, it can colonize nearshore areas influenced by canal discharge (Bay et al., 2003).

Physical exposure

Some of the essential factors that control the upper depth limit for seagrass distribution are current wave and tide action. Generally, seagrasses are estimated not to exist on very exposed shores or at a current flow velocity higher than 1.5 m/s (Greve et al., 2004). Sediment transport and resuspension due to current and wave action prevent seagrass growth and distribution. The resuspension affects the light state in the water column, and erosion can expose roots and rhizomes, causing the seagrasses to detach from the sediment (Greve et al., 2004). Currents, wave, and tide action are the most critical factors controlling the upper depth limit for seagrass distribution. However, some species such as *Posidonia and Cymodocea* with vertical shoots survive in high sediment areas by elongating their vertical shoots. In addition, powerful currents or wave action may disturb entire plants and prevent the establishment of new shoots (Greve et al., 2004). Even though the indirect effect of wave and ocean current affect seagrass growth, coastal or estuary waters in which they grow undergo complex hydrodynamics, including both wind-driven wave motions and tide-driven currents.

Seagrasses have also been said to reduce current velocities and oscillatory flows, impacting the flow structure both within and above the canopy. They are known to minimize sediments suspension because of their ability to modify flow due to their plant structure and the stabilizing effect of the root structure. This improves light availability at the seafloor and increases primary productivity, a process known as positive feedback (Reidenbach et al., 2018).

Substratum

While macroalgae grow attached to rocks and stones on the seafloor, seagrasses are mainly found in soft substrates of gravel, sand, or mud, where rhizomes can elongate, and roots can fasten. This makes a suitable substratum an essential factor in the seagrass's environment. For example, *Zostera marina*, *Z. noltii,* and *C. nodosa* can be found on gravel and in mud rich in organic matter. However, some species such as *P. oceanica* are often found in more coarse sediments, and some beds of seagrasses can also be found on rocky substrates (Greve et al., 2004).

Oxygen availability

Like all vascular plants, seagrasses are obligate aerobes that need a regular supply of oxygen for aerobic metabolism of both above and below-ground tissues (Greve et al., 2004). Seagrass roots and rhizomes may undergo a short time deprivation of oxygen. However, these tissues exhibit physiological adaptations that rely on periodic anaerobic fermentative metabolism (Borum et al., 1989). For the metabolism of both above and below ground tissues, seagrasses are required to supply oxygen. Seagrasses leaves are often in the oxygenated water column, while roots and rhizomes are buried in anoxic sediments (Borum et al., 1989). In normal conditions or a well-designed system of air tubes (lacunae) running through the plant, a simple diffusion from the leaves to the roots assure the transport of photosynthetically water column oxygen to roots and rhizomes (Greve et al., 2004). Because of the degradation of organic matter within the sediment and slow oxygen diffusion from the water column, coastal marine sediments are highly reduced and mostly anoxic (Borum et al., 1989).

In the condition of high degradation of organic matter in the sediment combined with stratified water availability, the underground tissue may lack oxygen and produce toxic substances if the water column is hypoxic or anoxic (Greve et al., 2004). This condition, in turn, affects the belowground tissue and could trigger an invasion of sulfide from the sediment and affect the metabolism of the plants leading to poor energy. All these negatively affect plants' growth and survival (Greve et al., 2004).

Nutrient availability

Lack of nutrient availability affects seagrasses' population structure and dynamics mainly through changes in their architecture, morphology, and mortality (Cabaço et al., 2013). Seagrasses are known for their difference in the level of inorganic nutrients, where nitrogen and phosphorous constitute the most important. Unlike other aquatic organisms such as macroalgae and phytoplankton, seagrasses have low nutrient requirements given the advantage to grow in poor nutrients biotopes than other primary producers. Seagrass requirement in nitrogen and phosphorous per weight is estimated to be about four (4) times less than this of phytoplankton cells. Generally, in the Mediterranean, where seawater is warmer, the water column nutrient levels of seagrass beds are very low (Greve et al., 2004). Because of the mineralization of organic matter, most sediments are known to be rich in nutrients. Therefore, seagrasses can also take up nutrients from the sediment in addition to the uptake of nutrients from the water column. Deposits such as carbonated ones bind phosphorus and induce phosphorous limitation to plants, and species of *Posidonia oceanica* and *C. nodosa* often grow on carbonate sediments (Greve et al., 2004).

Studies have also revealed that low nutrient concentrations can reduce the growth of plants. *Zostera marina* and *Z. noltii* usually grow in organic sediments and are rarely limited by nutrients (Greve et al., 2004). Experimental studies such as Hughes et al. (2004) showed that additions of inorganic nutrients to sediments generally stimulate seagrass growth and suggested nutrient limitation of plant production. However, high nutrient regimes lead to the build-up of organic matter, which may create unfavorable conditions to seagrasses, such as sediment anoxia or sulfide toxicity; and decrease seagrass growth and survival due to excessive growth of epiphytes, macroalgae, and phytoplankton under high nutrient loads (Hughes et al., 2004). The direct effects of nutrient toxicity on seagrass survival and development have also been revealed by several studies and are considered as the significant factors causing seagrass decline worldwide (Cabaço et al., 2013).

Carbon

In addition to light and other inorganic nutrients, seagrasses also need inorganic carbon for photosynthesis. Inorganic carbon in water exists in three forms depending on the water pH. It exists as carbon dioxide (CO_2), bicarbonate (HCO_3), and as carbonate ion (CO_3^{2-}). During the process of photosynthesis, seagrasses assimilate both CO_2 and HCO^3. Carbon limitation is more likely at high pH due to high rates of photosynthesis in shallow waters (Koch. Evamaria et al., 1996). This limitation is also more noticeable in estuaries that are supplied with freshwater poor in inorganic carbon contents such as the Baltic Sea, and the increase in atmospheric CO_2 could have even greater impacts (Greve et al., 2004).

Therefore, seagrasses may profit from the ongoing increase in global atmospheric carbon dioxide caused by the profound use of fossil fuels because of lower ocean pH and increase in the availability of inorganic carbon for photosynthesis (Koch et al., 1996). However, it is still not well understood to what extent inorganic carbon is transferred from sediment through roots and plant lacunae to seagrass leaves. This raises the need for further examining the importance of carbon limitation to seagrass photosynthesis and growth (Greve et al., 2004).

Sulfide

Sulfide (SO_4^2-) is a plant toxin that restrains respiration, and Sulfide existing in sediment, is poor in iron, and is rich in organic matter. High concentrations of sulfide in the sediment can affect seagrasses. It is oxidized in the root zone to the harmless compound of sulfate (S^{2-}) before reaching the root surface. In oxygen-deficient conditions in the water column, the supply of oxygen will be inefficient, causing root anoxia and sulfide invasion (Zieman et al., 2005). The penetration of gaseous sulfide to the lacunae can spread it and reach the meristem, where it might be lethal to the plant (Greve et al., 2004).

Therefore, in the presence of iron in the sediment, iron reacts with the sediment sulfides and precipitates them as iron-sulfur minerals and thereby "buffer" the effects of toxic sulfides on the seagrasses (Borum et al., 2004).

2.6.2 Biotic factors controlling seagrasses growth

Other biological organisms, including plants and animals, may cause beneficial and harmful effects on seagrasses. Competition and other complementary nature occur when plants and another organism grow together. This competition happens when plants are closely spaced and demand nutrients, the sunlight when they are in short supply (Singh, 2020).

2.7 Interaction with epiphytic organisms and grazers

The available surfaces in all aquatic environments are rapidly colonized by a variety of organisms that grow on the plant's surface and, known as epiphytes. These epiphytes are integral components of seagrass ecosystems and seagrass constituents, an excellent substratum for these organisms (Borowitzka et al., 1999). The aboveground sides of seagrasses are usually populated by a variety of epiphytic organisms' part of which many species of algae forms size from macroalgae. Seagrasses leave, and stems give these algae a suitable ground to attach and grow the diversity of algae species. Leaf shape also plays a role in epiphyte distribution, and flat-leaf surfaces species carry similar epiphyte communities on both sides, whereas, in the curved shape species, the concave side of the curved leaf supports a more diverse epiphytic community than the convex side (Trautman et al., 2014).

Seagrasses growth and distribution are affected by these organisms primarily via competition or herbivory, and the development of epiphytes and filamentous algae in high densities, which affect light availability, and then seagrasses depth distributions are caused by high loading of nutrients in the water column (Greve et al., 2004). Epiphyte organisms enlarge the boundary layers around leaves and limit the uptake of inorganic carbon, oxygen, and nutrients. Organisms such as filamentous algae could also form dense mats at the seafloor which reduce water flow around the leaves and reduce the oxygen content in the water once degraded (Greve et al., 2004).

Competition and grazing are the most important biotic factors affecting seagrasses growth and distribution (Borum et al., 2004). Seagrasses generally compete with epiphytes and algae for nutrients, and the most common grazers of seagrasses leaves are sea urchins, fish, waterfowl, as well as green turtles, the only reptile that consumes important quantities of seagrass (Lyimo, 2016). Some marine mammals such as manatees and dugongs also feed on seagrass (Borum et al., 2004). In general, the importance of grazing on seagrasses is considered to be relatively low, and grazers control epiphytes biomass either by direct removal of biomass or indirectly via removal of host substrate (Borowitzka et al., 1999).

2.8 Seagrasses growth and reproduction

Seagrasses are known to reproduce clonally and sexually, and the contribution of these two reproduction methods may rely on environmental regimes. The widely distributed species of seagrass in the northern hemisphere, *Zostera marina,* is said to form both annual and perennial meadows with different proportions of sexual versus clonal propagation depending on the environmental disturbance condition (Paulo et al., 2019). Seagrasses reproduce via asexual clonal growth or by sexual reproduction, and their growth is both horizontal and vertical. They capture sunlight and nutrients from the water column and sediment through their blades that extend upwards and the roots down and sideways. Seagrass colonizes and maintains the meadow by establishing patches from seed germination and plant fragments, as well as clonal growth. Vegetative growth is the main process for seagrasses to colonize space, and thus it is a critical mechanism for seagrass meadows to spread and persist (Duarte et al., 2004).

Environmental factors affecting successful plant establishment include disturbance and stress. Catastrophic disturbances may affect and change seagrass cover and trigger energy allocation into sexual reproduction (Paulo et al., 2019). Unlike clonal reproduction, which constitutes the major mode of space occupation for many seagrasses under some environmental conditions, sexual reproduction is known to be very important in community persistence and recovery from disturbances (Paulo et al., 2019). Yue et al. (2020) showed that *Zostera japonica* species adapt and maintain their population through different reproductive strategies, including both sexual and asexual reproduction.

2.9 Natural and human-induced disturbances

Although seagrasses conservation is recognized as a priority subject in international conventions such as Rio Convention, EU’s Habitats Directive, and national frameworks, it is evident that they are undergoing significant widespread decline (Borum et al., 2004). Seagrasses are found in the estuaries and along the coastal margins of tropical, temperate, and subarctic on the soft or sandy bottoms. Natural and anthropogenic activities are threatening seagrasses throughout the world, and quantifying the loss of their habitat is at its commencement. The interaction of natural and anthropogenic disturbance can exacerbate the impact in a way that exact causal factors are difficult to ascertain. For instance, land-use practices of a catchment may exacerbate the effect of natural catastrophic disturbance via an increase in soil erosion and nutrient run-off (Turner et al., 2006).

Compared to the 90,000-ha documented loss of seagrasses, the actual area lost is said to be certainly greater, and recently, the report of their decline has been regularly revealed (Wyllie-echeverria et al., 1996). Seagrasses and their ecosystem services are threatened by the direct impacts of coastal development, human activities that result from growing human populations, as well as by ecological degradation and climate change (Waycott et al., 2009). Therefore, the impacts of elevated atmospheric carbon dioxide, increasing land and sea temperatures, increasing sea level, and UV radiation combined with secondary changes will affect conditions of growth for both terrestrial and aquatic plants. The effects of global climate change on agricultural and other terrestrial plants have already drawn considerable attention. However, relatively not much emphasis has been putting on the possible impacts of global climate change on aquatic plant communities, including seagrasses (Frederick et al.,1999).

2.10 Natural disturbance of seagrasses

Geological phenomena such as volcanic eruption, the movement that causes coastal uplift or subsidence known as tectonic plate, coastal erosion due to oceanic waves and currents may affect or eliminate seagrasses. Beyond these, meteorological phenomena such as heavy and prolonged rains, winter storms, hurricanes, cyclones, and seasonal sea-ice formation and retreat, may lead to a loss of seagrass cover or a change in seagrass species assemblage. Its seasonal advancement and retreats may swipe the bottom and remove seagrasses in temperate and subarctic regions (Wyllie-echeverria et al., 1996). Additionally, biological interactions, such as grazing, sediment turnover, and disease, can also damage seagrasses from individual leaves to whole ecosystems (Frederick et al., 1999). Therefore, the extent to which a given disturbance changes the structure or function and then influences recovery time depends on the frequency, duration of the disturbance, plants' physiological conditions, and the characteristics of the associated species of seagrass. The level of damage sustained by seagrasses also determines their duration from the recovery (Wyllie-echeverria et al., 1996).

The movement of the tectonic plate can lead to coastal uplift resulting in the elevation of tide flats and then suppress seagrasses. This occurred in 1964 when Prince William Sound, Alaska, lifted the shoreline, exposing and killing *Z. marina* beds at several sites. A volcanic eruption may scatter ash and debris, smothering coastal seagrass areas (Wyllie-echeverria et al., 1996). The local and global dispersion of its smoke and ash can also block sunlight and affect seagrasses via reduced light availability (Wyllie-echeverria et al., 1996).

