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

PHYSICAL AND BIOLOGICAL CHARACTERISTICS OF A SEAGRASS BED OFF PORTO NOVO (SANTO ANTÃO), CABO VERDE

BÔLA-NLÉ CHRISTELLE AKONDÉ

Master Research Program on Climate Change and Marine Sciences

São Vicente
2023

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

PHYSICAL AND BIOLOGICAL CHARACTERISTICS OF A SEAGRASS BED OFF PORTO NOVO (SANTO ANTÃO), CABO VERDE

BÔLA-NLÉ CHRISTELLE AKONDÉ

Master Research Program on Climate Change and Marine Sciences

Supervisor | Dr. Henk-Jan Hoving
Co-supervisor | Dr. Teresa Amaro

São Vicente
2023

UNIVERSIDADE TÉCNICA DO ATLÂNTICO
INSTITUTO DE ENGENHARIA E CIÊNCIAS DO MAR
WEST AFRICAN SCIENCE SERVICE CENTRE ON CLIMATE CHANGE AND ADAPTED LAND USE

Physical and biological characteristics of a seagrass bed off Porto Novo (Santo Antão), Cabo Verde

Bôla-nlé Christelle Akondé

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

Supervisor

Henk-Jan Hoving
GEOMAR

Co-supervisor

Teresa Amaro
CESAM (Centre for Environmental and Marine Studies)

São Vicente
2023

UNIVERSIDADE TÉCNICA DO ATLÂNTICO
INSTITUTO DE ENGENHARIA E CIÊNCIAS DO MAR
WEST AFRICAN SCIENCE SERVICE CENTRE ON CLIMATE CHANGE AND ADAPTED LAND USE

Physical and biological characteristics of a seagrass bed off Porto Novo (Santo Antao), Cabo Verde

Bôla-nlé Christelle Akondé

Panel defense

President

Examiner 1

Examiner 2

São Vicente
2023

Financial support

The German Federal Ministry of Education and Research (BMBF) in the framework of the West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL) through WASCAL Graduate Studies Program in Climate Change and Marine Sciences at the Institute for Engineering and Marine Sciences, Atlantic Technical University, Cabo Verde.

Dedication

I dedicate this work to the Holy Trinity who has always guided my steps and accompanied me throughout this training and all the processes of my life.

I also dedicate it to my daughters Conania and Sheila, and to my mom Beatrice, whose love, support, and presence give me the strength to keep my sights on the goal.

Acknowledgments

I would like to thank the staff of WASCAL Cabo Verde, headed by Dr. Corrine Almeida, for their efforts in providing us with quality training and achieving my goals.

I would also like to thank all those who provided me with scientific support. I would like to mention Henk-Jan Hoving, Teresa Amaro, Rui Freitas, Clara Loureiro, and Julian Stauffer.

My heartfelt thanks to my family friend Codja for your love and presence all the time. Marie Michele for all your love, especially your presence at my children's side as mother and aunt, to fill the void of my absence as best as you could. I have no enough words to express my gratitude.

My friends Gerard Zinzindohoue, Desire Attiogbé, Paulo Pinheiro, and Jean Edwens Daniel, for supporting me in different ways at different levels and at different stages of this journey. My heartfelt thanks to each and every one of you.

To you, my fellow students of the 3rd batch of the WASCAL master program in marine science and climate change, for the path of learning with you and especially for your support and help during this training. Especially Amadou Biteye, thank you from the bottom of my heart.

Resumo

As pradarias de ervas marinhas são conhecidas pelos seus serviços e funções ecossistémicas, incluindo a biodiversidade. Recentemente foram documentadas a presença de quatro espécies na Eco-Região Marinha da África Ocidental (WAMER): *Cymodocea nodosa*, *Halodule wrightii, Ruppia maritima* e *Zostera noltei*. As ervas marinhas de Cabo Verde têm agora um novo registo na Ilha de Santo Antão desde o primeiro registo na ilha de Santiago em 2016. Por conseguinte, é necessário documentar o prado ao largo do Porto Novo (Santo Antão), com inclusão de parâmetros físicos e biológicos, bem como a biodiversidade do nekton envolvente. Para descrever as propriedades físicas e biológicas do leito de ervas marinhas, foram: 1) utilizadas ferramentas de imagem subaquática (dispositivo de câmara de inspeção Oktopus e a câmara de pé PlasPi) para mapeamento, descrições físicas e observação da biodiversidade, com foco na peixe; 2) uma sonda multiparamétrica EXO2 para medir as condições físico-químicas da coluna de água no habitat das ervas marinhas; e 3) um questionário dirigida às partes interessadas envolvidas no monitoramento de ervas marinhas, para investigar o estado de conservação das ervas marinhas em Cabo Verde. A erva marinha *Halodule wrightii* foi encontrada a uma profundidade média de 7 metros, no fundo arenoso, cobrindo 164,994 m^2 ao longo da costa leste da ilha, entre 17°0196264N, 25°0427160W e 17°027341N, 25°028557W. A temperatura média no habitat das ervas marinhas foi de 24°C e a salinidade média foi de 35,5 PSU; o oxigénio dissolvido médio foi de 7,4mg/l e a concentração média de clorofila-*a* foi de 0,4µg/l.. Quatro espécies diferentes de peixes (*Sphoeroides marmoratus, Stephanolepis hispidus*, *Gymnothorax vicinus, Pegusa cadenati*) foram registados no prado de ervas, uma espécie de algas verdes (*Avrainvellea sp*) e algas vermelhas (*Asparagopsis taxiformis spp*). No que diz respeito à conservação e ao estado das ervas marinhas no país, não foram tomadas medidas concretas desde então, e todas as realizações sobre as ervas marinhas foram basicamente conhecimento e sensibilização a diferentes níveis e plataformas. As ervas marinhas de Santo Antão necessitam de atenção para o estudo do seu habitat no que diz respeito à biologia e à diversidade do nekton. As ervas marinhas de Cabo Verde em geral e de Santo Antão em particular necessitam de uma documentação aprofundada e de medidas de conservação concretas.

Palavras-chave: Ervas marinhas, Nekton, Santo Antão, Biodiversidade, Imagens subaquáticas, Conservação, ambientes oceanográficos.

Abstract

Seagrass meadows are known for their ecosystem services and functions, including biodiversity. Four species have recently been documented in the West African Marine Eco Region (WAMER): *Cymodocea nodosa*, *Halodule wrightii*, *Ruppia maritima* and *Zostera noltei*. Cabo Verde seagrass now has a new record on Santo Antão Island since the first record on Santiago Island in 2016. Therefore, there is a need to document the meadow off Porto Novo (Santo Antão), including physical and biological parameters, as well as the fish. To describe the physical and biological properties of the seagrass bed we: 1) used underwater imaging tools (Oktopus inspection camera device and the PlasPi standing camera) for mapping; physical descriptions, and biodiversity observation, with a focus on macro and megafauna, 2) a multiparameter probe EXO2 to measure physicochemical conditions of the water column on the seagrass bed and 3) a questionary addressed to stakeholders involved in seagrass monitoring, to investigate the conservation status of seagrass in Cabo Verde. The seagrass *Halodule wrightii* was found at an average depth of 7 meters, on the sandy bottom, covering 164.994 m^2 along the east coast of the island between 17°0196264N, 25°0427160W and 17°027341N, 25°028557W. The average temperature in the seagrass habitat was 24°C, and the average salinity was 35.5 PSU; the average dissolved oxygen was 7.4mg/l and chlorophyll-a average concentration was 0.4µg/l. Four different species of fish (*Sphoeroides marmoratus*, *Stephanolepis hispidus*, *Gymnothorax vicinus*, *Pegusa cadenati*) were present in the grass meadow, a species of green algae (*Avrainvellea sp*) and red algae (*Asparagopsis taxiformis spp*) are recorded on the seagrass. Regarding the seagrass conservation and state in the country, no concrete measures have been taken since then, and all achievements on seagrass have been knowledge and awareness at different levels and platforms. Santo Antão's seagrass needs more attention to study their habitat regarding the biology and nekton diversity. Seagrasses of Cabo Verde in general, and Santo Antão especially, need deep documentation and concrete conservation measures.

Keywords: Seagrass, Nekton, Santo Antão, Biodiversity, Underwater imaging, Conservation, oceanographic settings.

Abbreviations and acronyms

AUV	Autonomous Underwater Vehicle
BMBF	Federal Ministry of Education and Research
C	Commercial
CSV	Comma-Separated Values
DNA	Direção Naçional do Ambiente
ECO CV	Cabo Verdean Ecotourism Association
EEZ	Exclusive Economic Zone
FNU	Formazin Nephetometric Units
GB	Gigabyte
GPS	Global Positioning System
LC	Low-Commercial
MAA	Ministerio do Agriculture é Ambirnte
MPAs	Marine Protected Areas
MPAs	Marine Protected Areas
MSP	Marine Spatial Planning
NC	Non-Commercial
NDC	Nationally Determined Contribution
NGO	Non-Governmental Association
ODO	Oxygen Dissolved Optical
ODV	Ocean Data View
OECD	Organization for Economic Co-operation and Development

ORP	Oxidation Reduction Potential
PA	Protected Area
PlasPi TDM	Temperature/Depth/Multispectral
QGIS	Quantum Geographic Information System
RFU	Radical Fundamentalist Unit
SAE	Santo Antão East
SD card	Secure Digital card
SGD	Sustainable Development Goals
TDS	Total Solid Dissolved
UICN	International Union for Conservation of Nature
USB	Universal Serial Bus
UTC	Coordinated Universal Time
VLC	VideoLAN Client
WAMER	West African Marine Eco Region
WASCAL	West African Science Service Centre on Climate Change and Adapted Lamd Use
WiFi	Wireless Fidelity
Win SCP	Windows Secure Copy

List of contents

Figure index

Table index

1. Introduction

Seagrasses are a unique group of flowering plants that have adapted to exist fully submersed in the sea, profoundly influencing the physical, chemical, and biological environments in coastal waters (Orth et al., 2006). Seagrasses are somewhat like true grasses (on land) in the mode of growth (Brasier, 1974), but unlike exhibit low taxonomic diversity (Orth et al., 2006), and form an ecological group in the coastal environment (Brasier, 1974). Seagrass sequesters approximately 10% of the annual carbon buried in ocean sediment (Resilient Seagrasses, 2022), and provides complex food webs to species and habitats way beyond the extent of their distribution (Omollo et al., 2022). They support an equally wide array of grazers and predators (Unsworth & Butterworth, 2021), and are mainly known for driving nekton's biodiversity (Hayes et al., 2020). Seagrass is found in all continents except Antarctica and form extensive habitats which support highly diverse communities (Duarte et al., 2008), they have a worldwide distribution and are newly recorded within the West African Marine Ecoregion (WAMER), namely Cabo Verde, the Gambia, Guinea Bissau, Guinea, Mauritania, Senegal and Sierra Leone (Vegh et al., 2019). Despite the little documentation and rudimentary knowledge of the region, four different species (*Cymodocea nodosa*, *Halodule wrightii*, *Ruppia maritima*, and *Zostera noltei*) occurrences have been identified, and *Halodule wrightii* is the main species of the region (Cheikh et al., 2022). In addition to its richness of endemic species, Cabo Verde has a large number of threatened marine species, giving rise to several innovative conservation measures (Florencio et al., 2021). These conservation measures are taken based on data collected, mapped and analyzed to produce results, especially with sampling methods that will not damage the habitat and kill species, including unnecessary bycatch (Walters & Scholes, 2017).

The territory of Cabo Verde consists of 99% ocean, and its economy and prosperity depend on the health and sustainable use of the ocean. For this reason, the country implements the 2030 agenda linked to SDG 14, and the African Union's Agenda 2063 to promote Marine Spatial Planning (MSP) and set Marine Protected Areas (MPAs) (OECD, 2022). The plan is basically to facilitate the patrol and control of some important areas that may offer benefits for marine ecosystems and local communities (OECD, 2022). For this to be done, vulnerable habitats and biodiversity hotspots need to be mapped in Cabo Verde waters to be better able to study them to understand their function and consider them for the health status of the local marine ecosystems. As a coastal marine ecosystem, seagrass is globally known as one of the most valuable habitats with a need for a high understanding, study and protection for the good of the ocean (Nordlund et al., 2018). Seagrass beds have only recently been discovered in west Africa and consequently are very little studied, despite their great importance and their ecological function (Touron-gardic et al., 2022). In Cabo Verde, the first record of seagrass was in 2016 in Santiago Island, Gamboa bay, however, there is no complete map of its distribution in this region, and it is still largely unknown what the biological and physical properties of the seagrass are (Vegh et al., 2019). Seagrass is particularly known as a driver of food security, a protector of the coast habitat and a food supplier for charismatic and endangered species, such as dugongs and sea turtles (Touron-gardic et al., 2022). They play a role in climate change effect mitigation by sequestration of carbon dioxide in the ocean (Omollo et al., 2022). Because of these unique ecological and societal roles, it is important to collect additional data on Cabo Verde seagrass beds.

Cabo Verde, an archipelago of ten islands and a few islets is located in the Atlantic Ocean on the coast of West Africa, in the so-called Macaronesia ecoregion at 500 km West of the Senegal coast (Eastern Atlantic Ocean). Unlike other Macaronesia islands, it is classified in the West African ecoregion with a tropical Atlantic transition due to its tropical climate (Piñeiro-corbeira et al., 2023). The country comprises 10 islands and 8 islets, comprising a land area of 4.033 km^2, and scattered over 58.000 km^2 of ocean (Hazevoet et al., 2010), with 734,000 km^2 of Exclusive Economic Area (EEZ). The archipelago islands of Cabo Verde, with its 1,000,000 km^2 of oceanic territory, depend mainly on marine resources in terms of fisheries and connected activities. Their coastal areas ensure human well-being through resource availability and jobs. This reality exposes the coastal areas of the country to great natural hazards, due to high pressure from anthropogenic activities (OECD, 2022). The lack of maps and valuable baseline knowledge on the environmental status of their marine ecosystems to ensure sustainable use, management, conservation, and restoration of their ocean and resources will make the situation worse in the future.

Santo Antão is the third most populated island of the archipelago, has the highest poverty rate and unequal income, and is highly vulnerable to extreme natural phenomena (Instituto Nacional de Estatistica, 2021). The coast of Santo Antão is rich and diverse in terms of valuable and threatened species, which makes the island one of the fishing points of the country. Despite its contribution to the cash biomass and presence of valuable and emblematic species, the coast of Santo Antão is exposed to overexploitation due to a lack of knowledge and the absence of a map and management plan for the use of their marine resources (Benchimol & Francour, 2009).

The COAST project is the short form of “Conservation of marine ecosystems around Santo Antão, Cabo Verde; implications for policy and society. It expects to improve current knowledge of the marine habitats of the island and to provide efficient management recommendations for their sustainable development, along with mitigation plans for the effects of global changes, in line with the needs of stakeholders and local communities. The baseline data collection on the project aims to review current knowledge on Santo Antão seabed morphology, biodiversity, and habitats focusing on the first 200 m below sea level to identify target survey areas [1]. With this project, new seagrass beds were discovered in Santo Antão. This discovery of seagrass off Santo Antão asked for a description and documentation to provide more knowledge about the presence of seagrass in Cabo Verde and specifically the island of Santo Antão. Therefore, we aimed to map the area of seagrass and its biodiversity and to collect new information for the protection and care of the habitat. Specific questions are proposed:

1. What are the physical parameters, size, depth of occurrence, conductivity and temperature of the seagrass meadow of Porto Novo (Santo Antão)?
2. Which marine nekton species occur on the seagrass meadow, and how does this biodiversity compare to a non-seagrass area?
3. What is the state of the seagrass in Cabo Verde, and which measures can be taken to conserve the seagrass off Porto Novo (Santo Antão)?

[1] https://www.coastcv.eu/

1.1 Objectives of the work

The work aims to document the seagrass meadow off Porto Novo (Santo Antão), including physical and biological parameters, specifically the macro and megafauna.

Specifically, the objectives are:

1- Describe the seagrass bed of Porto Novo (Santo Antão)
2- Compare the physical parameters of the seagrass field to a non-seagrass area off Porto Novo (Santo Antão)
3- Compare the fish biodiversity of the seagrass field to a non-seagrass area off Porto Novo (Santo Antão)
4- Investigate the ecological and conservation state of Cabo Verde seagrass and discuss measures for further research and conservation of the Porto Novo seagrass bed.

2. Literature review

2.1 Seagrass knowledge

- *Overview of global seagrass*

Seagrasses are true grasses that have adapted to life in the ocean by developing a specific morphology with an anchorage system comprising rhizomes and roots, air lacunae to supply roots with oxygen (Creed et al., 2016). They comprise a small taxonomic group of marine angiosperms with only about 60 species, which have a worldwide distribution and are found in both temperate and tropical regions (Orth et al., 2006). Seagrasses look similar to grasses on land and do not have charisma like other marine ecosystems while they provide a wide range of considerable ecosystem services. Recent literature shows that there are more than 1.000.000 km^2 of seagrass superficies despite the large unmapped areas around the world (Nordlund et al., 2018). Many southern seagrass species are perennial (grow all year round), covering extensive areas of Shark Bay, Cockburn Sound, Geography Bay, Flinders Bay, and along the southern coast (Bandeira & Björk, 2001) (Figure 1).

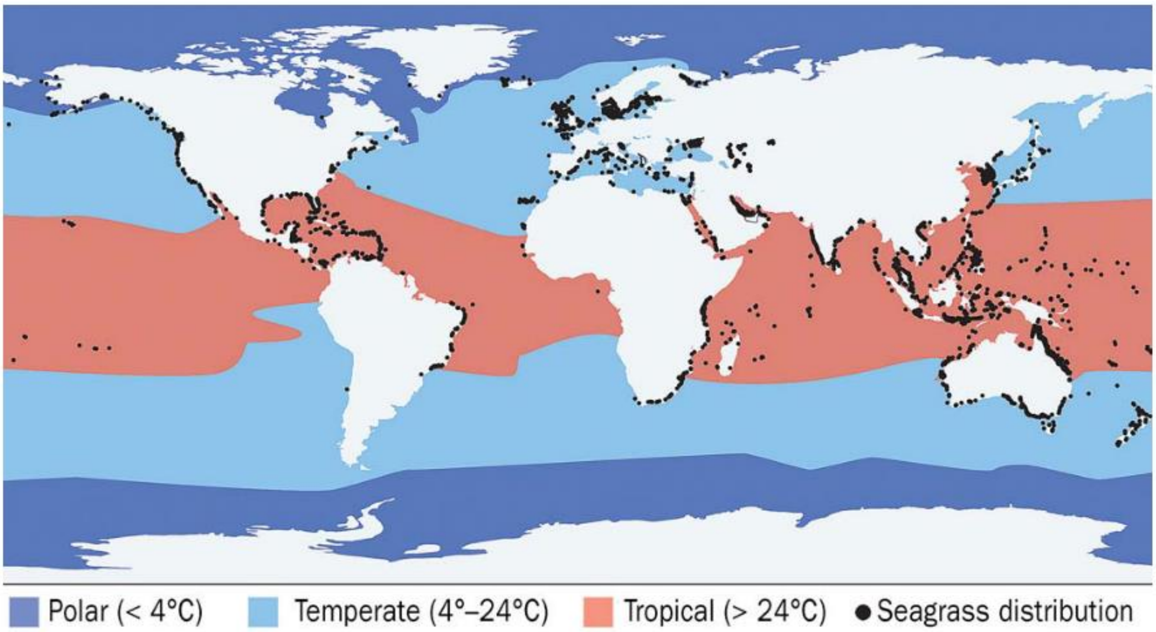


Figure 1: Seagrass worldwide distribution related to ocean mean temperature. Source: (Orth et al., 2006)

- *Overview of the seagrass situation*

Seagrass knowledge and consideration is underestimated and undertreated despite its large value and ecological importance for the ocean's health, marine organisms and indirectly for humans. Seagrass is now being lost globally rapidly due mainly to anthropogenic stressors (Nordlund et al., 2018). Seagrass loss declines at scales of square meters to hundreds of square kilometres. Therefore, there is a need to increase awareness of protection, monitoring, management, and restoration. The improvement of conservation and management of seagrasses, part of the broader category of coastal and marine ecosystems, requires increased knowledge not only of how seagrass meadows respond to environmental change but also of the magnitude of the benefits these ecosystems supply to humans locally, regionally and globally (Vegh et al., 2019).

- *Seagrass function and services*

Seagrass is a natural process and components that directly or indirectly benefit human needs. The seagrass beds increase the biodiversity of plants, animals and fungi in the areas where they occur, as a shelter for juvenile animals, and act as nursery and foraging areas for many species (Nordlund et al., 2018). Seagrass meadows are important nursery areas for countless marine organisms, including blue swimmer crabs, prawns, western rock lobster, whiting, tailoring, herring, and squid, many of which are recreationally and commercially important (Bandeira & Björk, 2001). Seagrass is also known as a habitat for marine megafauna such as green turtles, manatees and bonnethead sharks that eat seagrass (Pimiento et al., 2020).

- *Seagrass distribution on African Coast*

Seagrasses are found along the African coast, with about 12 species along the eastern coast and 9 species along the western coast. *Halodule wrightii* is known to occur along the west coast of Africa in Nigeria, Benin, Ghana, Sierra Leone, Guinea, Guinea Bissau and São Tomé and Príncipe; on the east coast of Africa in Mozambique, Tanzania, Kenya; as well as Madagascar, Oman and the east coast of India (Creed et al., 2016).

A study of seagrass in seven West African countries, including Cabo Verde brings out four seagrass species (*Cymodocea nodosa*, *H. wrightii*, *Ruppia maritima* and *Zostera noltei*) occurrences in those countries (Cheikh et al., 2022). In early 2016, the first species of seagrass *H. wrightii* Ascherson was recorded at Praia in Santiago Island of Cabo Verde at 1.4 to 1.6 meters depth on fine sand soft bottoms (Creed et al., 2016). *Ruppia maritima* is also reported in two other sites on the Island (Cheikh et al., 2022). Since that first record, several studies have been conducted from the sites to assess, monitor and conserve the seagrass habitat.

- *Species description*

Halolude wrightii (Figure 2) is a seagrass species characterized by bi-dental foliage and a whitish rhizome, known for its small size and sparse distribution in seagrass beds. It is a tropical species, often found in sheltered or semi-sheltered environments such as shallow banks, estuaries or lagoons (Touron-gardic et al., 2022). Literature has shown that seagrass such as *H. wrightii* Aschers. and *Zostera capensis* Setchel were the main source of nutrients in the southern bay at Lnhaca Island, contributing altogether with 490, 30 and 2 tons of C, N and P, respectively (Bandeira & Björk, 2001).

Figure 2: Seagrass species *Halodule wrightii*. Source: (Touron-gardic et al., 2022)

- *Seagrass of Cabo Verde*

Seagrass of Cabo Verde has been recorded in three different sites on the island of Santiago in Gamboa bay, Moia-moia/Baía of Nossa Sra da Luz, and the bay south of Porto Lobo (Creed et al., 2016). According to Cheikh et al., (2022), there is recent documentation of seagrass in Cabo Verde, that include one site on Sal Island, at Salinas de Pedra de Lume.

In Gamboa Bay, the species present is *Halodule wrightii*, in shallow water at 1 to 1.6 m depth, on fine sandy and muddy bottom, covering an area of 6243m^2. Associated with it, there are green algae (Seydouba, 2021), and brown algae (*Phaeophyceae*) (Vinaccia, 2022)reported on the seagrass of Gamboa Bay. Also, there are epiphytic species (Seydouba, 2021), and 1822 *Turritella bicingulata* Lamarck (marine gastropod) reported as the associated animal (Creed et al., 2016) on the same site of Gamboa Bay.

In Santiago Island, there was also a record of the seagrass species *Rupia maritima*, growing in a lagoon of Pedra Badejo wetland, which is a Ramsar site n° 1577, and mainly fed by seawater during the high tides (Martínez-Garrido et al., 2017).

2.2 Nekton biodiversity in the ecosystem

- *Overview of nekton and its importance.*

Nekton is all living and free-swimming organisms that range in size from a few centimetres, e.g., euphausiids (krill), to the largest whales (tens of meters) and inhabiting the coastal and open oceans and at all depths (Brodeur & Pakhomov, 2019). Nekton is predominantly vertebrates and is composed of a wide variety of bony fishes, elasmobranchs (sharks and rays), mammals (whales, seals, sea cows, and the polar bear), reptiles (sea turtles), a species of sea bird (i.e., the emperor penguin), and a few species of cephalopod mollusks (squids, and Octopuses) (Pimiento et al., 2020) that are the only invertebrates that can be considered as nekton.