The global mean atmospheric temperature was projected to continue rising by 0.64–0.69°C for 2011–2030 compared to 1980–1999 (Congbin et al., 2011). The increase in temperature of seawater will directly affect the metabolism of seagrass and its positive carbon balance maintenance, resulting in seasonal and geographical patterns of species distribution and abundance. It may also affect seagrass through direct impact on flowering and seed germination (Frederick et al., 1999). This direct effect of increased seawater temperature will also depend on the individual species' thermal tolerances, their optimum temperatures for photosynthesis, respiration, and growth (Frederick et al., 1999). In estuaries, temperature and salinity conditions are determined by the mixing of ocean water with fresh water. This can be modified by both changes in duration and frequency of seasonal rainfall, which may also result in affecting seagrass distribution (Wyllie-echeverria et al., 1996).

Wave is a disturbance that travels and transports energy without transporting mass. The waves that travel on the surface of the water are known as surface gravity waves; and are the ones that most directly affect nearshore seagrass beds (Koch et al., 2009). Oceanic waves and currents driven by wind can break seagrass leaves or uproot entire plants. Such disturbance has been reported on all coasts after wind storms or hurricanes, and seagrasses are piled up in extensive wrack zones along the shore. In addition, excessive wave motion and water mixing induced turbidity also limit light and affect seagrass plants (Wyllie-echeverria et al., 1996). Biological interactions such as bioturbation, grazing, and disease can disturb seagrasses. The report of several Zostera species grazed by waterfowl has revealed the reduction of their leaf cover or loss of entire plants. Species such as dugongs, manatees, herbivorous fish as well as sea turtles may reduce seagrass above- and below-ground biomass. However, the impact of such as grazing in reducing the cover of seagrasses over a large extend is not well known (Wyllie-echeverria et al., 1996).

2.11 Human-induced disturbance of seagrasses

The increased human population and subsequent increase in anthropogenic activities over the coastal area have enhanced todays' rates of change in coastal waters much faster than those witnessed in the past 100 million years of life history, and reported to be too fast to allow seagrass species to adapt. These pressures have reduced the genetic diversity of seagrasses and are said to compromise species adaption. In many areas, human conversion of coastal zone has resulted in a situation that prevents the shoreward migration of the seagrasses caused by sea-level rise (Orth et al., 2006). The human-induced disturbance of seagrass is reported to increase much more than that from natural disturbances. Additionally, coastal development such as marinas, industry, and canal estates are leading to significant loss and fragmentation of seagrass habitat with unspecified consequences for their long-term survival (Orth et al., 2006).

Beyond the well-documented causes of seagrass declines, there are other emerging threats. The introduction of non-native marine species has been revealed as a major environmental challenge for the world's oceans over the last 20 years. Larkum et al. (2007) indicated that through boating/shipping activities and aquaculture, at least 56 non-native species, seaweeds, and primary invertebrates had been established to seagrass beds. The ecological effects of less than half of these introduced species on seagrasses and associated communities were revealed to be negative. All species that introduce habitat outside their native range are always not invasive in the sense of causing a negative effect, but many warrant concern and potential management. According to (Orth et al., 2006), at least 28 non-native species have become established in seagrass beds worldwide, of which 64% are documented as negative. The main concern about this emerging threat of non-native species is the impossibility to virtually remove them after their spread and establishment.

Although individual reports of the impacts of coastal development, degraded water quality have been increasingly documented, and there are only a few quantitative global assessments of seagrass up to date. A comprehensive global assessment of 215 studies by Waycott et al. (2009) found that seagrasses have been disappearing at an accelerated rate of 110 km^2 per year since 1980 and that 29% of the known areal extent has disappeared since seagrass areas were initially recorded in 1879. Including both high and low latitude regions, seagrass meadows are said to have declined in all areas of the globe where quantitative data are available. Given all the sites and their study period, seagrass meadows have declined more significantly than predicted by chance (Waycott et al., 2009).

2.12 Seagrass ecosystem services

The direct or indirect benefits that humans derive from the ecological functions of the seagrass ecosystem in coastal environments are numerous, vital, and well-known. Seagrasses constitute the base of the food web and habitat for a myriad of marine species. They are utilized as a primary food source by reef fish, urchins, and turtles (Björk et al., 2008). Their meadows provide coastal protection services by attenuating waves (Lei et al., 2019), reducing tidal currents (Widdows et al., 2008), protecting the seabed from erosion (Potouroglou et al., 2017), and the cycling of important global atmospheric gases, particularly CO_2, as well as the production of oxygen (Björk et al., 2008).

Seagrass meadows are known to cover only 0.1– 0.2% of the global oceans and represent more in order of magnitude than this to total marine primary production (Lyimo, 2016; Hartog, 2014). Moreover, their role in long-term carbon capture and storage is also acknowledged as a viable strategy for tackling increasing levels of atmospheric CO_2 (Hartog, 2014). In addition, even though the process is not now well established, seagrasses are also thought to play an important role in dimethysulfide cycling, which in turn contributes to atmospheric cloud formation and significantly affects the Earth's climate (Hartog, 2014). The protective effect of seagrasses can be so important that their meadows may even prevent the need for sand nourishments and preserve beaches (James et al., 2020). The services that seagrass ecosystems provide have been highlighted for their significant economic value, particularly for the role they play in nutrient cycling. It was revealed in Hartog (2014) that the estimated value of combined seagrass and algae beds is more than the US $19,000 per hectare per year based on nutrient cycling service alone.

The global loss and disturbance of seagrass ecosystems affect not only natural resources but also the lives of people who directly or indirectly depend on these systems. Most people around the coastal regions' lives are closely linked to seagrass meadows, and many coastal communities have close spiritual and cultural relations with seagrass habitats (McKenzie et al., 2021). Therefore, their habitats are used in many cultural and religious ceremonies (Hartog, 2014). Coastal indigenous people in India also revealed that their forebears had used seagrasses for thousands of years for a variety of uses, from food to medicine (Newmaster et al., 2011). The nutritional composition of six tropical seagrasses has shown that they are rich in protein, fiber, and lipid. As such, their use in pharmaceuticals was said to be beneficial for diseases such as obesity and diabetes. Furthermore, the high concentration of chlorophyll and carotenoids in these seagrasses is also revealed to be beneficial since they can act like vitamins and antioxidants (Raja et al., 2013). Through fisheries, erosion control, and protection against floods, their ecosystem services play many functional roles in human well-being, and these contributions indicate the reason why seagrass needs to be conserved (Nordlund et al., 2016). In this regard, seagrass supports both directly and indirectly important subsistence and commercial fisheries either within seagrass or other connected habitats.

Seagrasses play a significant role in supporting food security, and new information on the relationship between seagrass and fisheries productivity is emerging (Warren et al., 2010). They play an important role in the coral reef and fisheries productivity. Seagrass meadows support commercially important species as well as species with high economic value for subsistence (Hartog, 2014). In assessing the link between seagrass meadows and fisheries productivity, Baker et al. (2014) stated that there is no simple, linear relationship between conservation of supporting services, maintenance of provisioning services, and social wellbeing, in his case understood as food security. Unfortunately, despite their socio-ecological importance, global seagrass loss is estimated at the rate of 5-7% per year, and one-third of its cover has been lost in the past seventy (70) years (Ruiz-frau et al., 2017). Seagrass losses disturb significant connections between their meadows and other habitats, and their ongoing area decrease is likely producing much larger and long-lasting impacts than the loss of the meadows themselves (Waycott et al., 2009). A call of urgent action is required to increase awareness, improve understanding and protect well-known and yet underappreciated ecosystem services that seagrasses provide.

2.13 Climate change and seagrass

Increased deforestation and burning of fossil fuels have led to atmospheric carbon dioxide concentration increase by 25% since the preindustrial revolution. Other atmospheric gases such as nitrous oxide (N_2O), methane (CH_4), and chlorofluorocarbons (CFCs) have also significantly increased as a result of anthropogenic activities. These gases, known as greenhouse gases, are said to be radiatively active because they absorb longwave thermal radiation from the Earth's surface and reemit back to the Earth (Frederick et al., 1999). The debate on the magnitude of increased greenhouse gases impact on the predicted global warming is still ongoing among environmental scientists, and it is agreed by the majority that accelerated warming of the Earth's surface has begun and is unstoppable. The thermal expansion of the world's oceans and melting of glaciers due to this increasing warming is predicted to speed up the rate of sea-level rise (Titus, 1990). In addition, CFCs and other chlorinated, as well as brominated compounds emission and accumulation, are also depleting the stratospheric ozone layer resulting in increased ultraviolet (UV) radiation at the Earth's surface (Coley et al., 1991).

Concerning seagrasses, though climate change effects on them are likely to be significant, these effects, however, are not easy to predict. Mainly, the potential impact arises from sea level rise, which results in decreased light availability due to more extended submerged periods and changes in tidal regimes (Ondiviela et al., 2014). Coastline regression and erosion of sediment due to rising sea level, including temperature increase which could affect growth and productivity and lead to the die-off of some species at their thermal tolerance limit, all arise from the long-term climate change effect (Turner et al., 2006). Unpredictable impacts that result from changes in intensity and repartition of extreme weather events increase the direct physical disruption of seagrass beds and improve sediment delivery to the coastal and estuarine environment (Frederick et al., 1999). However, increased concentration of carbon dioxide in the atmosphere could result in an enhanced level of carbon dioxide into seawater and increase the productivity and depth range of seagrass (Turner et al., 2006).

2.14 Management of activities in the coastal marine area

The Earth's surface is covered by 70% of coastal and marine environments and accommodates various habitats that support abundant marine life. These coastal communities are seagrasses, algae, pelagic and or open-ocean, and deep-sea communities (CBD, 2004). Concerning seagrass, their meadows are not immediately charismatic habitats and are sometimes found in muddy and turbid water conditions, which do not attract as colorful, biodiverse wonders of the world. However, its ecosystems do support International Union for Conservation of Nature (IUCN) Red List of threatened species, and are very important socio-economic and ecological resource that deserves protection (Hartog, 2014). It is commonly believed that the decline of seagrass health as a result of anthropogenic pressures such as nutrient loading, light attenuation, and physical disturbance or other environmental conditions can increase the vulnerability of seagrasses to the disease (Den Hartog, 1987).

Managing an ecosystem or activities within it, refers to managing areas at diverse scales in a way that biological resources and ecological services are conserved as well as appropriate human uses are sustained. The important ecological services include energy flow (productivity), maintenance of nutrient cycling (soil fertility), and operation of the hydrological cycle (Brussard et al., 1998). The management of seagrass, therefore, is intimately related to the management of estuaries and coastal ecosystems because seagrass is only a component of a broad system of habitats and communities. For such reason, managing seagrasses needs a holistic, ecosystem-based approach for the management of estuarine and coastal systems as well as their catchments. This will address the issues of seagrass and other sensitive and valuable estuarine and coastal communities (Turner et al., 2006). Activities that include navigational channels' dredging, boating, and coastal development have to be carefully performed to reduce direct physical impacts on seagrass habitat. There is also a need to be adequate in the development process and considered ex-situ or remote effect because seagrass meadows out of the exact development site may also be affected by changes in water quality and sediment transport patterns (Walker et al., 2001). Thus, good management of seagrass habitat requires a greater awareness and understanding of the consequences of modifications to estuarine and coastal systems, as well as activities within them.

For the effect of a development proposal on seagrass to be properly assessed, a detailed understanding of the site-specific importance of the seagrass habitat, including ecological, social, cultural, and economic significance and the implications of any loss or degradation should the development caused is required for the resource managers. This understanding is generally known not to be available. Accordingly, it is recommended by Walker et al., 2001 that for seagrass importance assessment, we should:

1- Identify the ecological functions of seagrass in the area of the proposed development site
2- Quantify the loss of ecological functions resulting from any historical seagrass losses in the areas
3- Determine the amount of loss of seagrass that can be sustained without significantly impairing the ecological function of seagrass in the area
4- Quantify the loss of ecological function in the area resulting from previous activities
5- Quantify the loss of ecological function that can be potentially replaced by mitigation.

The above-enumerated concepts are synthesized known theory about seagrasses which is less studied in West Africa. As science and research evolve, more evidence could be revealed in the future. Identification and quantification of seagrass habitats importance and the cost associated with loss or deterioration of these habitats is critical if resource managers are to be better informed about the consequences of management decisions. This study aims to contribute to West African seagrasses identification and characterization as part of the ResilienSEA project to increase awareness and guide management and conservation.

3. Material and Methodology

3.1 Study area description

The Republic of Cabo Verde is an archipelago in the central Atlantic Ocean, consisting of ten volcanic islands and eight islets. It is located between 16.0021° of the latitude north and 24.0132° longitude west, approximately at 500km west of the West African coast, opposite Senegal (Fig 3). The archipelago has an extensive coastline of about 1,020 km of white and black sand beaches, which are alternated with cliffs (Government of Cabo Verde; Ministry of Environment and Rural Development, 2010). The islands rise from the deep abyssal plain beyond the African continental shelf (Benchimol, 2013) and are divided into two groups based on their relative location to prevailing winds. The Windward (Barlavento) group situated to the North, include the islands of Santo Antao, Sao Vicente, Santa Luzia, São Nicolau, Sala and Boavista. The Leeward group (Sotavento) to the south are Maio, Santiago, Fogo, and Brava. Cape Verde has a total land area of 4,033 km^2 with an Exclusive Economic Area (EEZ) of 734,000 km^2.

3.2 Socio-economic and Political status

The country is politically stable with the highest literacy and educational level of any other nation in West Africa (Benchimol, 2013). Its economic sector is oriented towards public services and making over 70% of its total gross domestic product (GDP), including commerce, transports as well as tourism (Benchimol, 2013). Cape Verde had an estimated population of 543,767 inhabitants in 2018, and its capital is Praia, located within Santiago Island, the largest island of the archipelago and the focus of this study.

3.3 Climate characteristics and influencing factors

Regarding the climate, the archipelago is situated in a region where the Azores' subtropical variability plays a crucial role in regulating rainfall anomalies. It controls the characteristics of seasonal fluctuation of the maritime and continental trade winds during the dry months (November to June). While in the rainy season (July to October), there are the Southeast winds and disturbances from the East resulting from the Intertropical Convergence Zone (ITCZ) oscillatory movement. In general, the island is influenced by four climatic systems that affect the regional climate. These include:

1- Subtropical anticyclone of the Azores;
2- Equatorial low pressures;

3- Cold ocean current from the Canaries;

4- Thermal depression over the African continent during summer.

Based on observed rainfall data, intensity, and activity of the dominant regional weather systems, the archipelago has three distinct seasons: a dry season (March June), transition season (November to February), a rainy season (July to October). The mean annual precipitation is 225 mm, and the yearly mean temperature is around 25º C for coastal areas and 19º C in locations above 1,000 meters of altitude. The minimum temperature varies between 20ºc and 21º C and occurs from January to April, and the maximum values of 26º C to 28º C are observed in August-September.

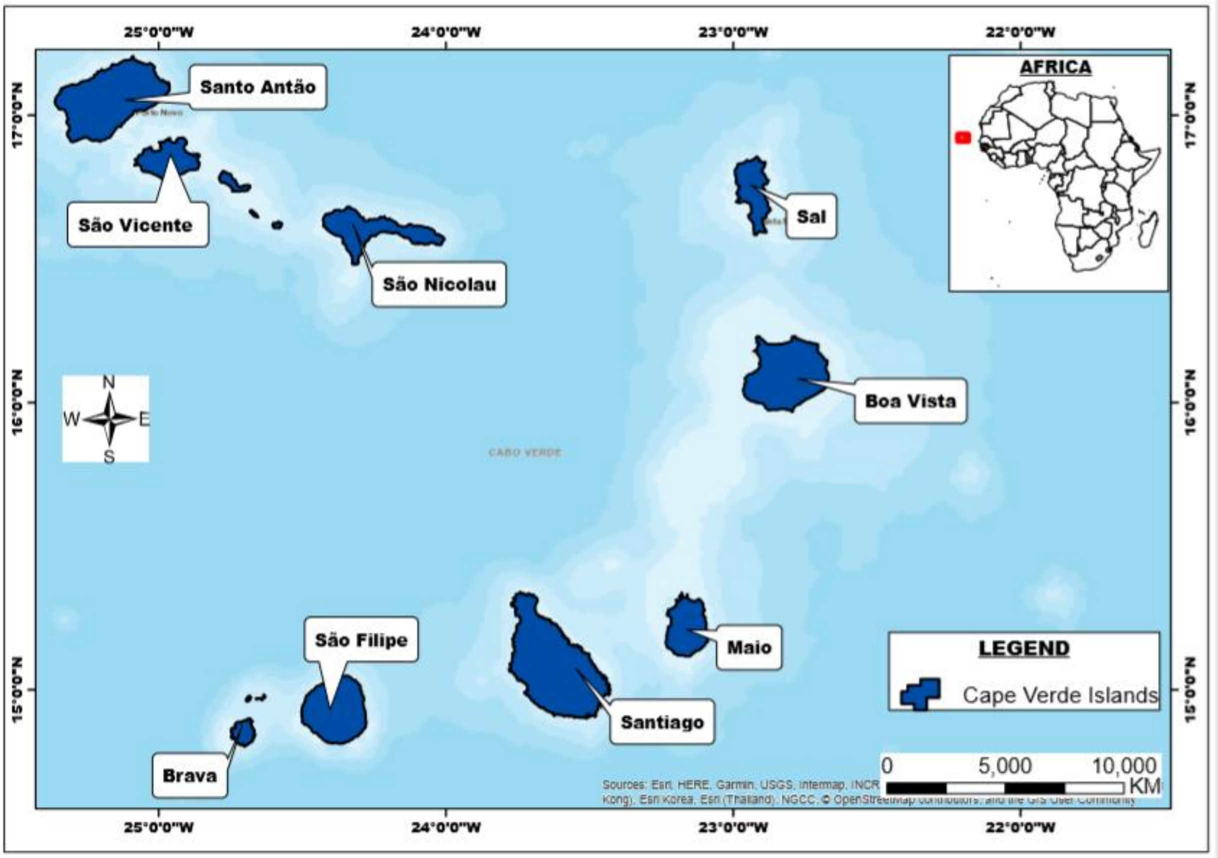

Figure 3: Map showing Cape Verde's geographical location and islands. Source (By the author 2021).

3.4 Strengthen management via involvement and research

Implementation of the management of the marine and terrestrial ecosystem and the potential conflicts that may arise between conservation and development is now a serious concern. Valuable natural resources management is under national regulation as well as international agreements and conventions. However, the operative implementation always belongs to the regional county or district administrative board. Therefore, initiating and allowing the participation of stakeholders in understanding the management of a given ecosystem and its relation to ecosystem service (ESS) may lead to beneficial consensus. A systematic study can thus help identify the strength and weaknesses of the management and advice rules and measures for sustainable improvement (Elggren, 2019).

To achieve the objectives of this study, both qualitative and quantitative research methods were used. Ground-based identification through diving and the use of a submarine camera were applied for accurate identification and evaluation. This was done in July 2021, after consulting the predicted sea conditions, which are day and period of low and high tide. To collect data on seagrass percent cover, species composition, biomass, and shoot density, a standard non-destructive method known as quadrat was used. This quantifies the structure of the seagrass community, measured as the percent cover of each seagrass species per m^2 and the number of the shoot (shoot density) in m^2 (MarineGEO, 2020).

3.5 Assessment of seagrass cover, density, and total extent

For the percent cover, 50 x 50 cm quadrats were randomly thrown in the identified seagrass meadow to estimate the percent cover. The mean estimates value of three percent cover estimated by three different individuals was recorded for each randomly placed quadrat, and this was replicated 30 times to cover the whole extent of the meadow (Fig. 4). The average recorded percent cover of the randomly placed quadrats was divided by the number of quadrats (n = 30) to estimate the total percent cover of the meadow.

For shoot density determination, 25 x 25 cm quadrat was randomly placed, and the number of seagrass shoots was counted and repeated 20 times to get an estimated shoot density of the meadow (Fig. 4). The mean shoot density in cm^2 of the meadow was then determined by dividing the recorded values by the number of 25 x 25 cm randomly placed quadrats (n=20). To estimate the shoot density in square meters (m^2), the 25 x 25 cm was converted in meter, then in a square meter, and was finally used to divide the number of shoots to determine the shoot density per square meter.

To determine the total extent of the meadow, the Universal Transverse Mercator Geo Map (UTM Geo Map) was used to record GPS coordinates of the meadow boundaries. This coordinate was imported into the Google Earth Pro to determine the total area and then imported into QGIS to establish the meadow map, seagrass boundaries, and its distance from man-made features.

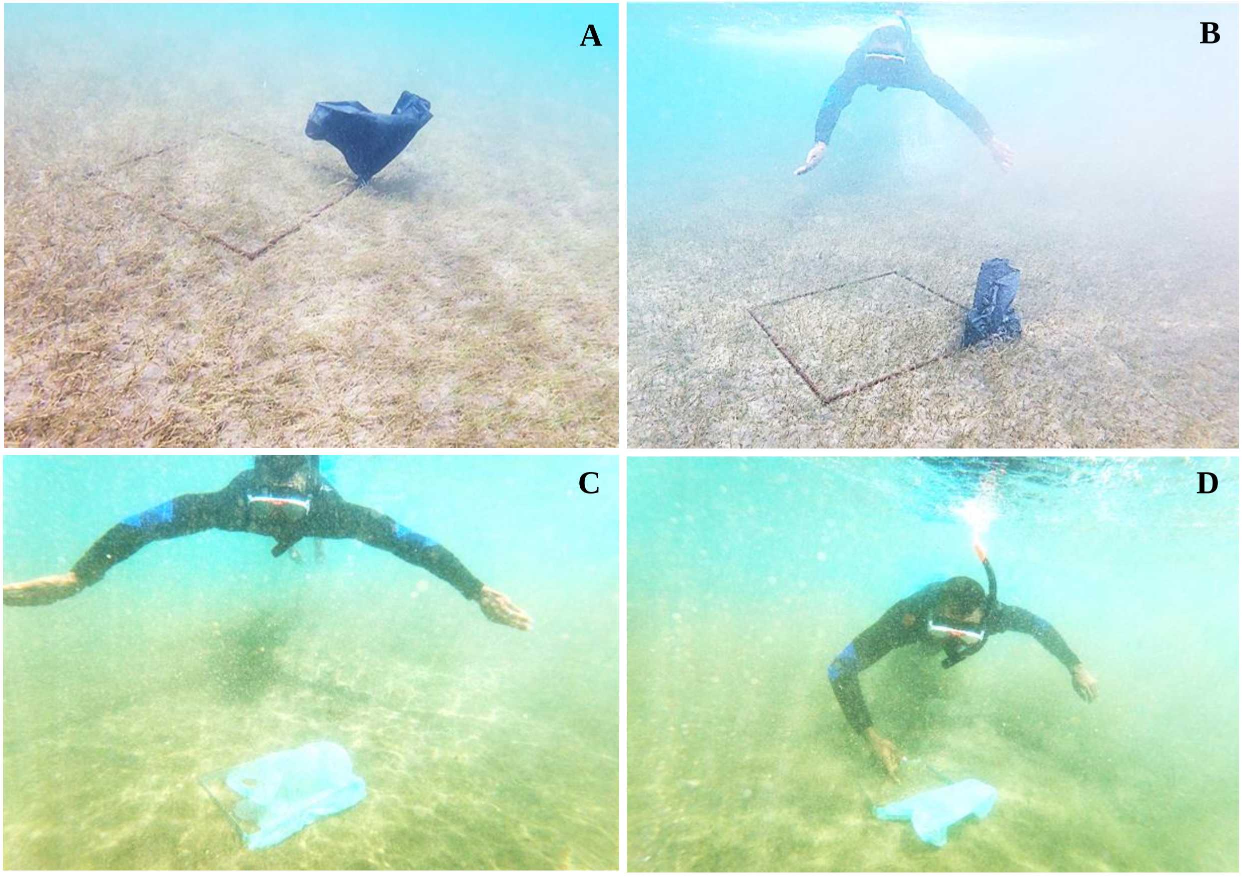

Figure 4:showing photographs of seagrass cover data collection procedures (A, B), and seagrass shoot density data collection procedures (C, D) in Gamboa, Santiago Island.

3.6 Biomass assessment

Nine (9) cores were taken within the identified meadow using the PVC core tube ~1 m length and 5 cm diameter to assess below and ground biomass. Sediment corer was placed over the bottom, and seagrasses were guided through the corer opening to avoid harming of seagrass blades and then pushed into the sediment up to ~ 10-15 cm depth. The corer was carefully retrieved from the benthos using hand under to support the sediment within the corer and prevent the sample from falling back. The collected seagrass core samples were deposited into the plastic bag, closed, gently agitated in the water to remove loose sediment, and stored in a cool, wet environment, and then transported immediately to the lab after returning from the field.

For the post-processing, nine (9) foil tins were prepared using aluminum paper, they were labeled, weighed, and the weight of each of the nine (9) foil tins was recorded. Seagrasses were separated into above- and belowground components by carefully pinching at the meristem (the intersection of the shoots and rhizomes) until they separate. The separated samples were put into the pre-weighed tins and then placed into a drying oven and dried at 60°C to constant weight (48 hours or two days) (Fig. 5).

Figure 5: showing photographs of seagrass biomass data collection procedures in the Laboratory: seagrass core sample(A); separated above and below ground biomass in the pre-weighed aluminum foil tins(B); Drying separated below and above ground biomass(C).

The separated dry above and below-ground biomass were weighed, and their biomass was recorded. The recorded weight of the foil tins was subtracted from the recorded below and above ground biomass to obtain the exact dry weight of seagrass in gram (g). Three leaves were randomly taken from each of the nine (9) samples and measured to estimate the leaf length or canopy height (Fig. 6).