Nekton plays outsized ecological roles as part of the ecosystem and supports wildlife tourism and even some fisheries. Some species are also culturally important in many places worldwide, and can be considered iconic, the embodiment of gods, symbols of power, or play a myriad of other roles (Grose et al., 2020). Other species provide food for birds, mammals, and larger fish (Raposa, 2009). Nekton species can physically transfer organic materials between intertidal and subtidal estuarine habitats, and as a guild, nekton can be used as an indicator of estuarine conditions. In some situations, nekton can exert substantial top-down control over estuarine system processes (Raposa, 2009).

Nekton comprises taxonomically, morphologically, and functionally diverse assemblages in estuarine and coastal systems (Allen, 2009). They serve a key role in ecosystem function, yet one-third are at risk of extinction. The study of understanding the potential consequences of their loss predicts 11% global loss up to 24% regionally if the current trajectories are maintained during the next century; 48% global loss; up to 70% at the poles with more marked reductions; and eventually total extinction beyond random expectations (Pimiento et al., 2020). Grose et al., (2020), to assist policymakers and grassroots organizers, point out effects on habitat and shelter, impacts on reproduction and disease, and changing distribution of food sources as climate change drivers that can lead to the loss or gain of nekton species. They finally suggest management strategies exist at international and local scales that could help mitigate the impacts of climate change (Grose et al., 2020).

- *Nekton diversity in Cabo Verde*

Cabo Verde Islands is known for being a hotspot of marine species in West Africa, because of its large endemic species (20 out of 315 reports) (Freitas, 2014). The biodiversity of Cabo Verde is composed of 17 cetaceans, 5 marine turtle species, an important population of whale shark and blue marling population (Benchimol & Francour, 2009), many endemic invertebrates such as corn snails (Pires et al., 2020), and many other deep-sea species that are not well documented (Hoving & Freitas, 2022). The coastal species are mostly reef-associated species, composed of 61 families and a total of 135 genera of fish, dominated by morays (*Gymnothorax* and *Muraena*) (Freitas, 2014). Marine coastal biodiversity is important for the country's economy, society and ocean health as it contributes highly to different sectors (Benchimol & Francour, 2009).

2.3 Overview of underwater image use for ecosystem monitoring

Observation is an important tool for information about biodiversity, especially in the marine environment. However, photography may be a helpful tool for increasing emotional engagement with biodiversity and nature and should be coupled with other activities to promote cognitive engagement (Hanisch et al., 2019). Marine data collection can sometimes face an issue of water depth, pressure, and scale at magnitudes typically not associated with other systems, restricting access to locations or sampling sites and increasing instrumentation costs (Bicknell et al., 2016). Remote camera technologies are helping to overcome some of these issues and provide non-destructive methods for monitoring the effects and impact of human activities on habitats and species. Observational data in marine protected areas (MPAs) across habitats and depths to detail reef change or recovery provided by underwater cameras contributed to an understanding of both direct (e.g. target population) and indirect (e.g. trophic cascades) effects of global change and the timescales of its effects (Bicknell et al., 2016). In situ observations will allow long-term observations and day and night comparison and also diversity measurements without the need to catch organisms. Underwater imaging also allows data collection and more details on the organism at the dept that is not physically reachable by men but can study species diversity in all details needed. This is the case of pelagic observation of scorpion fish in the water of Santo Antão by (Hoving & Freitas, 2022), and in the study of new and confirmed records of fishes from the Cabo Verde by (Freitas et al., 2018). With the need for ocean observation and habitat mapping for the sake of ocean health, sustainable use of our ocean resources and mitigation of climate change effects, technology of underwater imaging tools are required and in need (Wölfl et al., 2019).

3. Materials and Methods

3.1 Study site

- *General description*

The study area illustrated in Figure 3 is located on the Island of Santo Antão, in the republic of Cabo Verde. Santo Antão, one of the Windward (Barlavento) group, is the westernmost and northernmost island of the Republic of Cabo Verde. It is located at 25º 03' 31.94" W longitude and 17º 01' 1.65" N latitude (Borges, 2022), and is 16 km away from the island of São Vicente (Rampf, 2021). Santo Antão island, with an area of 779 km^2, is the second largest island and the third most populated island in the country, with 43 915 inhabitants (2010 census) (Borges, 2022), and the second Island with a high rate of species diversity (terrestrial and marine combine) of the country (DNA, 2015). The fieldwork was carried out in Santo Antão island, along the coast of Porto Novo (Figure 3A) at 17.0090N and 25.0336W coordinates (Figure 3).

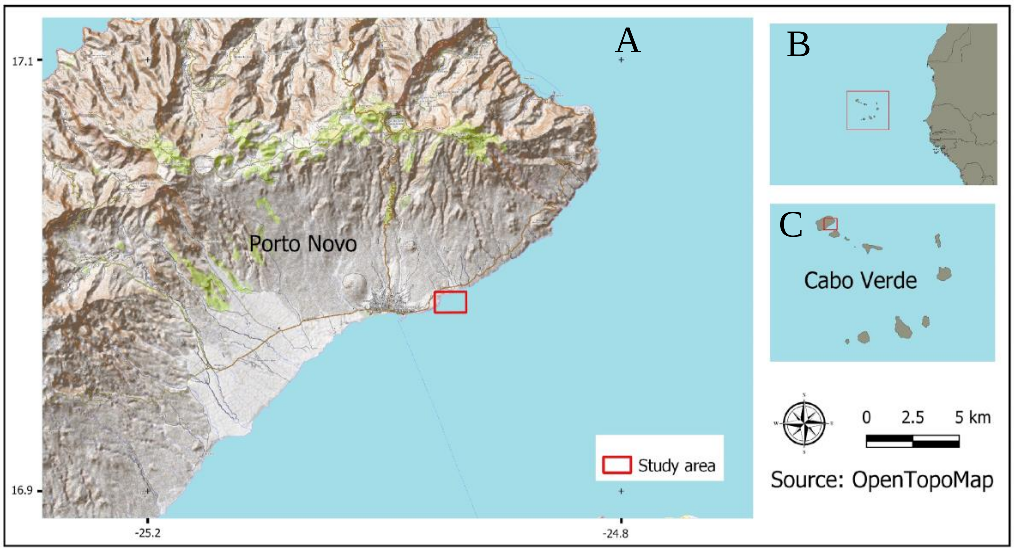


Figure 3: Location of the seagrass bed along the coast of Porto Novo (Santo Antão Island) (A) Santo Antão Island with the precision of the seagrass field on the coast of Porto Novo. (B) Cabo Verde location on the Ouest African coast of Senegal, in the eastern Atlantic Ocean (C) Cabo Verde islands

- *Physical and Climate conditions*

Cabo Verde is characterized by a tropical climate, sitting under the trade wind, with two seasons along the year, which are a dry season (December to July) and a warm and humid season (August to November), with the highest average rainfall of the year (73mm) in September and the lowest (0mm) in May. The temperature varies from 20°C to 35°C, with an average of 25°Ć to 29°C [2]. Cabo Verde has a convergence of different water masses, which with the strong downstream upwelling plume from the coast of Senegal and Mauritania, makes their waters highly productive. The tidal regime is mostly semi-diurnal, with an amplitude range from 0.5 m (neap tides) to 1.6 m (spring tide). Water temperature typically ranges from 21.5 ◦C in March to 25 ◦C in November (Piñeiro-corbeira et al., 2023).

- *Biology and biodiversity conditions on the sea*

The country has 9 terrestrial Protected Areas (PAs) 17 marine and coastal PAs operational over 46 PAs in general (DNA, 2015). These PAs are distributed in different islands of the country, including Santo Antão with its two PAs, which are Ribeira da Torre and Ribeira do Paul.

- *Socio-economic situation*

Biodiversity is a primary economic support of the country through various activities such as agriculture and forestry and livestock, fishing, seaside and beach tourism, water, recreational and leisure sports, and ecotourism (DNA, 2015). Marine tourism contributes to the rapid growth of the country's economy, lifting it out of the Least Developed Country (LDC) status in late 2007 and contributing to 20% of its Gross Domestic Product (GDP) (OECD, 2022). 90% of the population is settled along in coastal areas and have their economic income related to the sea. Fishing is the main source of animal protein, providing 26.2 % of the per capita consumption in 2000, and providing 5.2% of employment to the economically active population (Benchimol & Francour, 2009).

3.2 Materials

- *Materials of seagrass bed description (Oktopus Inspection Camera)*

The Oktopus Inspection Camera is the device used to map (transect data) the seagrass bed of Porto Novo (Santo Antão) the first objective of the research. This towed system is designed to observe the seafloor or object up to 300 meters in depth. It comprises a deck unit and an underwater unit connected by interchangeable cables of different lengths for easy handling while working in different water depths (Beschreibung, 2009) (Figure 4). The Deck Unit (Figure 4A) is a splash-proof plastic box in which a display and operating elements are integrated. A Navilock GPS USB (Figure 4B) device is connected to the output monitor on the

[2] https://www.metoffice.gov.uk/weather/travel/holiday-weather/africa/cape-verde

rear of the deck unit to record the real position of the sample areas. The underwater unit is composed of the inspection camera (Figure 4C) equipped with a tilt function with an angle of 135°, with the possibility to set the viewing direction from vertical to horizontal down up to 45° (Beschreibung, 2009). To this system, a GoPro camera (Figure 4D) is connected as an external monitor to record videos of the seafloor. We used the system from a local standard fishing boat and supplied power with an autonomous (stand-alone) generator using fuel.

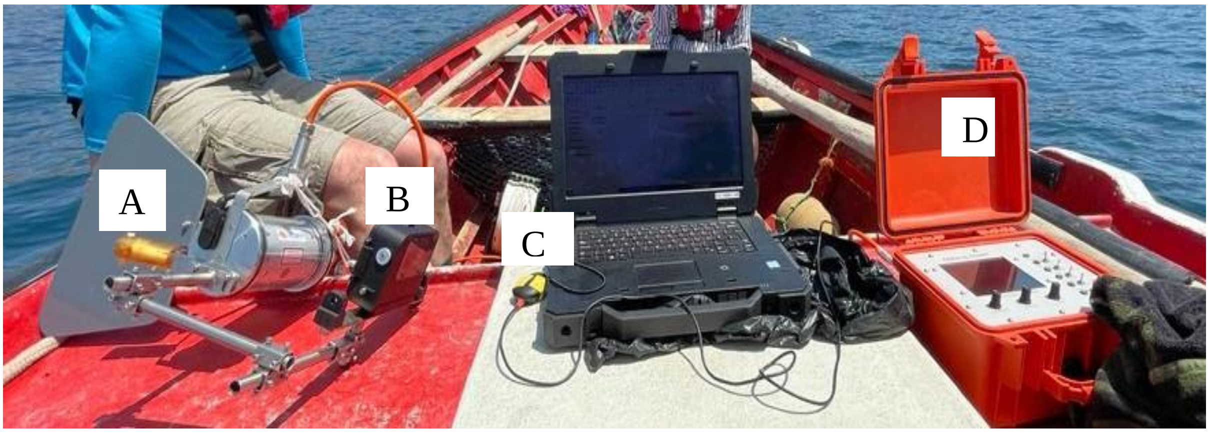


Figure 4: Oktopus inspection camera system used from a fishing boat for seagrass bed mapping with components. (A) Inspection camera; (B) GoPro camera; (C) Navilock GPS; (D) Deck unit.

- *Materials of physical parameters data collection*

Multiparameter probe EXO2 is used to profile water columns along the southeast coast of Santo Antão Island from YSI to Xylem Inc. to describe physicochemical conditions on the seagrass and rocky areas. The EXO2 is considered the latest generation water quality sonde, and it is a battery-supplied 7-port device that operates to the maximum depth of 250m. Collecting data through six different sensors (Temperature, Turbidity, Conductivity, pH, Total algae, and dissolved oxygen) and an integral pressure transducer. Parameters are measured via electrochemical, optical or physical detection methods. This water quality data collected in real-time for biological, chemical and physical characterization of a different water system allows us to complete the second objective of the study.

- *Materials of biodiversity data collection*

Four standard PlasPi marine cameras and one PlasPi TDM camera system were the devices used to observe animals (nektons diversity) present in the target regions of study. This allows us to have data for the third objective of the study.