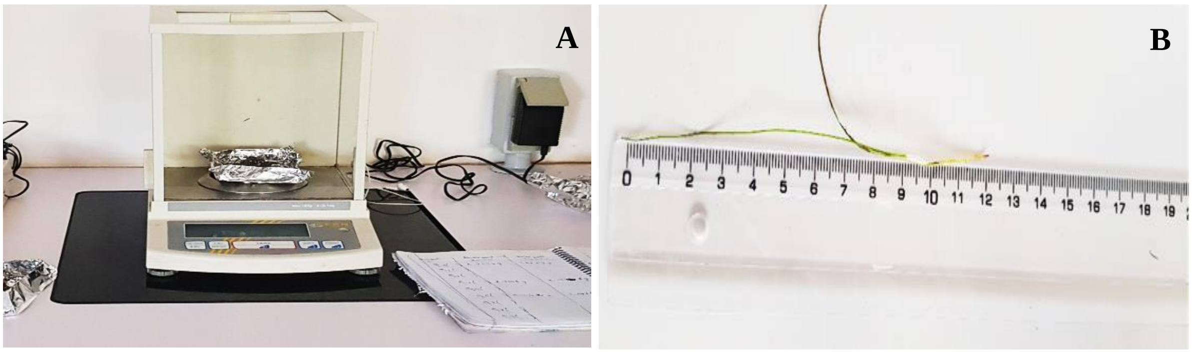

Figure 6:showing photographs of seagrass biomass data collection procedures in the Laboratory: Weighing dried samples using precision balance(A) and shoot length measurement(B)

To estimate the biomass in a square meter, the area of the 5 cm diameter corer used for sample collection was first calculated using this formula **$A= \pi * r^2$**, where **π =3.14** and **r is the radius**, which is half of the diameter. The mean below and above-ground biomass in g/m^2 was estimated by dividing the obtained biomass by the area under consideration. The total biomass was determined by summing the below and above-ground biomass. The visual graphs, the correlation between the collected parameters, and statistics such as mean, minimum, maximum, standard deviation, and standard error were calculated using R software. Data from this study and that from Creed et al. (2016) who also used the standard method, were compared for inference.

3.7 Survey data acquisition

To acquire survey data, it was required to determine the appropriate sample population that should be investigated and then extrapolates it to the total population. This is done because it is impractical or impossible to study the whole population when conducting a questionnaire survey. Thus, sampling is a method that allows a researcher to infer information about a population based on the results from the subset population without having to investigate every individual. This reduces the number of individuals in a study, reduces cost and workload, and may also make it easier to obtain high-quality information. In this study, a minimum sample size that can be extrapolated to the overall population was used because of the short time range and cost linked to the study.

3.8 Sample size determination

For sample size determination, the reported total fishers population of 1729 of Santiago island (World Bank , 2008) was considered as sample frame or fishers population. Knowing the sample frame, we determined using the sample size the **Yamane** formula: $\mathbf{n=N /1+N\times e^2}$ with a margin of error of 10% and a confidence level of 90%. Where **n** is the sample size, **N** is the known population, and **e** is the margin of error with the correspondent confidence level. The sample size obtained was 99 people. Since these 99 people represented the whole of Santiago Island, one-third of it (1/3 = 30) was used to represent the sample size of the study area.

To assess perceptions about seagrass, the questionnaire set based on the research objectives was used to acquire the needed information (see appendix I). A survey was done to collect data about what fishers know about seagrass in terms of morphology, benefits, threats, and ecosystem services (ESS). The ESS described in the questionnaire were all in connection with seagrass and seagrass meadows and may all be affected by anthropogenic activities in and around the study area (Gamboa). To identify how the respondents perceive seagrass and the ESS from their meadows, the questionnaire was categorized by section and was included in the survey. This was established to get an insight into what information the participants might be lacking and will like to gain. The survey was written in Portuguese for the interview, and the answers were all translated to English for analysis. A total number of 30 fishers were interviewed to know their demographic status (section A), fishing practices (section B), and perceptions about seagrass (section C).

4. Results

4.1 Ecological characteristics

Seagrass meadow comprising of *H. wrightii* was found occupying an important area of Gamboa bay in Praia, Santiago Island (14.914"N 23.512"W) at a depth range of 1 – 1.6 m on fine sandy and muddy bottom (see Fig. 7). The total extent of the meadow is estimated as 6243m^2 and its distance from the newly constructed bridge is between 32 to 100 m; 32 m for the closest distance to the meadow boundary and 100 m for the other end boundary (Fig. 7). The green marine algae are also present at approximately more than 8 m from seagrass, and space on the rocky bottom at the depth range of less than 1.2 m. The seagrass species present in the meadow (*Halodule wrightii)* is in large part covered by epiphytic species. The meadow of *H. wrightii* is growing in accumulated fine and muddy sediment, making banks of 10-15 cm height. The mean shoot density was 989.6 shoots/m^2 (SE = 150.2). The mean aboveground biomass was 117.7g/m^2 (SE = 28.4), belowground biomass was 194.3 g/m^2 (SE = 49.5), and the total biomass was 311.9 g/m^2 (SE = 71.7). Mean shoot or leaf length was 9.5 cm (SE = 0.5) and mean rhizome length was 10.3 cm (SE = 0.7). Seagrass observed in the study area had no flowers and fruits with stiff, green, strap-shaped blades.

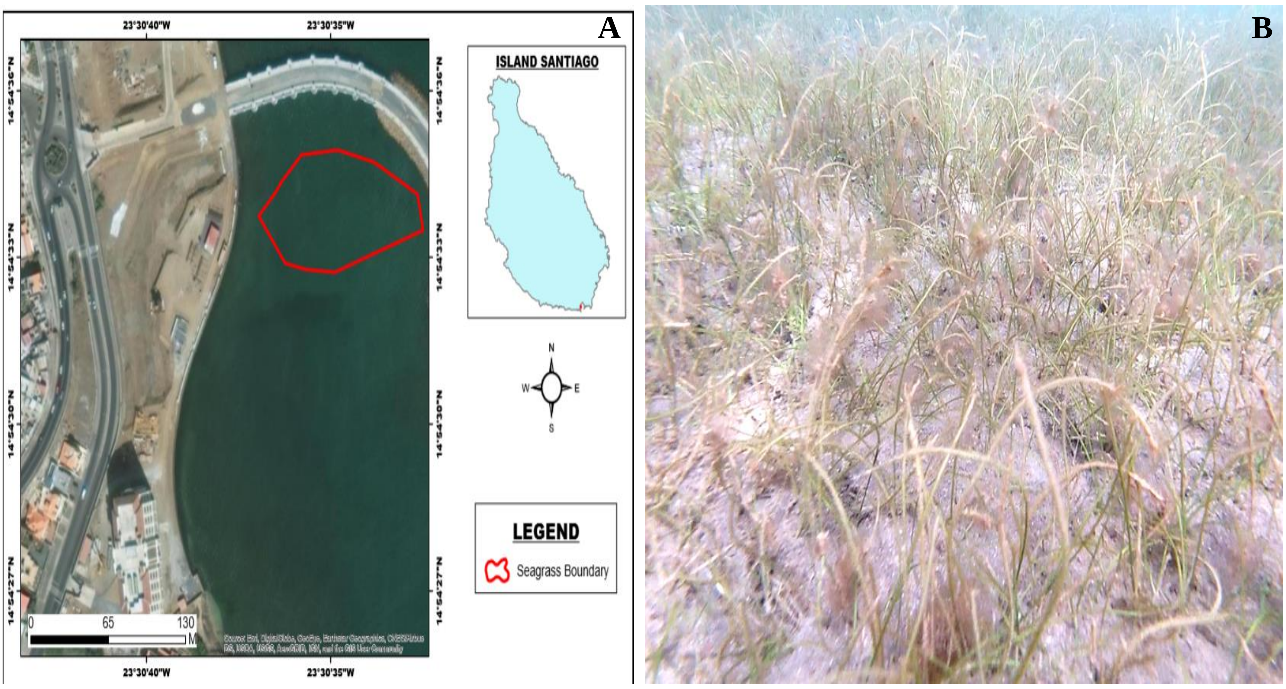

Figure 7: Map showing the study, seagrass meadow extent (A) and *H. wrightii* photograph (B) in Gamboa, Santiago Island, Cape Verde. Source (by author, 2021).

4.2 Comparison and statistical inference

Compared to the description done by C. Creed et al., 2016, the recent characterization of the meadow shows an increase in *Halodule wrightii* (shoal weed or shoal grass) area. The ten (10) patches of 20m^2 of *H. wrightii* area described then is now 6243m^2. There is an increase in below ground and above ground biomass, canopy height, and total biomass. However, the study shows a decrease in shoot density on the extending area (Table 2).

Since the information for comparing the mean values and any measure of the amount of variation or dispersion of a set of values (e.g., standard deviation) is not available, we cannot perform T- test. As a consequence, we cannot statistically test the results from year 2016 and 2021. However, it can easily be seen that the difference between the two values is greatly large (Table 2).

Table 2: Table showing the ecological parameters of seagrass (*H. wrightii*) for 2016 and 2021

Ecological parameters	Year 2016	Year 2021
Area	20 m^2	6243m^2
Cover	NA	60%
Shoot density	5998shoots / m^2	989.6 shoots / m^2
Canopy height	8.3cm	9.5cm
Below ground biomass	22.98g/ m^2	117.7 g/ m^2
Above ground biomass	101.25 g/ m^2	194.3 g/ m^2
Total biomass	120 g/ m^2	311.9 g/ m^2

4.3 Correlation between biomass, shoot density, shoot length and rhizome length

The correlation analysis between the collected ecological parameters shows no statistically significant relationship between the parameters. However, the correlation coefficient shows that there is a moderate positive significant relationship between the above and belowground biomass ($r = 0.66$, p-value = 0.05089) and a weak relationship between the canopy height and the above-ground biomass ($r = 0.48$, p-value = 0.1861). A weak negative relationship existed between the rhizome length and above-ground biomass ($r = -0.30$, p-value = 0.438) (Fig. 8).

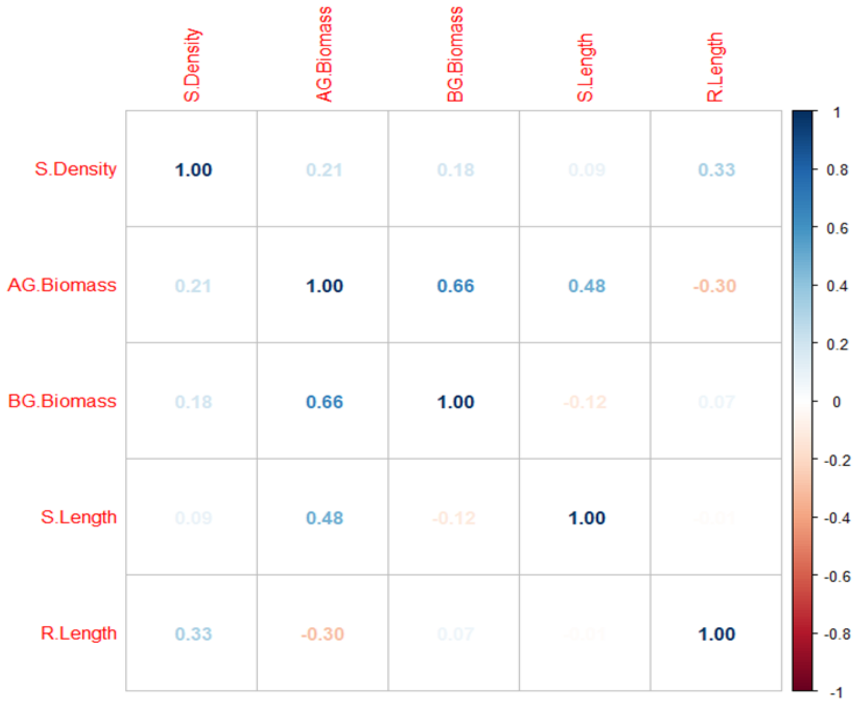

Figure 8: showing correlation between the collected ecological variables

4.4 Fishers profile and perception on seagrasses

4.4.1 Background information of fishers in the study area

Table 3 shows the age, educational level, and fishing experience of the fishers in the study area. It indicates how old was the targeted survey sample population, their education, and fishing experience. As a result, it has been shown that respondents age varies from 18 to more than 57 years old. Within this age range, 26.7% of the fishers have their age between 34-40 and 49-56 years old. Those between 41-48 years old represented 16.7% of the fisher's population, and it is only 6.7% of the fishers that have their age between 18-25 years old. All the participants in the survey were male, and there were no female participants. This is because fishing activities are only exercised by males in the study area. With regard to their educational level, 70% of fishers attended primary school, 26.7% attended secondary school, and only 3.3% went through non-formal education. For their fishing experience, more than half of the fisher's population have more than 20 years of skill in fishing, 23% have 15 years of fishing experience, and only 6.7 % have almost five (5) years of experience in fishing.

Table 3: showing the age range, education, and experience of the respondent in Gamboa

Questions	Answers	Frequency of responses (%)
	18-25	6.7%
	26-33	13.3%
Age	34-40	26.7%
	41-48	16.7%
	49-56	26.7%
	>= 57	10.0%
	Primary	70.0%
Education Level	Secondary	26.7%
	Non-formal	3.3%
	Almost 5 years	6.7%
	10 years	13.3%
Fishing experience	15 years	23.3%
	more than 20 years	56.7%

4.4.2 Fishers described fishing practices in Santiago Island, Praia, Gamboa

In order to identify the threats related to boating and fishing activity, respondents were asked about their fishing habits in and around the study area. As a result, when they were questioned about the type of fishing nets they use, 35.2% indicated use of drag nets, 38.9% said that they make use of hooks and lines, 18.5% indicated the use of drift nets, and only 7.4% said that they make use of all the above mentioned in fishing (Fig. 9). For the source of their fishing materials, almost 95% (96.7) of fishers indicated to be the only provider of their fishing materials, none of them acquire material from the government, and only 3.3 % said to obtain material from a non-governmental organization (appendix II).