The 'PlasPi' marine camera designed by Purser et al., (2020) (Figure 5A and Figure 5B), is to capture underwater still images over an extended period. It is built around a Raspberry Pi

Zero W microcomputer board and runs open-source Python 3.0 scripts to operate. The PlasPi is a shallow water (150 m depth rated) camera system with a plastic pressure housing (Purser et al., 2020). The PlasPi TDM, assembled by Zinzindohoue, (2021) (Figure 5C) has the same structure as the previous PlasPi, with the difference that the payloads are extended by the addition of Temperature, Pressure, and Multispectral sensors (Zinzindohoue, 2021).

A special frame is adapted to each PlasPi according to the reality of each region of study. In the rocky field, the cameras are mounted on the standard low-standing quadpod (Figure 5B and Figure 5C) easily attached to the rock on the seafloor. In the sandy area of the seagrass bed, special high frames (Figure 5A) have been designed for the stability and good view of the camera system. These new frames are 75 cm high, with four strong legs which allow strong storms to attach to them like anchors to sustain strong currents.

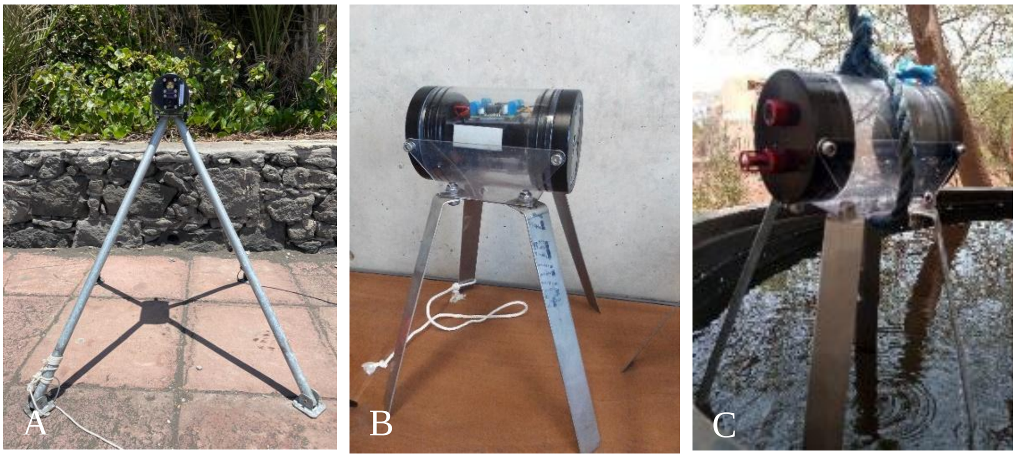


Figure 5: PlasPi cameras deployed on different frames for the nekton diversity study with (A) High frame deployed in the seagrass bed, (B) small frame deployed in the rocky area, and (C) PlasPi TDM deployed in the rocky area. Source: Fig4 (C) (Zinzindohoue, 2021)

- *Materials of interview on seagrass state in Cabo Verde*

For the fourth objective, a list of questions was prepared to ask key organizations interested in seagrass monitoring Cabo Verde to make a state of seagrass conservation in the country (Santiago Island). The questionnaire is attached in the appendix1 of the document.

3.3 Data collection

- *Data collection of seagrass bed description*

The Octopus inspection system provided MP4 video and CSV files containing various data types. The CSV file obtained from the octopus inspection system contains temperature and depth data, date and time data in local time (UTC-1) Cabo Verde time. The system recorded the data at regular times intervals of 10 seconds. The MP4 videos show the seafloor observation all along the transect with every detail going on. The camera system is also set in Cabo Verdean local time. GPS systems also provide CSV files containing latitude and longitude data, with date and time data recorded at regular time intervals of one second. The GPS systems operate at a universal time (UTC). These transect deployment has been done on two successive days, and the files have been organized accordingly. Every deployment and retrieving (in and out of water) time of the camera has been recorded manually in a notebook to facilitate the cleaning and analysis of the data. This helps to cut out every unnecessary data recorded by the system. The deployment protocol used is detailed in Table 1.

Table 1: Deployment protocol for oktopus system

Days	GoPro video	Start video	In water	out of water	End
Day1	1	07:07:00			07:37:00
	2	07:45:45	07:45:50	08:02:00	08:02:40
	3	08:05:10	08:05:20	08:10:43	08:11:00
	4	08:15:05	08:15:50	08:26:26	08:26:50
	5	08:46:00	08:46:36	09:18:31	09:18:42
	1	09:33:50	09:34:05	10:08:12	10:08:22
Day2	2	10:12:15	10:14:00	10:16:35	10:16:48
	3	11:36:00			11:47:45
	4	09:12:44			09:17:00
	5	09:25:00			09:32:55
	6	09:33:50			10:08:22
	7	09:12:44			09:17:00

- *Data collection of oceanographic setting*

The data collection is performed within the COAST project, according to the activities plan of the project. 14 stations were performed using the EXO2, a multiparameter sonde along the southeast coast of the island, for water column features. At each station, the EXO2 was deployed to the maximum bottom depths, through the use of a rope, collecting data for Temperature (T-°C), Salinity (S-PSU), Chlorophyll-a (Chl-ug/L), Optical Dissolved Oxygen (DO-mg/L), Total Dissolved Solids (TDS - mg/L), Turbidity (Tur. - FNU), and pH. Information about time, date, geographical position and depth was recorded before the deployment. 6 sensors were used for direct measurement of the parameters through the filtering process. In detail, it has been collected, or it was collected:

- Temperature was measured using temperature sensors that provide accurate and quick response temperature data in ºC (with a resolution of 0.001ºC).

- The Conductivity sensor recorded measurements in micro-Siemens/centimetre with a resolution of 0.0001 to 0.01mS/cm, Seawater salinity was calculated according to standards where the practical salinity scale is used in unitless values since the measurements are carried out about the conductivity of standard seawater at 15 ∞C.
- Total dissolved solids (TDS); the depth and level sensor that measures the water depth -in m (with a resolution of 0.001 m) through a differential strain gauge transducer that measures pressure with one side of the transducer that is exposed to the water and the other that is exposed to the vacuum.
- Depth was calculated from the pressure exerted by the water column minus the atmospheric pressure.
- the dissolved oxygen (ODO) sensor measures oxygen -in % Saturation, mg/L (with a resolution of 0.1% air sat. 0.01 mg/L, respectively).
- pH and ORP where pH -in pH values (with a resolution of 0.01 units) describes the acid and base characteristics of water and the ORP – in millivolts (with a resolution of 0.1mV) that designates the oxidizing-reducing potential of a water sample and is useful for water which contains a high concentration of redox-active species, such as the salts of many metals and strong oxidizing (chlorine) and reducing (sulfite ion) agent.
- Turbidity sensor that gives an indirect measurement of the suspended solid concentration in seawater – in FNU (formazin nephelometric Units, with a resolution of 0-999 FNU: 0.01 FNU 1000-4000 FNU: 0.1 FNU) by looking at the light that is scattered from the particles. Turbidity is considered a fundamental water quality parameter when we consider the source of the concentration of suspended solids in the seawater. These can differ in nature (such as silt, clay, algae, and organic matter) but all particles can be impacted by the light transmittance which results in a turbidity signal. This information can be useful when trying to look for environmental changes in the ecosystem; lastly,
- The total algae sensor is composed of a dual-channel fluorescence sensor that generates different data according to the excitation beam. If blue it excites the chlorophyll a -in mg/mL (with a resolution of 0.01 RFU, 0.01 mg/L) molecule that is present in all photosynthetic cells, and if orange, it will excite the phycocyanin accessory pigment that is found in blue-green algae (cyanobacteria).

The 14 stations deployments are shown in (Figure 6) below. The seagrass field (Porto Novo) is covered by stations SAE-39, SAE-40, SAE-41, and the rocky field (Praia do Vulcão) is covered by stations SAE-33, SAE-34, SAE-35.

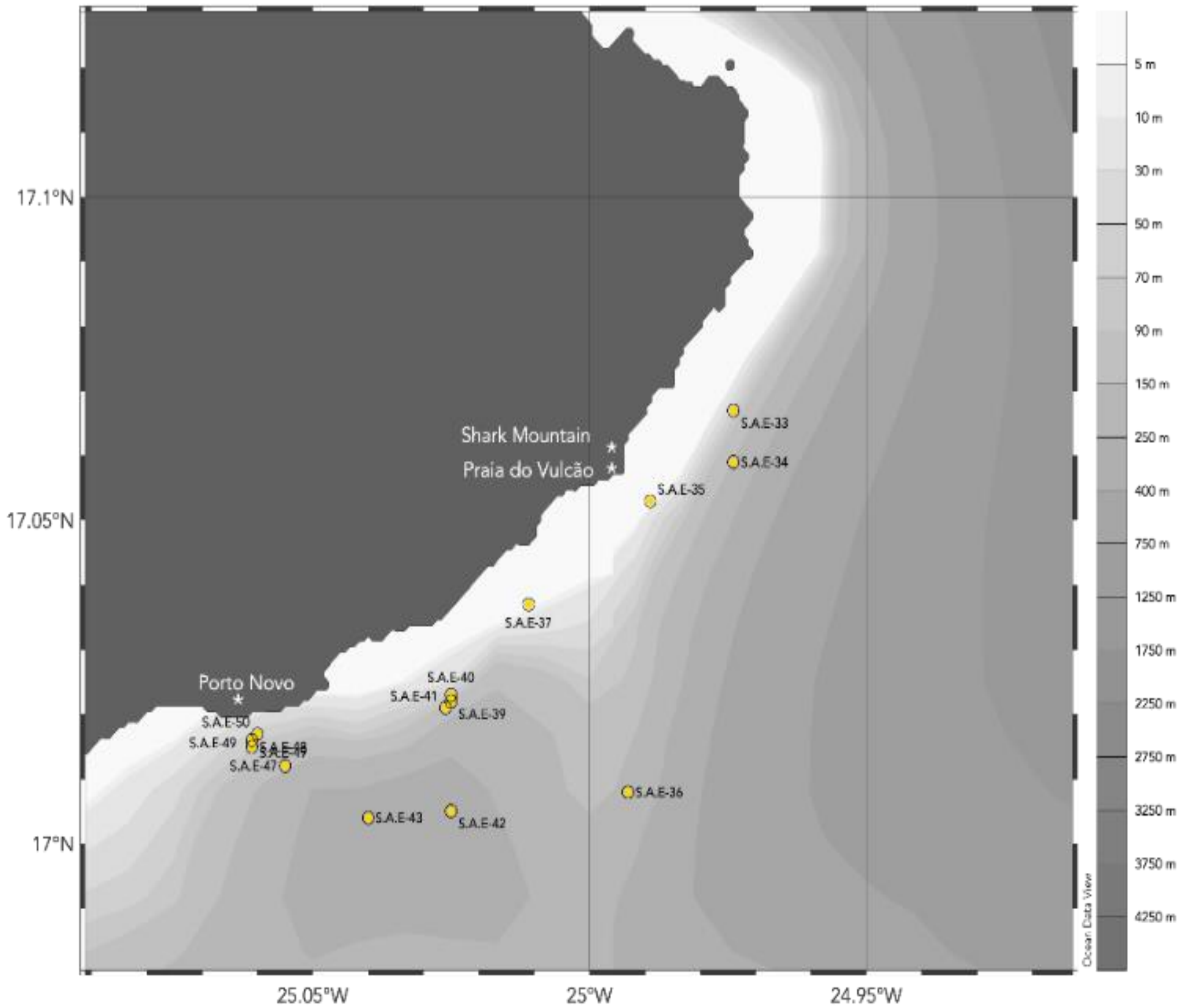


Figure 6: Map of Santo Antão coast showing the 14 stations collected with an EXO 2 sonde.

- *Data collection of nekton diversity in the target areas*

The PlasPi Camera (Figure 7) settings were made via Wi-Fi, using a router to connect to the fritz-box system. The cameras have been programmed to record 60-second videos with a time interval of 15 min for 26 hours (Figure 7B). This setting was made based on the battery capacity, which is 72 hours, and the capacity of the SD card inserted into the system, which is 32GB. Two PlasPi were deployed on the seagrass bed to cover the region by facing each other in the seagrass. In the rocky area, two Plaspi have been attached to the rock by facing the region. In the seagrass area, after 24 hours of deployment, the PlasPi was retrieved and redeployed for another 24 hours because the previous deployment could not record any data. This new deployment has been set for only photos recorded for 24 hours of 1 image every 3 seconds. One small frame was attached to the big frame (Figure 7A) for video recording in the seagrass bed making a total of three cameras in that area for the second deployment. The two PlasPi (TDM and normal) that were deployed in the rocky area were hard to retrieve because of the distance of the site to the harbor, and the strong current of the ocean. These were retrieved four days later and there was no data recorded, and the PlasPi (TDM) was leaked (Figure 7C).