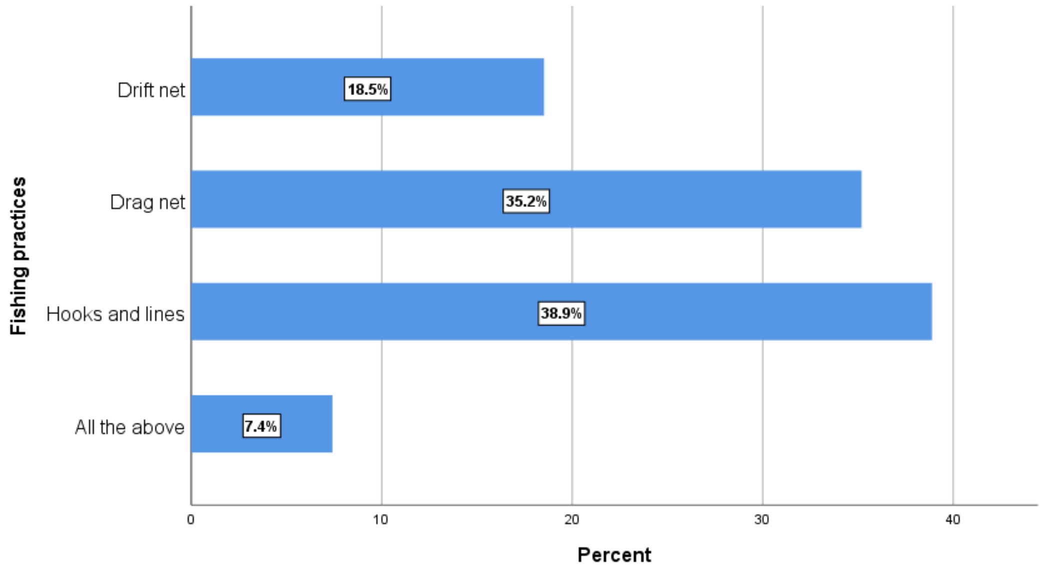

Figure 9: showing the fishing practices in the study area

When they were asked whether they anchor in shallow areas, 30% of respondents that they don't, and 70% of fishers responded that they anchor in the shallow areas, and most of them indicated stepping on shallow areas (Fig. 10).

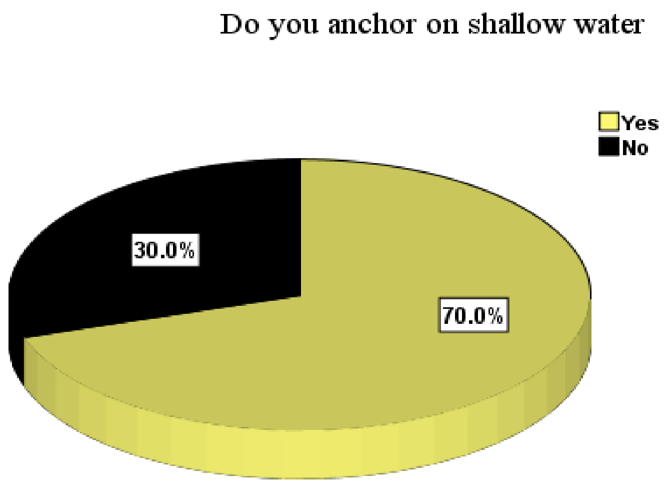

Figure 10: showing the fishers response about anchoring in shallow water

When fishers were questioned about the use and how they dispose of some material they carry to the sea, 36.7% indicated that they carry with them both plastic and old clothing, 33.3% said they carry along only old clothing, and 30 % responded that they carry with them only plastic material when going to the sea. Therefore, it is only 3.3% of these fishers throw these materials into the sea, and 96.7% of the fishers carry them back to the land (Table 4).

Table 4: showing materials carried to the sea by fishers and how they get rid of them

Questions	Answers	Percent responses
Which of these materials do you carry with you into the sea?	Plastic	30.0%
	Old clothing	33.3%
	Others(both)	36.7%
How do you dispose of the materials you carry into the sea?	Throw into the sea	3.3%
	Carry it back	96.7%

4.4.3 Fishers knowledge and perception about seagrass in Santiago Island, Praia, Gamboa

In order the identify fishers' knowledge and perception about seagrass, questions were initially asked about the recognition of seagrass to understand and establish if there is a difference between being aware of and being able to identify it. Further, they were also questioned on their specific need for information and knowledge they may want to know about seagrasses. As a result, when the respondents were asked whether they know seagrass and where are seagrasses found, 90% responded that they know it, and only 10% of them said that they don't (appendix II). Of the percent that affirmed of knowing seagrass, 21.4% said that they are only found in shallow waters, 53.6% said they are found in only deep areas, and only 25% indicated they are found in both shallow and deep water. It is only 16.7% of the respondents who said to attend training on seagrasses, and 83.3% of fishers indicated that they did not attend any training on seagrasses (Table 5).

Table 5: showing fishers responses on seagrass location and their training on seagrass

Questions	Answers	Percent responses
If yes, where are they found?	Shallow area	21.4%
	Deep-sea	53.6%
	In both	25.0%
Did you attend any training on seagrasses?	Yes	16.7%
	No	83.3%

To investigate the difference between knowing and being able to identify seagrass, photographs of 5 underwater plants were presented to fishers as visual aids and asked to identify seagrass among them (appendix I). As a result, 43.3% indicated green marine algae as seagrass, 36.7% were able to identify seagrass, 13.3% showed red algae as seagrass, and only 6.7% of fishers confused seagrass to seaweed (Fig11).

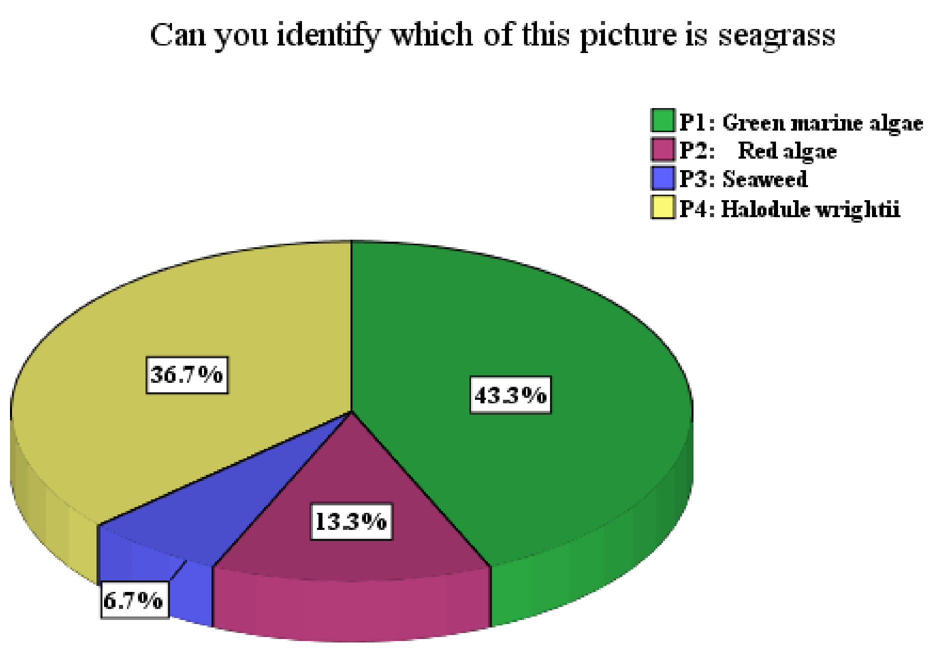

Figure 11: showing fishers answers to the picture showing underwater vegetations

For the certainty of the fishers' answers about seagrass, they were also asked about how they found the question about underwater plants. As a result, over 80% (86.7) responded that "No, it was easy," 6.7% said that it was "neither difficult and no easy," and only 3.3% indicated that "they knew one or two" and the same number responded that "doubt their answer" (Table 6)

Table 6: showing the certainty of respondents about their responses about underwater vegetation

Did you find the question with a picture of plants difficult?	Frequency	Valid Percent
I doubt about my answers	1	3.3%
I knew one or two	1	3.3%
Neither difficult nor easy	2	6.7%
No, it was easy	26	86.7%
Total	30	100.0%

4.4.4 Respondents perceived threats and impact of the threats on seagrass in Santiago Island, Praia, Gamboa

To assess the perceived threat of fishers on seagrass, questions related to direct and indirect threats on seagrass were given as multiple-choice answers. The questions were set in an individual perspective and were formulated based on different types of threats and situations that actually prevail around the study area. When they were asked about threats that can disturb the seagrass ecosystem, 60% responded that they know, and 40% said that they don't know. Among respondents who confirmed the threats on seagrass in the study area, bad fishing practices was indicated by 36.4% as threats on seagrass in the study area, 31.8% attributed it to sewage, 22.7% stated climate change, and only 4.5 % mentioned boating activities and coastal development (Fig. 12).

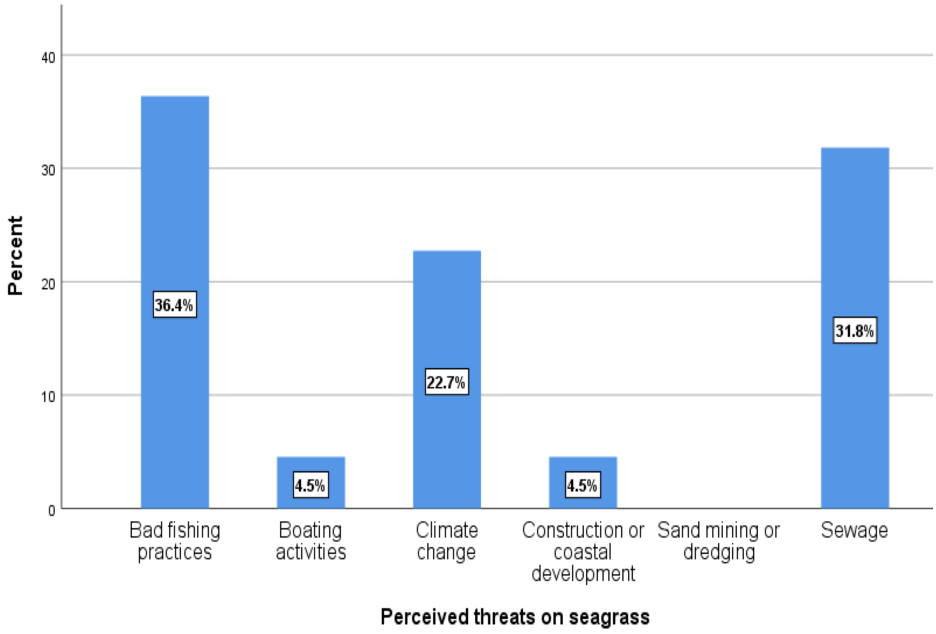

Figure 12: Showing fishers perceived threats on seagrass in Gamboa

When asked about actions or occurrences connected to these threats, 53.8% of the fishers indicated the reduction of catch, 38.5% responded that they reduced biodiversity, and 7.7% of fishers said that they increased nutrient loading in the sea (Fig. 13). Further, when participants were questioned about the mitigation solutions, 33.3% of the fishers said that the threats could be prevented and reduced by protecting the marine environment through the prevention of sewage, plastic, and nutrients loading as well as cleaning the ocean. 20% of the respondents indicated that they could be mitigated through reduction of the fishing contract with foreign forces and training of fishers. 43.3 % responded that they don't know how the threats can be prevented or reduced, and 3.3% of the fishers indicated that only God could prevent or reduce the existing threats (appendix II).

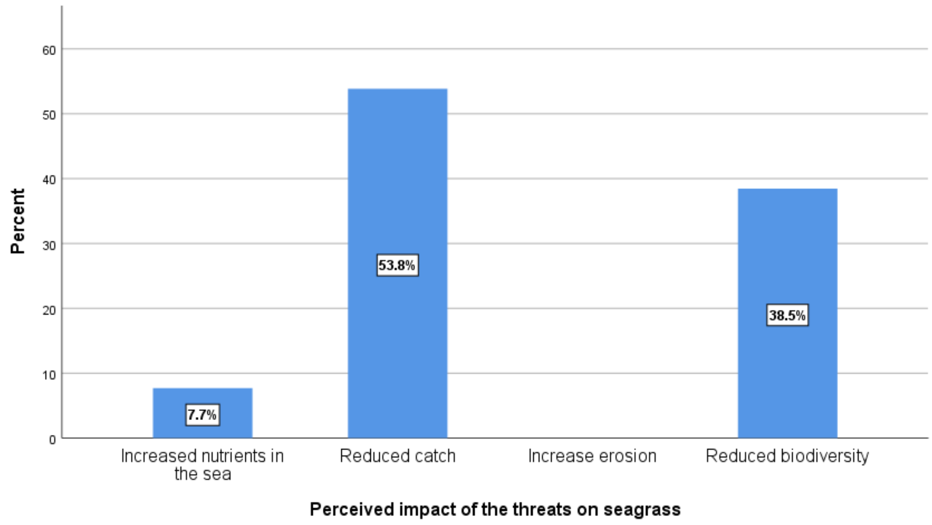

Figure 13: showing fishers perceived impact on seagrass in Gamboa

4.4.5 Fishers perceived ecosystem services of seagrass in Santiago Island, Praia, Gamboa

To draw the perceived ESS provided by seagrass from the participants, questions were framed in an individual set and given multiple-choice answers. The question on ESS included 6 sets of questions derived from provisioning and regulating services of seagrasses with alternative answer options of *"don't believe"* and "*don't know*" (Dolnicar et al., 2014). Numeric values were assigned to all the possible answers, and multiple-choice analyses were applied for inference.

As a result, 32.5% of fishers indicated that they believe that seagrasses provide shelter and refuge for the young and marine animals, 28.9% said that seagrass provides food for fish, sea turtles, and other marine animals, 20.5% responded that they hold bottom sediment and toxins and then stabilize and purify water, 12.0% mentioned that seagrass could increase catch and income, 4.8% indicated that they store more carbon than forests and reduce climate change, and only 1.2% of the fishers responded that they don't know (Fig. 14).

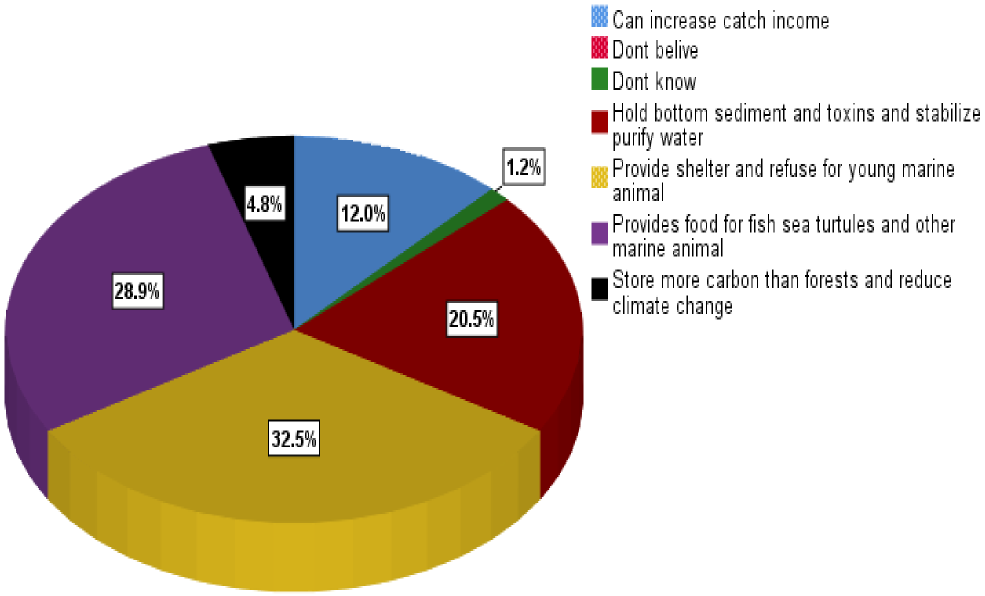

Figure 14: showing fishers perceived ecosystem services provided by seagrasses

4.4.6 Fishers need for information on seagrass and marine environment around Santiago Island, Praia, Gamboa

For the final questions, fishers were asked whether they would like to know more about seagrasses and the marine environment around Santiago Island and also asked about which information channel they would prefer to receive such information. As a result, 96.3% of respondents indicated that “Yes,” they want to know more about the seagrasses and marine environment around the island, and only 3.3% responded that “No.” Among those that were interested to learn more about seagrasses and the marine environment around Santiago Island, 27.8% of fishers were interested in understanding how seagrasses are important, 26.8% were interested in knowing how to protect seagrasses, 22.7% were interested in knowing how to identify seagrass, and another 22.7% were concerned about knowing in which kind of environment seagrasses are found (Table 7).

Table 7: showing fishers need for information on seagrasses and marine environment in Santiago Island, Gamboa

Questions	Answers	Percent responses
Will you like to know about the seagrass coastal environment in Santiago?	Yes	96.7%
	No	3.3%
If so, what would you like to know more about?	Be able to identify seagrass	22.7%
	Know how to protect them	26.8%
	Know how it is important	27.8%
	Know the type of environment is found	22.7%

Regarding the way they would like the information to be given to them, a set of questions with a multiple-choice answer including the option “others” was given to respondents with the possibility of chosen more than two answers. As a result, 30.2% indicated that they prefer the information to be given to them on TV, 20.9% indicated they prefer radio as a source of information, 18.6% said that they like the sign of information on the area where seagrass is found, and only 11. 6% of respondents indicated that they needed information through the meeting (Fig. 15).

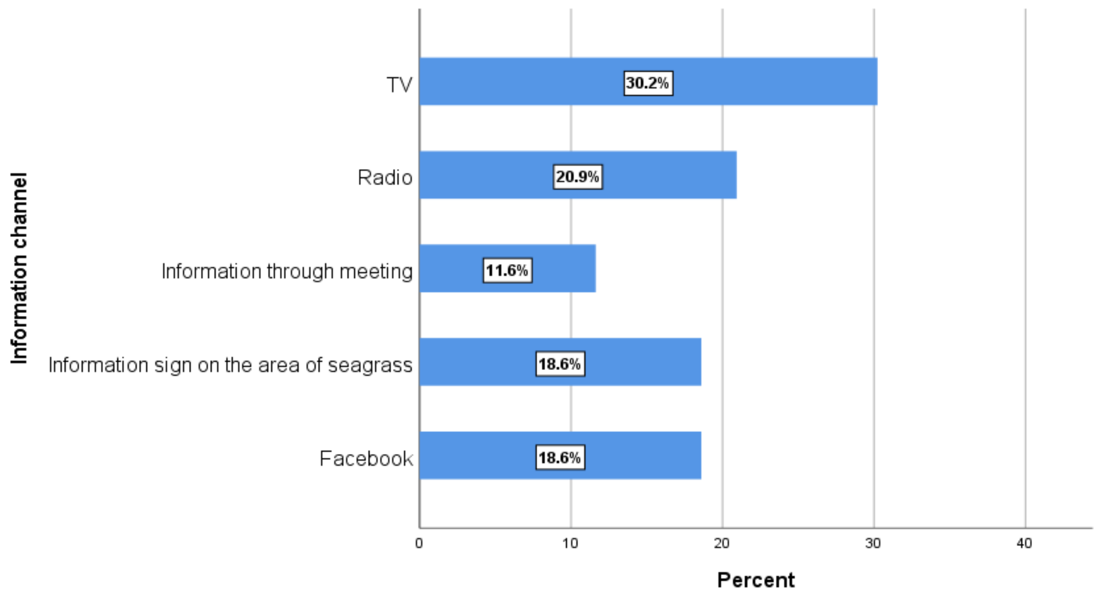

Figure 15: showing fishers preferred channel for information on seagrass and marine environment in Santiago Gamboa

4.4.7 Relationship between respondents' educational level, fishing experience, and their ESS of seagrass in the Gamboa, Praia, Santiago Island.

In order to uncover the hidden relationships between survey data variables and know whether respondents' educational level, fishing experience, and age play a role in their perception, cross-tabulation analysis was also used to explore and identify relationships between variables. This is done considering the fact that, when their educational level and fishing experience is highly related to their perceived knowledge on seagrasses, it is likely that their awareness will positively affect their perception of seagrasses and then improve the management and protection of the seagrass's ecosystem in the study area.

When fishers educational level and perceived ecosystem services were cross-tabulated, it has been shown that among the total number 20.5% of fishers that believe that seagrass "*Hold bottom sediment and toxins and stabilize, purify water*" 16.9% and 3.6% respectively attended primary and secondary education, and none (0%) of those that did not attend any formal education believe in such ESS from seagrasses (Table 8). Furthermore, it is also shown in the table that basic ESS such as *"Providing shelter and refuse for young marine animal" and "providing food for fish sea turtles and the other marine animal"* are well perceived and understood by fishers than those that require more knowledgeable theory such as *"Store more carbon than forests and reduce climate change" and "Can increase catch income."*

Table 8: showing the relationship between respondent perceived ESS and their educational level

Ecosystem services and Education Crosstabulation						
			Education			
			Primary	Secondary	Non-formal	Total
Fishers perceived ESS	Hold bottom sediment and toxins and stabilize purify water	Count	14	3	0	17
		% within $ESS	82.4%	17.6%	0.0%	
		% within Education_3	25.9%	11.5%	0.0%	
		% of Total	16.9%	3.6%	0.0%	20.5%
	Provide shelter and refuge for young marine animal	Count	19	7	1	27
		% within $ESS	70.4%	25.9%	3.7%	
		% within Education_3	35.2%	26.9%	33.3%	
		% of Total	22.9%	8.4%	1.2%	32.5%
	Provides food for fish, sea turtles, and the other marine animal	Count	16	7	1	24
		% within $ESS	66.7%	29.2%	4.2%	
		% within Education_3	29.6%	26.9%	33.3%	
		% of Total	19.3%	8.4%	1.2%	28.9%
	Store more carbon than forests and reduce climate change	Count	1	3	0	4
		% within $ESS	25.0%	75.0%	0.0%	
		% within Education_3	1.9%	11.5%	0.0%	
		% of Total	1.2%	3.6%	0.0%	4.8%
	Can increase catch income	Count	4	5	1	10
		% within $ESS	40.0%	50.0%	10.0%	
		% within Education_3	7.4%	19.2%	33.3%	
		% of Total	4.8%	6.0%	1.2%	12.0%
	Don't know	Count	0	1	0	1
		% within $ESS	0.0%	100.0%	0.0%	
		% within Education_3	0.0%	3.8%	0.0%	
		% of Total	0.0%	1.2%	0.0%	1.2%
Total		Count	54	26	3	83
		% of Total	65.1%	31.3%	3.6%	100.0%

Percentages and totals are based on responses.
a. Dichotomy group tabulated at value 1.

With regard to the relationship between fishers perceived seagrass ecosystem services and their fishing experience, Table 9 shows that the total 32.5% of the respondents who believe that seagrass "Provide shelter and refuse for young marine animal", 16.9% have more than 20 years of experience, 8.4% have 15 years' experience and only 2.4 % have around five (5) years fishing experience. Further, the results from the table also show that fishers having 15 to more than 20 years of fishing experience recognized well the ESS of seagrasses than those around 5 to 10 years of fishing experience (Table 9).

Table 9: showing the relationship between respondent perceived ESS and their fishing experience

Ecosystem services and Fishing experience Crosstabulation

			Fishing experience				
			Almost 5 years	10 years	15 years	more than 20 years	Total
Fishers perceived ESS	Hold bottom sediment and toxins and stabilize purify water	Count	0	3	5	9	17
		% within $ESS	0.0%	17.6%	29.4%	52.9%	
		% within Fishing experience	0.0%	27.3%	19.2%	22.0%	
		% of Total	0.0%	3.6%	6.0%	10.8%	20.5%
	Provide shelter and refuge for young marine animal	Count	2	4	7	14	27
		% within $ESS	7.4%	14.8%	25.9%	51.9%	
		% within Fishing experience	40.0%	36.4%	26.9%	34.1%	
		% of Total	2.4%	4.8%	8.4%	16.9%	32.5%
	provides food for fish, sea turtles, and the other marine animal	Count	2	4	7	11	24
		% within $ESS	8.3%	16.7%	29.2%	45.8%	
		% within Fishing experience	40.0%	36.4%	26.9%	26.8%	
		% of Total	2.4%	4.8%	8.4%	13.3%	28.9%
	Store more carbon than forests and reduce climate change	Count	0	0	3	1	4
		% within $ESS	0.0%	0.0%	75.0%	25.0%	
		% within Fishing experience	0.0%	0.0%	11.5%	2.4%	
		% of Total	0.0%	0.0%	3.6%	1.2%	4.8%
	Can increase catch income	Count	1	0	3	6	10
		% within $ESS	10.0%	0.0%	30.0%	60.0%	
		% within Fishing experience	20.0%	0.0%	11.5%	14.6%	
		% of Total	1.2%	0.0%	3.6%	7.2%	12.0%
	Don't know	Count	0	0	1	0	1
		% within $ESS	0.0%	0.0%	100.0%	0.0%	
		% within Fishing experience	0.0%	0.0%	3.8%	0.0%	
		% of Total	0.0%	0.0%	1.2%	0.0%	1.2%
Total		Count	5	11	26	41	83
		% of Total	6.0%	13.3%	31.3%	49.4%	100.0%

Percentages and totals are based on responses.

a. Dichotomy group tabulated at value 1.

5. Discussion of the results

5.1 Ecological characteristics of seagrass in Gamboa, Santiago Island

The conservation and management of marine ecosystems such as seagrasses call for an accurate understanding of its extent, its dynamic, and factors leading to changes to envisage ways that limit the vulnerability and furnish means that improve the livelihoods of indigenous communities. Recently, the Coastal Ecosystem Monitoring project of Cabo Verde planned to develop a coastal monitoring program in regions where no systematic ecosystem observations exist to improve local knowledge about the marine coastal environment and the biodiversity around the islands. As such, the goal of achieving this was predicted to be accomplished through a pilot field survey including state-of-the-art technologies and community-based observations (OSCM, 2020).