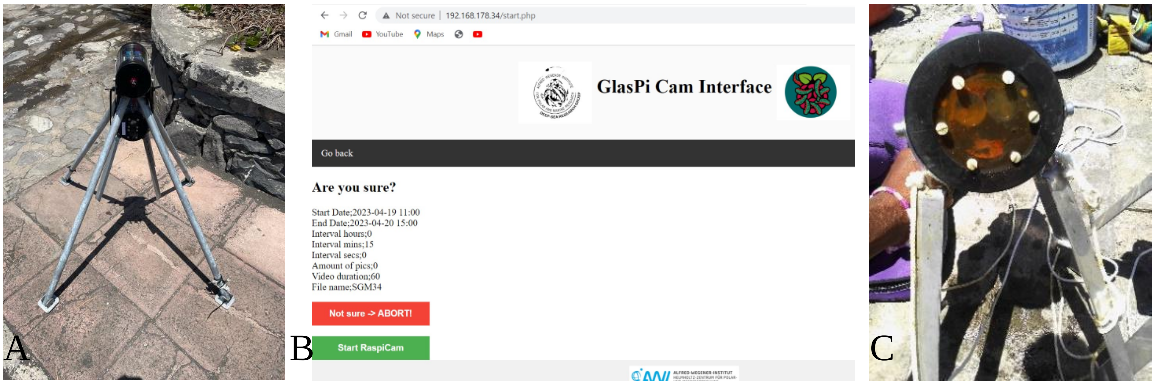


Figure 7: Different PlasPi deployed and interface with (A) small frame attached to the high frame and deployed in the seagrass field. (B) interface of PlasPi programmed for deployments. (C) PlasPi TDM leaking after retrieved

From April's fieldwork, only one PlasPi recorded photos for 24 hours without valuable useful data. This gap has been filled with the data collected by the COAST project during the fieldwork of November 2022, from the three successful deployments done in Praia do vulcão (rocky area), further north of the seagrass region. Two scuba divers did all the deployment and retrieving of the cameras. Table 2 shows the different points of the PlasPi deployments in November and April.

Table 2: PlasPi deployment along the coast of Santo Antão in Porto Novo and Praia do Vulcão

Periods	Camera deployed	Region Name	Region Type	Altitude	Longitude	Depth (m)
November	1	Praia do Vulcão	Rocky	17.060343	-24.985876	35
April	2		Rocky	17.051981	-24.989881	11
November	1	Praia do Vulcão	Rocky	17.052348	-24.99014	18
November	1	Praia do Vulcão	Rocky	17.036627	-25.011287	10
April	3	Porto Novo	Seagrass	17.036627	-25.23203	6

Videos data collected from the oktopus inspection system were used to study the nekton diversity on the seagrass field, filling the gap of the technical failures of the PlasPi during the April deployment.

- *Data collection for seagrass state of Cabo Verde*

The interview questions were sent in one Word file via email to three actors of seagrass in Cabo Verde. Those actors are Mr. Iderlindo Jorge Silva dos Santos Birdlife, ECO CV NGO and Lisdalia Moreira from Ministério da Agricultura é Ambiente/ Direção Nacional do Ambiente (MAA/DNA), the government of Cabo Verde.

The interview was structured in three main points which were:

- Seagrass situation in Cabo Verde
- Biodiversity around seagrass in Cabo Verde
- Importance of seagrass in Cabo Verde

The interview questions were sent via email to each person and the feedback was received via email.

3.4 Data analysis

- *Data analysis for the seagrass bed description*

The processing of the CSV files obtained from the oktopus inspection system was done under Microsoft Excel, by first deleting the data out of the time interval of the system in the water. The upset value added by the oktopus inspection system (Figure 8) to the normal depth recorded was found and cut out by plotting the clean-up data on Excel, and later on sum-up the maximums and considering the average value as the upset value.

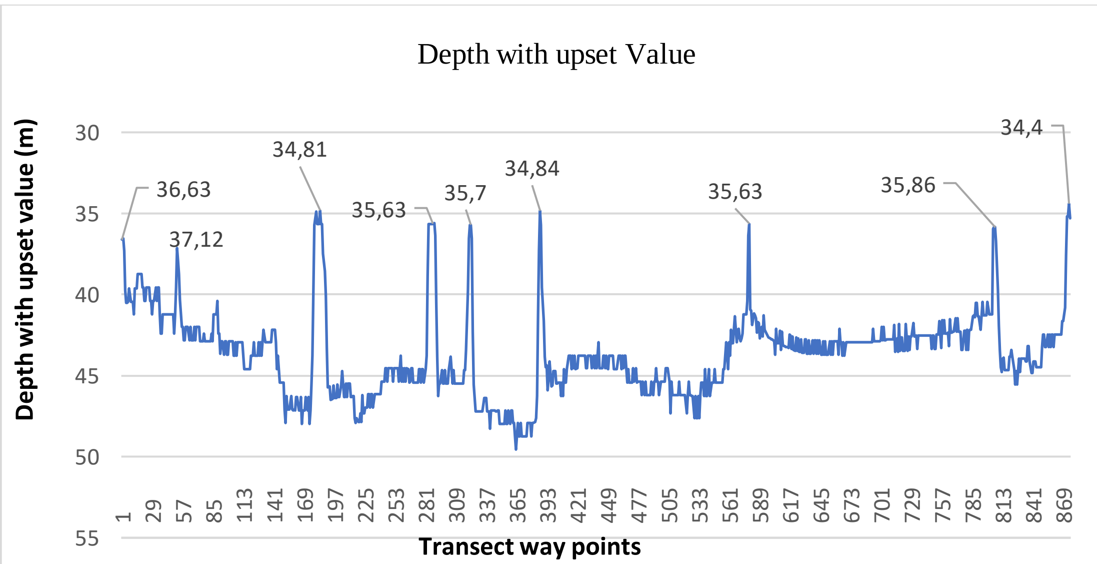


Figure 8: Upset value on the depth data obtained in CSV file from the Oktopus inspection system

The Go Pro video data obtained from the Oktopus inspection system, combined with the GPS track file that was used to capture the spatial distribution of the seagrass in the study area, was presented as waypoints. The Kernel Density Estimation (KDE) interpolation method was employed to create a comprehensive map illustrating the spatial distribution of seagrass. The resulting distribution map was categorized based on seagrass density, ranging from absence to higher density, based on self-observation of the GoPro system videos by going through all the videos according to the time record on the CSV file and note in the notebook during the deployment's protocol. For this analysis, the monitor has been connected to the laptop for multiple screen use with the regular stop time of 10 seconds for the videos and the distribution of the density from 0 to 4 based on our observation.

To estimate the surface area covered by seagrass, the distribution map was converted from raster to shapefiles format to allow the utilization of area calculation functions to estimate the extent area of the seagrass field coverage area. Both ArcGIS and QGIS software were employed for these processes. Depth and temperature general description of the seagrass field was plotted with Excel under Microsoft office after data cleaning, that was to take out all the data recorded within the time "out of water", recorded in our protocol of deployment.

- *Data analysis for oceanographic setting data*

The data (that passes through a filtering process that is automatically produced in each sensor) was later downloaded by Bluetooth using the KOR Software and analyzed in ODV (Ocean Data View) 5.6.3 (Schlitzer and Reiner, 2022). Direct reading of the probe was recorded using the manufacturer's original calibrations. Afterwards, Python software is used to plot data of each parameter of the different regions to compare the ocean condition of the seagrass field (Porto Novo) and rocky field (Praia do Vulcão).

- *Data analysis of biodiversity comparison data*

The fish's photos were extracted from the transect videos taken by the Oktopus inspection system for the biodiversity analysis on the seagrass bed (Porto Novo) under VLC video software. Organisms' photos taken by the PlasPi devices during November's deployment were used for the biodiversity analysis on the rocky are (Praia do Vulcão). From the PlasPi, WinSCP software was used to extract the data (photo) from the SD card to the local drive. The fish species were separated manually from images recorded by visual recognition. Thus, their identification was processed with the help of Mr Rui Freitas, (an expert on fish species of Cabo Verde and lecturer at Universidade Technica do Atlântico (UTA). João Valente database (matrix) and FishBase website were used to confirm the identification of the fish species and general knowledge concerning the identified species [3].

- *Data analysis for the state of seagrass conservation in Cabo Verde*

The responses from the interview were gathered together and summarized to narrate the information received. This is supported by the literature of existing work and some links directed by the respondent.

[3] https://fishbase.mnhn.fr/search.php

4 Results

4.1 Description of the seagrass field of Porto Novo (Santo Antão)

4.1.1 Localization and description of the seagrass bed

The seagrass bed of Santo Antão island (Figure 9A) is located at the coast of Porto Novo between 17°0196264N, 25°0427160W and 17°027341N, 25°028557W GPS position recorded during the mapping of the field. The only species was *Halodule wrightii* and it was found on fine sandy seafloor and identified by image observation from the GoPro video of Oktopus inspection system. The field has a coverage area of 164 997 m², not far from the shoreline (beach) of Porto Novo, with various distributions of density all along. The distribution of the seagrass, defined by self-visual appreciation, was qualified as "total absence", "low density", "moderate dense", "high dense" and "very dense" (Figure 9B). From a general view, it was confirmed that the seagrass distribution along the coverage area was moderately dense with unstable distribution.

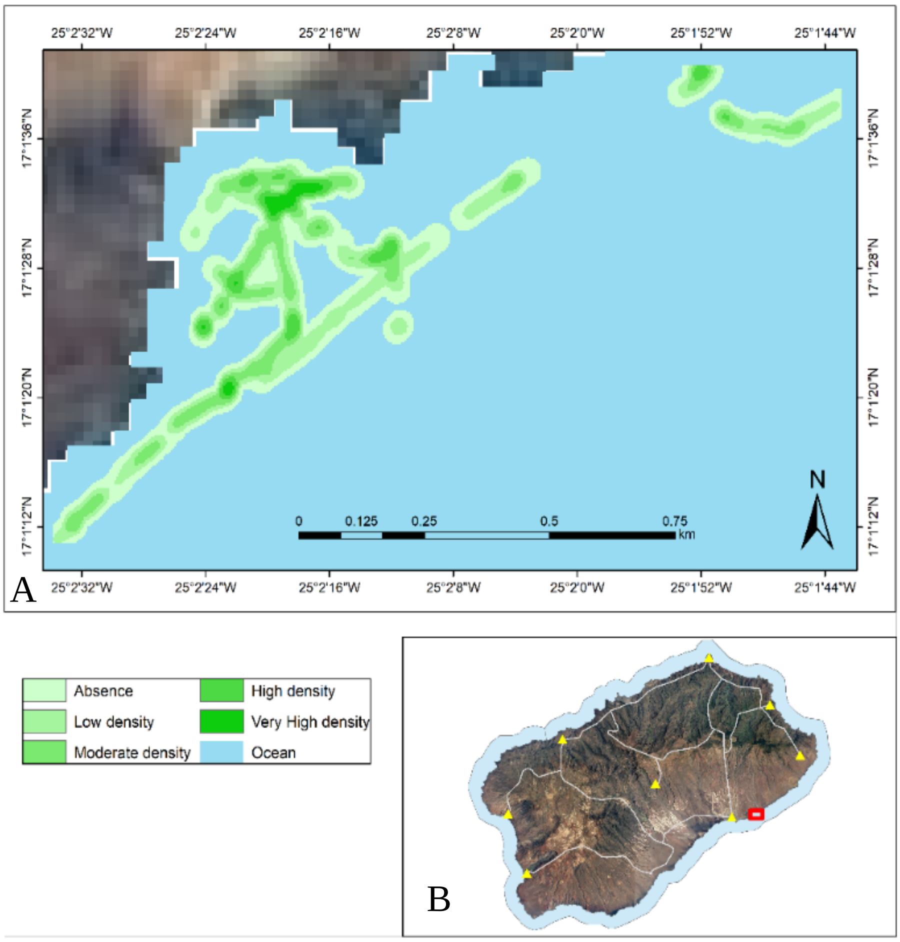


Figure 9: Seagrass location and distribution along the coast of Porto Novo (A) seagrass covered area (B) Santo Antão island.