Through some of these means, this study describes and compares the actual and previous status of seagrass ecological characteristics of Gamboa bay, a wave protected bay in Santiago Island (Creed et al., 2016) situated in the central Atlantic Ocean. The identified species (*Halodule wrightii*) is known to occur in all the six (6) ecological bioregions of seagrasses except the Temperate Southern Oceans (Short et al., 2007). It was for the first time reported on the western coast of Africa (Alexandre et al., 2017) and in Cape Verde (Creed et al., 2016). *Halodule wrightii* is one of the three abundant seagrass species along the Tropical Atlantic coast of American associated with *Thalassia testudinum* and *Syringodium filiforme.*

As compared to the first report (Creed et al., 2016), *Halodule wrightii* ecological parameters such as the meadow extent, biomasses, and canopy height have increased from 2016 to 2021. The increased biomasses of the meadow are weakly correlated with the meadow shoot density, and the above-ground biomass (AGB), negatively correlated with the rhizome length. The positive correlation between biomass density is a consequence of seagrasses clonality, and the growth-form plasticity demonstrated in clonal terrestrial plants (Ye et al., 2006) and clonal algae (Vieira et al., 2018). This is an adaptive plant growth strategy in which ramets of the same genetic individual are dispersed and exchange resources through rhizomes or roots. Clonality is an important way by which plants can reproduce and spread vegetatively, and the integration of its interconnected ramets is advantageous for using resource-rich patches in heterogeneous environments (Wang et al., 2020). According to Vieira et al. (2018), seagrasses often have a positive relationship between biomass and shoot density, and that different species have a different maximum efficiency of space occupation. The canopy height of seagrasses is relatively shorter as compared to their terrestrial counterparts since they generally lack secondary metabolites with anti-fouling properties often known for algae and hence prevent accumulation of epiphytes using a basal meristem and changing leaves regularly, which affect both leaf length and biomass accumulation (Vieira et al., 2018).

The actual shoot density of seagrass meadows in Gamboa has declined to about 5-fold lower than the 5998 shoot/m^2 (SE = 1247) reported by Creed et al. (2016). The underwater survey conducted in Sao Tome and Principe Islands, off the western equatorial coast of Central Africa, the shoot density of 4349 shoots/m^2 (SE=1028) was reported for Sao Tome by Alexandre et al. (2017). In contrast, the density of 1114 shoots/m^2 (SE=314) was reported for the island of Principe on a total area of 135 m^2. However, the volcanic archipelago of Fernando de Noronha, located in the equatorial South Atlantic, 360 km off the coast of Brazil, reported a higher mean shoot density of 6690 shoots/m^2 (SE=2670) on a total area of 50000 m^2 (Magalhães et al., 2021). Seagrasses, particularly *Halodule wrightii* shoot density, are quite variable and inconsistent throughout the Oceanic islands of the Atlantic, which could be attributed to local environmental conditions and reputed genetic variations. The observed shoot density in Gamboa is close to that recorded in Brazil (1955 ± 1475 shoots/m^2) by (Magalhães et al., 2017), and this of Principe Island (1114 ± 314 shoots/m^2) by Alexandre et al. (2017).

Halodule wrightii biomasses including above, below and total biomass observed in Gamboa bay is many folds over than those reported in Sao Tome and Principe islands (AGB=23.65 ± 6.36g/m^2, BGB = 84.38 ± 39.41g/m^2 ; and AGB =1.91 ± 1.11g/m^2, BGB = 6.07 ± 2.75g/m^2 respectively); in Fernando de Noronha (AGB = 15.3±8.5g/m^2 and ABG = 69.5±61.6g/m^2); and in Brazil (ABG = 9.6g/m^2 and BGB = 28g/m^2) (Alexandre et al., 2017; Magalhães et al., 2021; Magalhães et al., 2017). The increase in biomass recorded during the last five (5) years is possibly a result of the meadows fertilization either by abiotic factors such as good light irradiance due to low water turbidity and nutrients input from the nearby coastal development activities, or biotic factors such as low level of grazing and epiphytic organisms. It has been shown by (Fourqurean et al., 1995) that the species composition of seagrass correlates with nutrient availability. Further, he found in his experiment of zonation of species in relation to point sources of nutrients in Florida Bay that *Halodule wrightii* occurrence is correlated with areas of higher nutrient availability than *Thalassia testudinum*. This suggests that *H. wrightii* has a higher demand for nutrient availability than most of the seagrass species such as *Thalassia testudinum,* and why is that the case is still not well understood (Fourqurean et al., 1995). Vieira et al. (2018) also revealed that when a monospecific plant stands (or species) experience active growth resulting in increased biomass, competitive stress may create mortality. The consequent death of the weaker plants provides resources such as space, nutrients, and light, allowing the further growth of survivors. This process, understood as self-thinning, also reflects the efficiency of space occupation since more efficient stands show higher biomasses under similar stand densities. In addition, *H. wrightii* is very tolerant to disturbance when water condition is suitable for its survival and rapidly recolonize strip areas (Ramírez et al., 2017). This confirms its capacity for recovery and gives occasion to extend its distribution in Gamboa Bay.

5.2 Stakeholders' perception of seagrass and their ecosystem services

The actual worldwide challenges in seagrass conservation and management of their ecosystems are the assessment of their status (distribution and population dynamics) and societal recognition of their ecosystem services. Increasing knowledge on seagrass meadows, the roles they play in the marine environments, and the opportunity of involvement in natural resource management activity could change stakeholders' perception of seagrasses. The increased understanding of their importance and the need to be protected may lead to some behavioral change in the sense that link human activities with ecological literacy (Elggren, 2019; Pitman et al., 2016). Part of this study investigated stakeholders' (fishers) fishing practices, understanding about seagrass and their ESS in and around Gamboa bay. Further, their need for information and how this information could be circulated to increase awareness of their existence and various ecosystem services were also assessed.

Many fishing practices cause changes in the structure of marine environments and may determine the composition, biomass, diversity, and productivity of the connected biota. The effect of some fishing on the marine ecosystem is often a cumulative effect on individual plants and invertebrates as their habitats are formed by living organisms. The direct effects are mostly related to fishing gears, and the indirect effect occurs when a fishing practice creates shifts in the connection between organisms and factors responsible for habitat development and degradation (Jennings et al., 1998).

As revealed by this study, the majority of fishers in Santiago Island age vary from 34 - 56 years old with more than 20 years of fishing experience, and most of them have a basic education. Their understanding of maintaining the cleanness of the sea is adequate since only the minority discard used materials such as plastic materials and old clothes once on the sea. Most of them anchor their boat in shallow water, which can possibly damage seagrass meadows. The dominant fishing practice in and around Santiago Island (Gamboa) is hooks and lines fishing. This refers to any fishing that uses a combination of lines and hooks to catch fish;

it includes but, not limited to the use of lines composed of monofilament, wire, and cord, with attached lures, hooks, and jigs (Dixon, 1994). It is used by relatively small coastal vessels, does not damage marine habitat because it does not touch the seabed. However, it has been reported as a threat in Areas Important for the Survival of Threatened Fish Species (Dixon, 1994). Therefore, Cape Verde being a hotspot of endemic fish species (Freitas, 2014), an unsustainable increase of this fishing may possibly affect the community of endemic species. Dragnet fishing, also known as trawl net fishing, constitutes their second dominant fishing method which consists of dragging weighted nets across the seabed to catch fish. It is designed to increase their contact on the seafloor and has an essential impact on the substratum. The contact of the fishing gear with the substratum has a direct effect on marine plant communities, and seagrass is physically vulnerable to its disturbance through direct contact and resuspension of bottom sediments (Jennings et al., 1998). Drift net fishing is also known for its environmental impact due to bycatch non-targeted species (Sala, 2015), which is the least used fishing method in Santiago Island (Gamboa). It is not known to impact marine plants such as seagrass, and its effect on non-targeted species can be reduced by regulating the net mesh size.

Considering the concept that well-informed stakeholders comply more with the establishment of the conservation area has increase research on the understanding of people's perception and attitudes when it comes to marine ecosystem protection. For the successful implementation of management of the marine ecosystem, it is crucial to investigate drivers that prevent its implementation (Elggren, 2019). Studies such as these of Gelcich et al. (2014) and Lotze et al. (2018) revealed that examining how people or stakeholders are linked to different aquatic threats and whether they are cognizant of it may lead to their behavioral change. This study shows that fishers in and around Gamboa are less informed about seagrass, their morphology, and where they are found in the marine environment. Although 90% affirmed of knowing seagrass, they were unable to confirm where seagrasses are likely to be in a marine environment. They believe that seagrasses are mostly found in the deep sea while they are known to occur both in shallow and deep water with a high probability of occurrence in shallow water depending on light availability (Short et al., 2016).

In terms of seagrass feature, an important number of fishers identified seagrasses through pictures, but the majority confused seagrasses to marine green algae and others, to the red algae and seaweed. They indicated that the seagrass ecosystem in Gamboa is primarily threatened by bad fishing practices such as the dominant dragnet fishing, sewage, climate change, coastal development, and boating activities. Sewage runoff and coastal development in and along the seagrass ecosystem in Gamboa are the most visible and identifiable threats. These might be the main source of pollution and nutrients loading, the excess of which is causing harm and/or will affect seagrass meadow. This has reduced their catch, marine biodiversity as perceived by fishers in and around Santiago Island (Gamboa). In addition to fishers' perception about seagrass, their identification, and environment, the perceived ESS of seagrass included the provision of shelter and refused for the young marine animal, provision of food for fish, sea turtle, and other marine mammals, holding bottom sediments, toxins, and purifying water; as well as increasing catch.

Yet, there was a noticeable difference between different groups of education and fishing experience, which showed individual fishers' understanding or awareness across the study. The basic ESS of seagrass such as "Providing shelter and refuse for young marine animal" and "providing food for fish sea turtles and the other marine animal" are well perceived and understood by fishers than those that require more knowledgeable theory such as "Store more carbon than forests and reduce climate change" and "Can increase catch income." Therefore, the ESS, such as "Store more carbon than forests and reduce climate change," was perceived by fishers that have a higher level of education and fishing experience. Fishers were curious to know more about seagrass and the marine environment around Santiago Island, including knowledge about how seagrasses are important, how to protect them, their features, and the type of environment seagrasses inhabit. Access to such information was suggested through local TV, radio, information signs along the beach where seagrass are found, and via meetings. Both socio-economic and political issues can arise when environmental protection increases, increasing studies on differences in stakeholder perceptions may guide and help policymakers, managers of marine ecosystems, educators, and conservationists to sustainably improve management and conservation in a way that positively relates people to the sea (Elggren, 2019).

6. Summary of the findings, conclusion, and policy recommendations

6.1 Summary of the findings

The main findings from the ground true indication and characterization reveal that: *Halodule wrightii* species of seagrass reported in 2016 by Creed et al. has increased in biomass, canopy height, and total area. However, its shoot density has decreased from 2016 to 2021.The actual shoot density was 5-fold less than that reported by Creed et al. (2016), and the total biomass was higher than this reported by Creed et al. The ten (10) patches of $20m^2$ reported then have extended to $6243m^2$.

The main findings of the survey indicate that fishers:
Understand the importance of the sea, and are conscious about its cleanliness. Are less aware of how seagrasses look like and where they can be found. Are aware of the basic provisioning and regulating services of seagrasses, but not fully aware of ESS such as “Storing more carbon than forests, reduce climate change” and “Can increase the catch. “Attribute the impacts on seagrass and their meadow to bad fishing practices, released sewage, climate change, boating, and coastal development. Are unsure about how to protect seagrasses and willing to know more about seagrass and their environment.

6.2 Conclusion

This study characterizes and compares the actual state of the seagrass meadow in Gamboa, Cape Verde, Santiago Island and further assesses fishers' perception of seagrass and their ecosystem services. *H. wrightii* showed an increasing ecological characteristic such as the meadow extent, biomass, and canopy height. However, the shoot density has decreased from 2016-2021. The observed increase in biomass could be a result of the meadows fertilization either by abiotic factors such as good light irradiance due to low water turbidity and nutrients input from the nearby coastal development activities, or biotic factors such as low level of grazing and epiphytic organisms. *H. wrightii* has a higher demand for nutrient availability than most of the seagrass species and is very tolerant to disturbance when water condition is suitable for its survival, and rapidly recolonize strip areas. The biomass of the meadow was correlated with the meadow shoot density, which is hypothesized as a result of seagrasses clonality and the growth-form plasticity demonstrated in clonal terrestrial plants and clonal algae. The actual shoot density was 5-fold less than that reported by Creed et al. (2016), and that reported by Magalhães et al. (2021). However, it was close to those reported in Brazil by Magalhães et al. (2017) and in Principe Island by Alexandre et al. (2017).

The marine ecosystem plays an important role for people living on Santiago Island. Respondents from the survey in and around Gamboa expressed their link to the sea, perception of seagrass, and its ecosystem services. The main findings reveal that fishers' understanding of sea maintenance was sustainable since the majority were conscious of the cleanness of the sea. Their dominant fishing activity does not impact seabed, including seagrass but could be a threat to some endemic species on the island. However, practices such as dragnet fishing and boat anchoring in shallow water could damage seagrass meadows. When it comes to their perception, fishers were less aware of seagrass, their features, and biotope. The majority confused seagrasses to marine green algae and others, and believe that they are only found in the deep sea. They are aware of ESS provided by seagrass and attribute the threats on seagrass to bad fishing practices such as dragnet fishing, sewage, climate change, coastal development, and boating activities. Therefore, there was a notable difference in the perception of fishers who have higher experience and educational level than others. Basic regulating and provisioning ESS of seagrass meadows were better perceived and understood by fishers than those requiring more knowledgeable theory such as "Storing more carbon than forests and reducing climate change" and "Can increase the catch." These ESS were perceived by fishers that have a higher level of education and fishing experience. They would like to know more about seagrasses, their environment, and how to protect them. This suggests that when information is provided, awareness may increase and lead to fishers' involvement in management. If policymakers, managers, and conservationists pay more attention to this, directives and information can be simply circulated and positively affect conservation and management activities.

6.3 Recommendations

Based on the findings, this study recommends regular monitoring of seagrass ecological characteristics in parallel with sea surface temperature, salinity, and nutrient level to understand the relationship between changes in seagrass ecological parameters and these variables.

Socio-economic adjustment needs to be accomplished if further conservation and management of seagrass are intended. Fishers should be trained about seagrasses, their environment, their ESS, and how they can be protected. This can be done through TV, radio, using information signs along the beach where seagrasses are found, or through a meeting. They should be sensitized on their destructive fishing practices in and around seagrass meadows and be provided with legal fishing equipment as an incentive.

Sewage runoff and coastal development should be prohibited near seagrass meadows, and environmental impact assessment should be conducted for any further development around the meadows.

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Appendices

Appendix I

QUESTIONÁRIO PARA OS PESCADORES

O objetivo deste questionário é recolher informações que serão utilizadas no estudo de avaliação da opinião dos pescadores e dos trabalhadores costeiros sobre o ecossistema de ervas marinhas em Cabo Verde (Baía de Gamboa). Este estudo é conduzido em cumprimento parcial ao meu programa de Mestrado em Alterações Climáticas e Ciências Marinhas na Universidade Técnica do Atlântico, Mindelo, Cabo Verde. O vosso apoio e disponibilidade para responder a estas questões são muito importantes para o sucesso do meu estudo. Por essa razão, solicito-lhe gentilmente que responda a todas as perguntas e forneça informações claras e adequadas acerca do tema. Assegure-se de que as suas informações serão utilizadas apenas para os fins relacionados com o meu estudo.

A. INFORMAÇÃO DEMOGRÁFICA

Esta secção será utilizada para obter o perfil pessoal e os dados demográficos dos entrevistados

1. **Género**

   Masculino ☐ Feminino ☐

2. **Idade**

   18-25 ☐ 26-33 ☐ 33-40 ☐ 41-48 ☐ 49 - 56 ☐ acima dos 57 ☐

3. **Nível de Escolaridade**

   Primário ☐ Secundário ☐ Superior ☐ Informal ☐

B. PRÁTICAS DA PESCA

Esta secção ajudará a obter informações sobre as atividades da pesca praticadas na área de estudo. Isto pode ajudar a identificar a fonte provável de ameaças às ervas marinhas, e que informações são necessárias para as minimizar.

4. **Há quanto tempo pratica a pesca?**

   quase 5 anos ☐ quase 10 anos ☐ quase 15 anos ☐ Mais de 20 anos ☐

5. **Que tipo de material de pesca usa?**

rede de arrasto ☐ ede de emalhar de deriva ☐ ıas e anzóis ☐ t os listados acima ☐

6. **Quais são as fontes do seu materials de pesca?**

Governo ☐ ONGs ☐ outros: especifique………….

7. **Segue os conselhos de especialistas no sentido de não utilizar utensílios de pesca inadequados?**

Sim ☐ Não ☐

8. **Se não, porquê?**..

9. **Durante as atividades de pesca ancora-se em áreas rasas?**

Sim ☐ Não ☐

10. **Se sim, pisa no chão?**

Sim ☐ Não ☐

11. **Normalmente, leva os seguintes materiais para o mar?**

plástico ☐ roupa velha ☐ Outros: especifique………….

12. **Como é que se desfaz do lixo que transportou consigo durante a pesca?**

atiro para o mar ☐ levo-o de volta ☐ outros: especifique………….

C. <u>PERCEÇÃO</u>

Esta secção fornecerá informações sobre o conhecimento e a perceção dos pescadores sobre as ervas marinhas. As questões são inicialmente sobre o reconhecimento da erva marinha, para compreender e estabelecer se existe uma diferença entre estar consciente e ser capaz de a identificar. E também conhecer as suas necessidades específicas de informação.

13. **Sabe o que são ervas marinhas?**

Sim ☐ Não ☐

14. **Se sim, onde stão localizados?**

zonas rasas ☐ mar profundo ☐ Ambos ☐ Não sei ☐

15. **Frequentou alguma formação sobre ervas marinhas?**

Sim ☐ Não ☐

16. Se sim, qual o departamento ou ministério responsável pela sua organização? Por favor especifique...…….

17. Consegue identificar o que isto é relativamente à vegetação submarina? Escolha uma das opções a partir das imagens

F1 ☐ F2 ☐ F3 ☐ F4 ☐

Achou difícil a pergunta com as fotografias das plantas marinhas?

Sim, duvido das minhas respostas ☐ Eu conhecia uma ou duas ☐

Nem difícil nem fácil ☐ Não, foi fácil ☐

18. Quais são as principais atividades perto da zona das ervas marinhas/ou atividades que têm lugar perto da linha costeira?

descarga de peixe ☐ moínhos de peixe ☐ Cais ☐ povoações ☐

19. **Quais são alguns dos sinais/indicadores de uma possível identificação de localização de ervas marinhas que conhece?** ………………………………………………………………………………………………

20. Que tipo de organismos aquáticos se encontram habitualmente em torno da região rasa?

Tartarugas ☐ caranguejos ☐gas marinhas ☐ıs marinhas ou☐ especifique………….

21. Conhece alguma possível ameaça que possa perturbar o ecossistema das ervas marinhas?

Sim ☐ Não ☐

22. Se sim, por favor, enumere-os:

Más práticas da pesca ☐ Mudanças climáticas ☐

Atividades náuticas ☐ Construção ou desenvolvimento costeiro ☐

Mineração de areia ou dragagem ☐ Esgotos ☐

Outros: especifique………….

23. O que vê como a principal ameaça para esta zona frontal da água entre 0-10 metros de profundidade

Más práticas da pesca ☐ Mudanças climáticas ☐

Atividades náuticas ☐ Construção ou desenvolvimento costeiro ☐

Mineração de areia ou dragagem ☐ Esgotos ☐

outros: especifique…………

24. Qual é, na sua opinião, o impacto destas ameaças nesta área?

Redução de biodiversidade ☐ Aumento de nutrientes no mar ☐

Captura reduzida ☐ Aumento da erosão ☐

25. **O que pensa que pode ser feito para prevenir e/ou reduzir as ameaças acima referidas?**

……………………………………………………………………………………………
……………………………………………………………………………………………
…………

26. **Acredita que as ervas marinhas?**

Retém os sedimentos e toxinas do fundo e depois estabiliza e purifica a água ☐
Oferece abrigo e refúgio para os animais juvenis e marinhos ☐
Fornece alimento para peixes, tartarugas marinhas e outros animais marinhos ☐
Armazena mais carbono do que as florestas e reduz as mudanças climáticas ☐
Pode aumentar a sua captura e rendimento ☐
Eu não acredito ☐ Não sei ☐

27. Como pescador, acha que tem interesse na protecção das ervas marinhas?

Sim ☐ Não ☐

28. **Assim sendo, o que acha que pode fazer para melhorar o ecosistema das ervas marinhas**?.........................

29. **Deseja saber mais sobre as ervas marinhas e o ambiente costeiro em redor da ilha de Santiago**?

Sim ☐ Não ☐

30. Se assim for, sobre o quê gostaria de saber mais?

Ser capaz de identificar as ervas marinhas ☐ Saber como protegê-las ☐

Conhecer a sua importância ☐ Conhecer o tipo de ambiente onde se encontra ☐

Outros: por favor especifique………………...

31. **Que tipo de informação consideraria bom para aprender mais sobre as ervas marinhas e o ambiente costeiro em Santiago?**

Facebook ☐ TV ☐ Rádio ☐

Placas informativas na praia em zonas onde temos ervas marinhas ☐

Informações através de reuniões ☐ Outros: por favor especifique…………….☐

Underwater vegetation photographs used to assess knowledge about seagrasses features

P1: green marine algae

Source :
https://www.123rf.com/photo_19760643_macro-extreme-closeup-of-strands-of-green-marine-algae-on-white-background.html

P2: Rhodophyta red algae

Source :
https://www.123rf.com/photo_91832448_rhodophyta-red-algae-in-quintana-roo-of-mexico.html?vti=mjcoqidd3axcf3p30p-1-24

P3: Seaweed

Source :
https://www.gettyimages.ie/detail/photo/seaweed-at-ulva-of-mull-in-scotland- royalty-free-image/587958342?adppopup=true

P4: Halodule wrightii

Source :
https://www.gettyimages.ie/detail/photo/seaweed-at-ulva-of-mull-in-scotland- royalty-free-image/587958342?adppopup=true

P5: Halodule wrightii Cape Verde

Source : https://www.gettyimages.ie/detail/photo/seaweed-at-ulva-of-mull-in-scotland- royalty-free-image/587958342?adppopup=true

Appendix II

Table showing the ecological parameters Statistiques

Statistiques / Parameters	Mean	Standard deviation	Minimum	Maximum	Standard error
Shoot Density (per m 2)	989.6	671.6	144	2320	150.2
Above ground biomass (g/m2)	117.7	85.3	31.5	319.9	28.4
Below ground biomass (g/m2)	194.3	148.6	87.6	533.7	49.5
Total biomass (g/m2)	311.9	214.96	122.2	853.6	71.7
Shoot length (cm)	9.5	1.5	7	12.4	0.5
Rhizome length (cm)	10.3	2.2	6.8	15	0.7

Figure: showing changes in seagrass ecological parameters between 2016 – 2021 in Gamboa

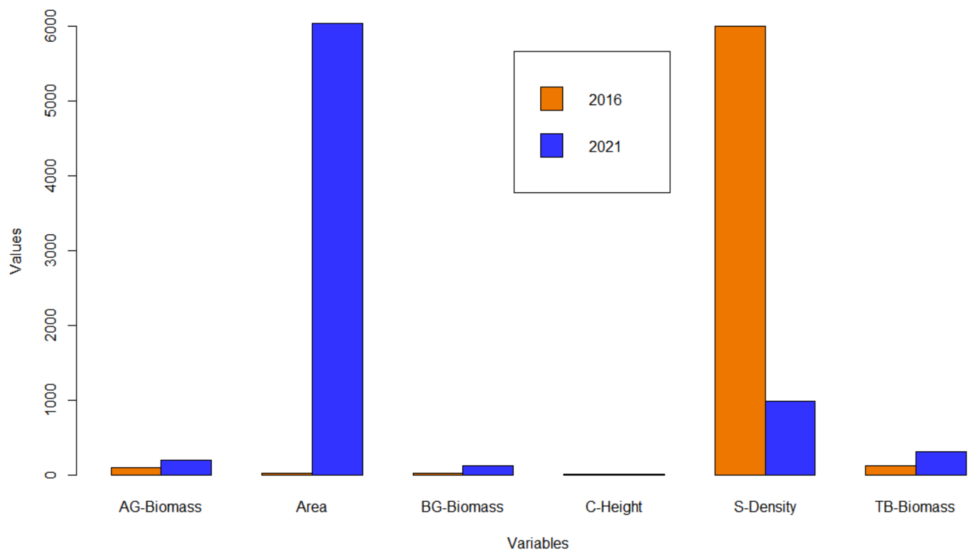

Table showing Source fishing material

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	NGOs	1	3.3	3.3	3.3
	Other	29	96.7	96.7	100.0
	Total	30	100.0	100.0	

Figure showing fishers responses about seagrasses

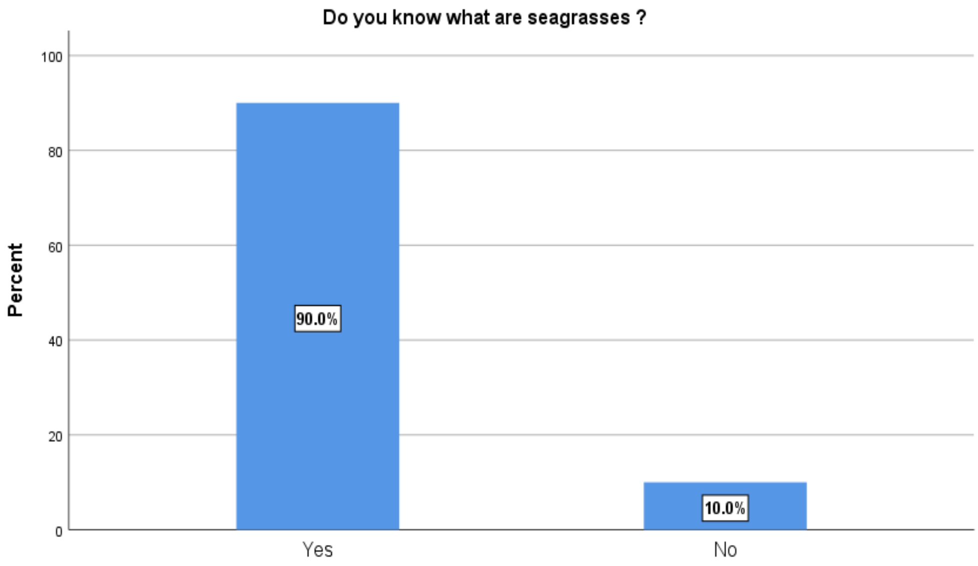

Table showing respondents proposed mitigation practices to reduce treats on seagrass

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Protect the environment	3	10.0	10.0	10.0
	Stop sewage	1	3.3	3.3	13.3
	prevent nutrient plastic loading and erosion	2	6.7	6.7	20.0
	Only GOD	1	3.3	3.3	23.3
	Good fishing practices	2	6.7	6.7	30.0
	Don't know	13	43.3	43.3	73.3
	Reduce contrate with foreign forces	1	3.3	3.3	76.7
	Cleaning the ocean	4	13.3	13.3	90.0
	Training fishers	3	10.0	10.0	100.0
	Total	30	100.0	100.0	

Appendix III

Photographs showing survey interviews with some fishers


Fly
Emirates


HARD
ALL NIGHT LONG

Appendix IV

Photographs showing sewage channels and coastal development in the study area

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