In the natural environment, zones with a total absence of seagrass were noted, as well as zones with high densities of seagrass. The Figure 10 shows the correspondent photo of each of type of seagrass density encountered on the field. Total absence (absence) (Figure 10 A) of seagrass means only sand observed, and zero presence of vegetation seen on the seafloor. Low density (presence) (Figure 10 B) of seagrass means the presence of a few and rare vegetation seen on the ground in the middle of a vast area of sand. Moderate dense (patchy) (Figure 10 C) means a large presence of vegetation of medium clump, very spaced with considerable gaps filled by the presence of sand, seen on the seafloor. High dense (dense) (Figure 10 D) means large herbaceous vegetation with a well-distributed clump but with rare and regular gaps in the sandy soil, or of irregular size in distribution. Very dense (Figure 10 E) means high grass vegetation (compared to moderate dense), very bushy, with no gaps in its distribution seen on the seafloor.

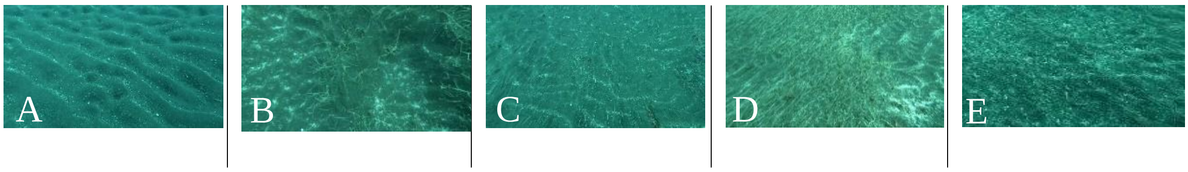


Figure 10: Illustration of the seagrass density distribution along the transect (A) Total absence (B) Low density (C) Moderate dense (D) High dense (E) Very dense

4.1.2 Depth and average temperature along the seagrass bed

- Depth effect

The seagrass species *H. wrigthii* was found in deep water at a maximum depth of 13 meters, with an average trend range from 9 to 7 meters deep all along the coast of Porto Novo, a few meters far away from the shore (Figure 11). The minimum depth (sea surface value) from the water surface was inferior to 2 meters due to the strong current and high waves of the sea in the area on the days of the fieldwork (data collection).

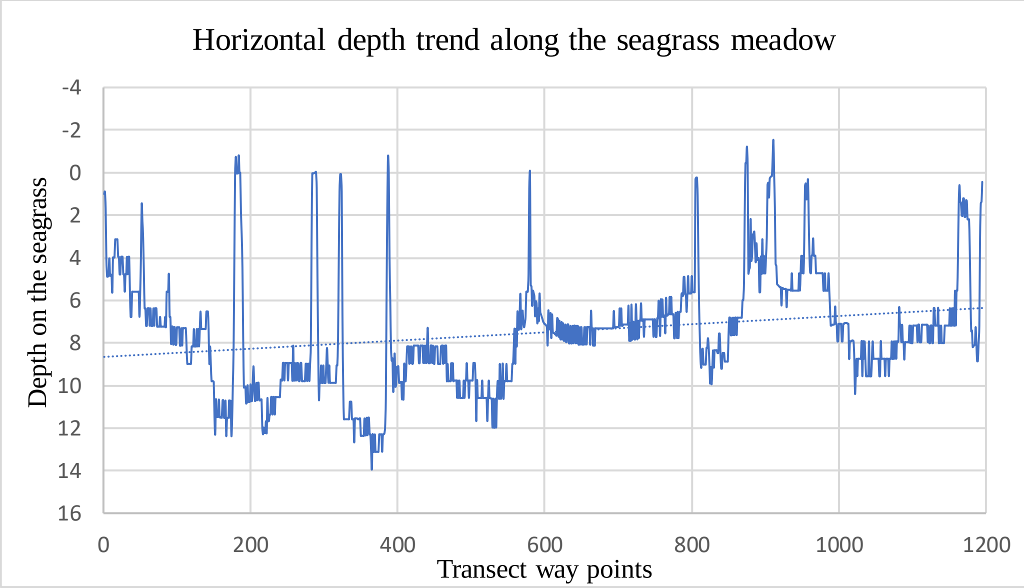


Figure 11: Depth profile on the seagrass bed along the transect

- Temperature effect

The water temperature on the seagrass along the transect shows an average trend range from 24°C to 25°C, but suddenly a maximum value of 28.5°C (Figure 12). This drastic change occurred between 17°0264975N, 25°0321675W and 17°025339667N, 25°038781833W GPS position, where there is more absence of the seagrass distribution seen from video data provided by the Oktopus inspection system.

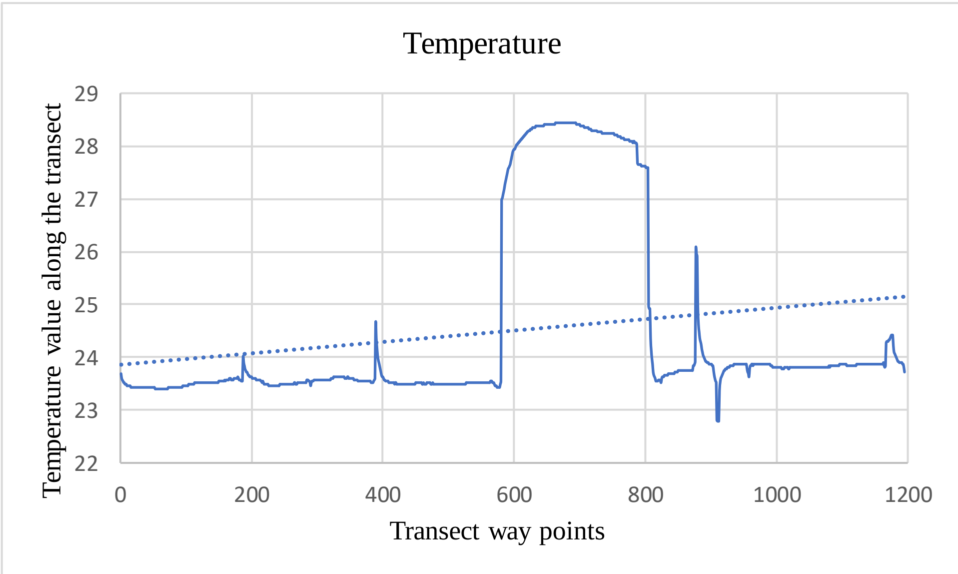


Figure 12: Temperature trend on the seagrass meadow along the transect

4.2 Physical parameters comparison between seagrass field and rocky area field.

4.2.1 Temperature and salinity vertical profile of seagrass area of Porto Novo and rocky area of Praia do Vulcão

The temperature profile in the seagrass field (Figure 13A) is more stable, with less variation in the seagrass field than in the rocky area (Figure 13B). After the first decrease of the temperature at 2.5 meters depth, in the seagrass field, the temperature stayed almost stable till 9.5 meters depth where it decreased again. Meanwhile, in the rocky field, at 2.5 meters depth, where the temperature starts decreasing, there is a lot of variation in the trend. The average temperature value in the seagrass field is around 24°C while it is around 23°C in the rocky field.

The salinity abundance in the seagrass field (Figure 13A) is from the surface to 2.5 meters deep, while it stopped at 1.5 meters deep in the rocky area (Figure 13B). However, the salinity value has the same range in the two regions.

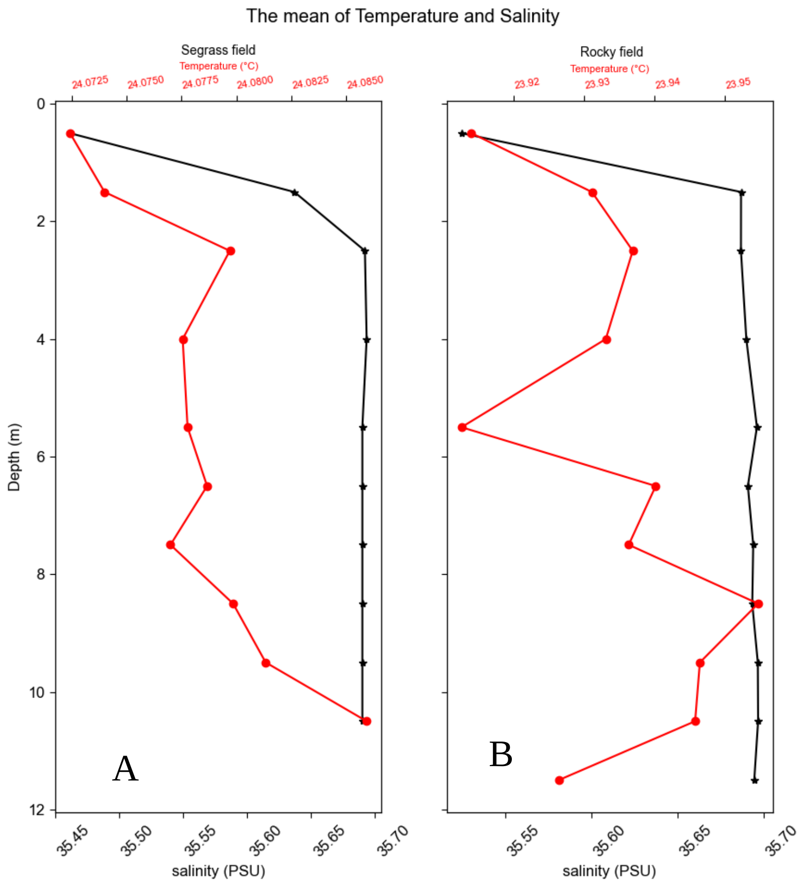


Figure 13: Temperature and salinity vertical profile of target areas (A) seagrass field (B) rocky field

4.2.2 Oxygen and Chlorophyll-a profile of seagrass area of Porto Novo and rocky area of Praia do Vulcão

The Oxygen Dissolved Optical (ODO) is abundant and high in value from the surface to 2.5 meters depth in the seagrass field (Figure 14A), while in the rocky area (Figure 14B), the ODO abundance zone stops at 1.5 meters depth. Also, the maximum value of the ODO availability in the seagrass field is higher (7.4 mg/L) than in the rocky field (7.2 mg/L).

The Chlorophyll-a abundance in the seagrass field (Figure 14A) is from the surface to 7.5 meters depth, while in the rocky field (Figure 14B), the abundance stopped at 6.5 meters depth. The chlorophyll-a value in the seagrass field is higher (0.4 µg/L) than in the rocky area (0.2 µg/L).

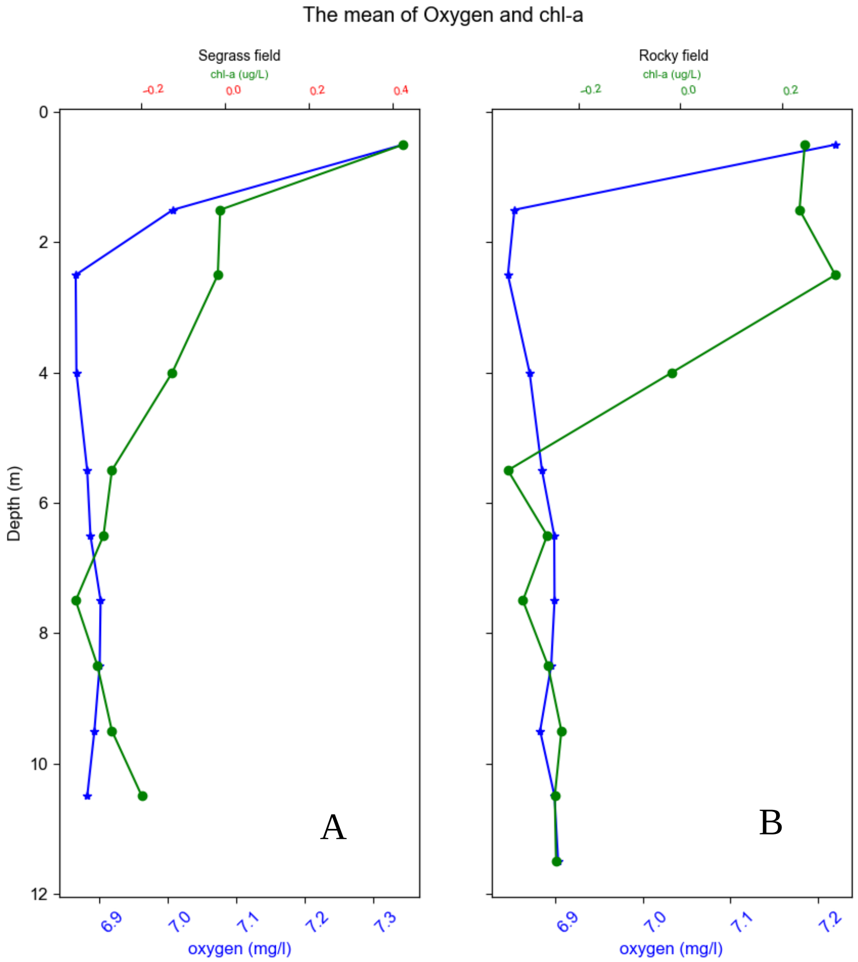


Figure 14: Mean oxygen and chlorophyll-a profile of target areas (A) seagrass field (B) rocky field

4.2.3 Turbidity and Total dissolved solid (nutrient) profile of seagrass area of Porto Novo and rocky area of Praia do Vulcão

The Total Dissolved Solid (TDS) in the seagrass field (Figure 15A) increased progressively from the surface to 2.5 meters depth, while the increase was drastic and stopped at 1.5 meters depth in the rocky field (Figure 15B). The value range is the same in the two regions.

The turbidity abundance in the seagrass field (Figure 15A) decreased progressively from the surface to 8.5 meters depth, while in the rocky field (Figure 15B), it decreased drastically from the surface to 7.5 meters depth. The abundance value of the concentration is higher in the rocky field (2.5 FNU) than in the seagrass field (2 FNU) but occurred at the same depth (2.5 meters) in both fields.

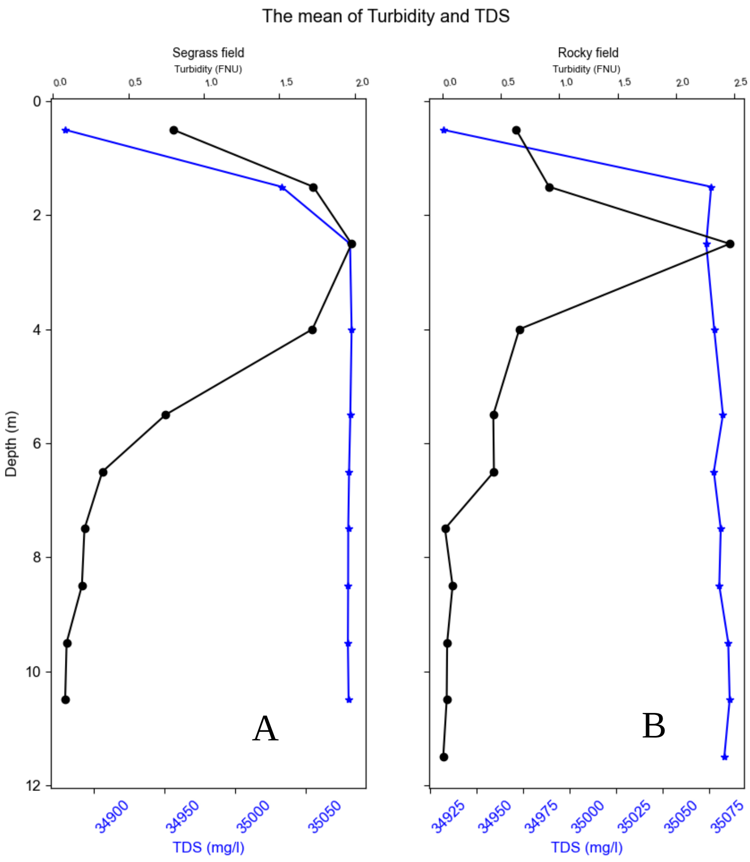


Figure 15: Turbidity and Total dissolved solid (nutrient) profile comparison of the target areas (A) seagrass field (B) rocky field.

4.2.4 pH profile of seagrass area of Porto Novo and rocky area of Praia do Vulcão

The average value of pH in the seagrass field (Figure 16A) and rocky field (Figure 16B) occurs almost at the same depth of 7 meters, with an average value of 8.14 in the rocky field and 8.23 in the seagrass field (Figure 15).

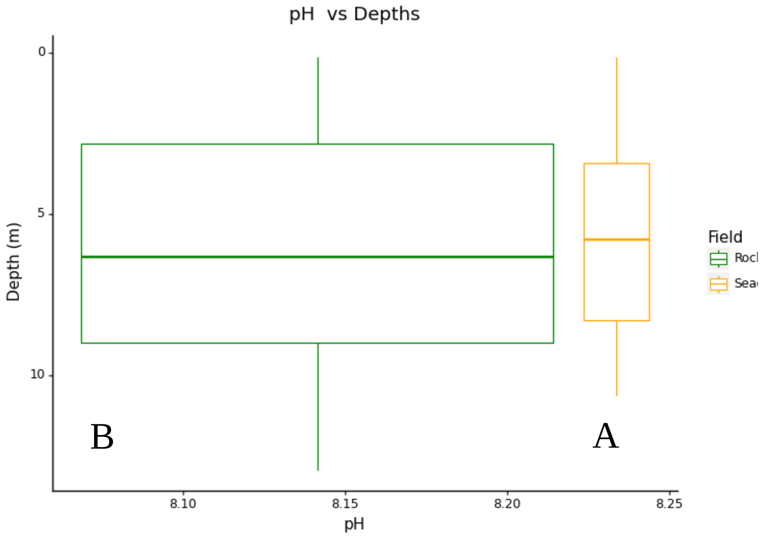


Figure 16: pH vertical profile comparison of the target areas (A) seagrass field (B) the rocky field

From the comparison of the various physical parameters between the seagrass field and the rocky field, we noticed that the seagrass meadow offers better conditions than the rocky area, even if the difference is slight. Dissolved oxygen (ODO), chlorophyll-a, Temperature and Salinity, even the dissolved solids (TDS), and turbidity have better profiles and value in the seagrass meadow in terms of abundance and availability than in the rocky area. These parameters have more deeper abundance in the seagrass field than in the rocky field. This confirms the plus value of seagrass in the ocean condition of the area it occurs.

4.3 Biodiversity comparison between the seagrass of Porto Novo and the rocky area of Praia do Vulcão

These results focus on the qualitative analysis of nektons diversity in each habitat. This is an identification of the organisms observed in each area and a comparison of them. These results are summarized in table 3 and table 4 for each habitat.

4.3.1 Fish diversity around the rocky area (Praia do Vulcão)

16 different fish species were recorded in the rocky area (Praia de Vulcão). 50% of the species are carnivore fish, feeding on small reef invertebrates and 56.25% of them have high commercial value (C) meanwhile, there are others non-commercial value (NC) species and low commercial value (LC) species. Only two of the fish species (*Chromis lubbocki*, and *Virididentex acromegalus)* (Figure 17A and Figure 17B) are endemic to Cabo Verde, and some of them (37.5%) are from the tropical western Atlantic bioregion. The common length of all the species ranges from eight (8) centimetres to about forty (40) centimeters, except *Aulostomus strigosus* (Figure 17C) which, the common length is about sixty (60) centimeters [4].

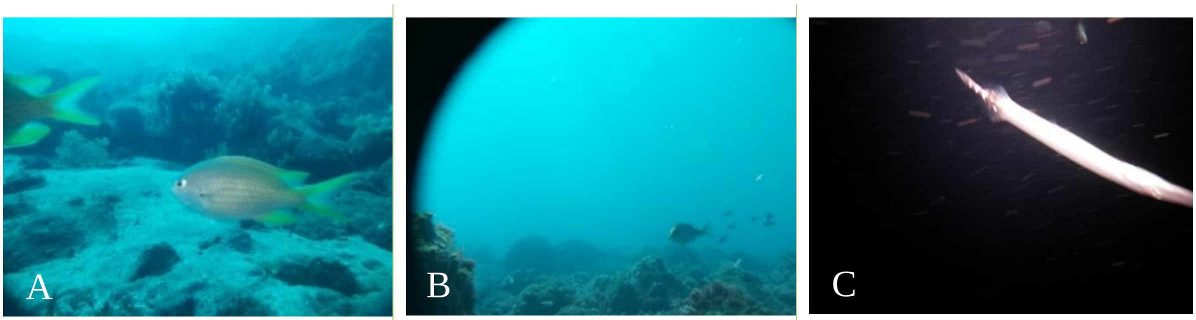


Figure 17: Endemic species of Cabo Verde present in the rocky area (Praia do Vulcão) (A) *Chromis lubbocki*, (B) *Virididentex acromegalus*, (C) *Aulostomus strigosus*

[4] https://fishbase.mnhn.fr/summary/Aulostomus-strigosus.html

Table 3: Fish diversity recorded in the rocky area (Praia do Vulcão)

Common name	Family	Species	Endemism	Trophic	Economic value	Behavior	Diet (food habit)	Common length (cm)	Biogeography	Spawn
Docteur	Acanthuridae	*Acanthurus monroviae*	Non endemic	Roving Herbivore	C		Feed on algae and seagrass	38	East Atlantic	
Trumpetfish	Aulostomidae	*Aulostomus strigosus*	Non endemic	Piscivore	NC	Camouflage ability	Smal fish, Crustaceans and Invertebrates	60	AnfiAtlantic	March April May June
Blue-spotted seabass (grouper)	Serranidae	*Cephalopholis taeniops*	Non endemic	Carnivore	C	Nocturnal activity and color display	smaller fishes, crustaceans, and cephalopods.	40	Tropical West Africa	June July August September October November
Butterflyfish	Chaetodontidae	*Chaetodon robustus*	Non endemic	sessile Invertebrates	NC	Territory protectors.	Selective feeders of coral polyps and algae	10	Tropical West Africa	
Lubbock's Chromis	Pomacentridae	*Chromis lubbocki*	Endemic to Cabo Verde	Planktivore	NC	Schooling as defense behavior	copepods, small crustaceans, and other tiny invertebrates	8	Endemic to Cabo Verde	

Brown chromis	Pomacentridae	*Chromis multilineata*	Non endemic	Planktivore	LC	Schooling habits for defense, foraging, and reproduction	Plankton and small crustaceans	12	AnfiAtlantic	
Porcupinefish	Diodontidae	*Diodon hystrix*	Non endemic	Carnivore	NC	Ability to inflate its body, by ingesting water or air when threatened or stressed.	small fish, crustaceans, and mollusks	61	AnfiAtlantic	
Atlantic Emperor	Lethrinidae	*Lethrinus atlanticus*	Non endemic	Carnivore	C		Small fishes, invertebrates, crustaceans, mollusks, worms	30	Eastern Central Atlantic	
Sand steenbras	Sparidae	*Lithognathus mormyrus*	Non endemic	carnivorous fish	LC	Schooling and night behavior	small fish, crustaceans, mollusks, and benthic invertebrates	30	Eastern Atlantic	June July August Septembre October November
Yellow goatfish	Mullidae	*Mulloidichthys martinicus*	Non endemic	mobile Invertebrate	C	Bottom-dwelling fish with Head-	worms, crustaceans,	28	Western Atlantic	

				feeder (Carnivore)		standing feeding technique	mollusks, and small fishes			
Blackbar soldierfish	Holocentridae	*Myripristis jacobus*	Non endemic	Carnivore	LC	nocturnal and exhibit strong schooling behavior	small invertebrates and zooplankton	20	Western Atlantic	
West African goatfish	Sparidae,	*Pseudopeneus prayensis*	Non endemic	Mobile Invertebrate feeder	C	Schooling behavior	small invertebrates, crustaceans, mollusks, algae, seagrass	35	Western Mediterranean Sea, Eastern Atlantic	
Atlantic bigeye	Priacanthidae	*Priacanthus arenatus*	Non endemic	mobile Invertebrate feeder (Carnivore)	C	Bottom or near-bottom dwelling	small fish, crustaceans, and various types of invertebrates	35	Western Atlantic	February March
Greater soapfish	Scorpaenidae	*Rypticus saponaceus*	Non endemic	Carnivore	C	Solitary and nocturnal species	Small fish, crustaceans	25	Western Atlantic	November December
Parrotfish	Scaridae.	*Sparisoma cretense*	Non endemic	Herbivore	C	parrotfish poop for algae renews	Algae feeder	30	East Atlantic	July August September October

Bulldog dentex	Lutjanidae	*Virididentex acromegalus*	Endemic to Cabo Verde	Carnivore	C	solitary and territorial fish	smaller fishes, crustaceans, and other invertebrates	30	Endemic to Cabo Verde	

4.3.2 Fish diversity around the seagrass area (Porto Novo)

Four different fish species (*Sphoeroides marmoratus*, *Stephanolepis hispidus*, *Gymnothorax vicinus*, *Pegusa cadenati*) (Figure 18) were recorded in the seagrass area (Table 4). Most of them (75%) were small invertebrate carnivorous feeders, and only a few (25%) were omnivorous (*Stephanolepis hispidus)* (Figure 18A), but also feeding on small invertebrates. None of them is endemic to Cabo Verde but are tropical Atlantic biogeography regions. Few of them (25%) have high commercial value (C) and others (75%) have non-commercial value (NC). Only the common length of *Gymnothorax vicinus* (Figure 18C) is known (70 cm). *Pegusa cadenati* (Figure 18D) is usually found in shallow water between a depth range from 10 to 30 meters and in sandy bottoms [5]. All the species are known to occur in brackish water in the bay around the mangrove ecosystem. Their relationship with the seagrass ecosystem is not known (Table 4).

Figure 18: Species recorded on the seagrass meadow of Porto Novo (Santo Antão) (A) *Sphoeroides marmoratus* (B) *Stephanolepis hispidus* (C) *Gymnothorax vicinus* (D) *Pegusa cadenati*

Figure 19, shows the photo of red algae identified as (*Asparagopsis taxiformis spp)* (Figure 18A) and a green algae identified as (*Avrainvellea sp*,) (Figure 19B), all recorded by the Oktopus inspection system suspended on the seagrass bed of Porto Novo in Santo Antão Island.

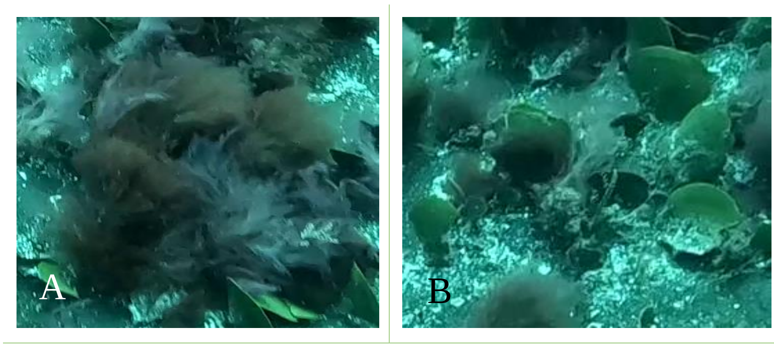


Figure 19: Green algaes recorded on the seagrass bed of Porto Novo (A) *Asparagopsis taxiformi* (B) *Avrainvellea sp*

[5] https://fishbase.mnhn.fr/summary/Pegusa-cadenati.html

Table 4: Fish species present in the seagrass habitat

Common name	Family	Species	Endemism	Trophic	Economic value	Behavior	Diet (food habit)	Common length	Biogeography	Spawn
Guinean puffer	Tetraodontidae.	*Sphoeroides marmoratus*	Non endemic	Carnivore	NC	inflate their bodies by swallowing water or air when threatened	Small invertebrates, such as crustaceans and mollusks.		Eastern Atlantic	
Planehead filefish	Monacanthidae	*Stephanolepis hispidus*	Non endemic	Omnivore	NC		small invertebrates, algae, aquatic plants, and occasionally, small fish		Western Atlantic	May June July August September October
Purplemouth moray	Muraenidae	*Gymnothorax vicinus*	Non endemic	Carnivore	NC	nocturnal hunter with an excellent sense of smell	Small fish, crustaceans, and other marine invertebrates.	70	Western Atlantic	
Cadenat's sole	Soleidae	*Pegusa cadenati*	Non endemic	Carnivore	C		small invertebrates such as crustaceans, mollusks, and worms		Eastern Atlantic	

The comparative biodiversity of fish species occurring in the rocky area of Praia do Vulcão and the seagrass bed of Porto Novo (Table 3 and Table 4) shows that the fish diversity in the rocky area is higher than in the seagrass bed (4/16). The most (50%) common length sizes of Cabo Verde coastal fishes range from 10 to 50 cm and are characterized as median size. 25% belongs to benthic invertivores or cleaners' dietary groupings over the 16 groups that exist (Freitas, 2014).

4.4 Seagrass state of Cabo Verde regarding conservation

This objective, based on interview questions is to understand the state of seagrass off Cabo Verde, the reality of its biodiversity and if there is a conservation decision and action so far.

4.4.1 Seagrass situation in Cabo Verde

- For how many seagrasses have been discovered since the first record in 2016, the respondent [6] justifies and supports his response based on (Creed & al, 2016) paper and the ResilienSea website. Joel Creed 2016 recorded three sites of seagrass on Santiago Island (Cabo Verde). There are Gamboa bay, Moia-moia or Baía of Nossa Sra da Luz and Porto Lobo Bay (these two on the southeast side of Santiago Island) (Creed et al., 2016). Since 2016, Gamboa bay (5,100 -6,000 m^2 covered area) was recognized as the main seagrass site in Cabo Verde until 2023 when the first place goes to the bay of Porto Lobo, Sao Domingos, Santiago, because of its size of 32,116 m^2 (3.21 hectares)[7] (ECOCV NGO). According to ResilienSEA, Gamboa bay seagrass has a coverage area of 6,243 m^2 in 2021 (Vinaccia, 2022a). The species present in all sites is *Holodule wrightii*. From ECOCV NGO response, seagrass has been found in Cabo Verde only in Santiago Island, not elsewhere till now. In Santiago, there is seagrass in the following bays: Gamboa, Porto Lobo, Sao Francisco and Nossa Sra da Luz for *H. wrightii* and Pedra Badejo for *Rupia maritima.*
- Regarding the general condition of the seagrasses discovered so far, Mr. Iderlindo Santos referred to (Creed et al., 2016) for his response. The seagrass of Cabo Verde is found on fine sand soft bottoms between 1.4–1.6 m, with a shoot density of 5998 shoots·m−2 (SE), which was the main site of seagrass (Creed et al., 2016) *Holodule*

[6] Mr. Iderlindo Santos
[7] https://www.ecocv.org/

wrightii is the species discover and remains the main and most valuable species of Cabo Verde. ECOCV said that they have not yet data to share about the general conditions of seagrasses discovered so far. Two different species have been found *Halodule wrightii* in four sites and *Rupia maritima* in one site. *Halodule wrightii* is the most spread and remains the main and the most valuable seagrass species in the country.

4.4.2 Biodiversity around seagrass in Cabo Verde

None of the respondents have information about how Cabo Verde seagrass beds relate to other Macaronesia islands, also about the biodiversity around seagrasses of Cabo Verde regarding flora and fauna. ECOCV NGO responded that they are still analyzing their data and have no information to share.

4.4.3 Importance of seagrass to Cabo Verde

The respondents have no information about various known functions of seagrass applied to Cabo Verde. Regarding consideration given to the seagrass of Cabo Verde, the response was that populations, stakeholders, and scientists are actors involved in the seagrass conservation issues. There was awareness, training, and capacity building. Regarding protection, conservation, or restoration plan or action taken for seagrasses in Cabo Verde, ECOCV support by DNA response that Seagrass was included in the NDC of Cabo Verde/ Nationally Determined Contribution/Paris Agreement.

By reference to (*Resilient seagrasses*, 2022) concept note, 5 strategies have been implemented for seagrass conservation in Cabo Verde since 2016. Many important results were achieved in terms of scientific research and monitoring, training on seagrass conservation, awareness and advocacy, Strengthening the legal frameworks and effective management of seagrass sites, and strengthening the partnership. The objectives of Resilient Sea project phase 3, to 2027, were to instore:

- System to value carbon sequestration and ecosystem services of seagrass in West Africa.
- Effective protection of 3 key seagrass sites.
- Effective platform for knowledge sharing and experience exchange on seagrass conservation.

5 Discussion

This study reports for the first time the existence of seagrass beds along the coast of Porto Novo (Santo Antão Island), a gap in seagrass occurrence, distribution and density within the West African Marine Ecoregion (WAMER). It increases the number of seagrass beds known to occur in Cabo Verde (first one now two) and confirms the occurrence of seagrass on another Island, the Island of Santo Antão. While Cheikh et al., (2022) mentioned the existence of seagrass in Sal Island, at Salinas de Pedra de Lume, there is no further reference source of this information or more details in his paper. The seagrass site of Porto Novo (Santo Antão) has the same seagrass species (*H. wrightii*) as Gamboa Bay in Santiago, but it has a bigger coverage area **(**164 997 m²/16.5 hectares) and the seagrass occurs deeper (13 meters depth maximum) (Creed et al., 2016). This size coverage area of the seagrass bed may indicate a high ecological importance and may suggest that it is one of the largest seagrass areas in the country. Better still, Cabo Verde, which had the smallest extended area of seagrass (0.62 ha) among the seven West African countries (Mauritania, Senegal, Gambia, Guinea Bissau, Guinea, Sierra Leone) classified in the WAMER (Cheikh et al., 2022), now may moves up to sixth position with 17.1 ha of seagrass extend area, ahead of Sierra Leone, which will become position seven with its 15.4 ha of extend area. Furthermore, the oceanographic setting of the seagrass field shows positive input to the ecosystem compared to the rocky field (higher value of chlorophyll-a concentration (0.4 ug/l) and dissolved oxygen concentration (7.4 mg/l), more stable temperature distribution along the depth, and lower concentration of turbidity (2 FNU)). Therefore, the seagrass function known to improve the water quality and nutrients around the region of occurrence (Seydouba, 2021) has been confirmed in this seagrass habitat of Porto Novo from the comparison of the physical parameters between the two target areas of study. For Bandeira & Björk, (2001), the seagrass species *H. wrightii* which is a tropical species is known as a nutrient driver, and East et al., (2023) found that seagrass produces a substantial quantity of sediment good for geomorphology and protection of the region. This species occurrence also confirms the gap in the global map, such as UICN red list, where there is no mention of *H. wrightii* occurrence in Cabo Verde (Creed et al., 2016), while it is shown as the main species and most spread of the country and now going beyond Santiago Island.

Seagrass is known as a shelter for fish and habitat for vertebrate and invertebrate species, thus impacting the biomass production of species (Orth et al., 2006). *H. wrightii* is one of the seagrass species known as habitat for fish, and nursery for vertebrate species in their area of occurrence (Vegh et al., 2019). The survey of the seagrass bed of Santo Antão shows the presence of four different fish species (*Sphoeroides marmoratus*, *Stephanolepis hispidus, Gymnothorax vicinus,* and *Pegusa cadenati*). Literature shows that these species occur in Western and Eastern African regions, and are coastal reef or seagrass related species (*Search FishBase*, 2023), while the survey for this study did not show their occurrence in the rocky field (Prai do Vulcão) but only in the seagrass field (Porto Novo). All of these fish species recorded on the seagrass field feed on small invertebrate and crustacean and underwater vegetation (algae, seagrass), and occur in estuaries, bays, and mangrove area (*Search FishBase*, 2023). A study of the differential importance of deep and shallow seagrass to nekton assemblages of the Great Barrier Reef World Heritage in Queensland (Australia) found that deeper meadows supported higher biomass, and shallow meadows supported higher abundance of smaller animals of the same species (11 species) for both meadows (shallow and deep) (Hayes et al., 2020). In Cabo Verde, seagrass related animals recorded from Gamboa Bay are marine gastropods, with *Turritella bicingulata* as the main related animal species (Creed et al., 2016), and epiphytic species without specification recorded by Seydouba, (2021). Associated epifauna were also recorded in the seagrass meadow of Gamboa Bay which are species crawling on the ground or buried in the substrate (Diouf, 2023). Despite this rise of research to know more about different seagrass meadows of Cabo Verde, especially Gamboa Bay, there is still absence of documentation on seagrass related fish species or nekton of Cabo Verde. Meanwhile, Cabo Verde is considered like biodiversity hotspot and is recognized by its richness of endangered species and endemic fishes in the Atlantic Ocean (Freitas et al., 2018).

Of 315 fish species listed in Cabo Verde, 20 of them are endemic to the country (Freitas, 2014). New records and correction of erroneous records have been done since to improve the knowledge of the country's species. It appears that most of these species are coastal and reef related species in the country (Freitas et al., 2018). Thus, there is a need of regard on study seagrass related species referring to nekton (from macro to megafauna) in Cabo Verde, considering the importance of fishery and the state of biodiversity for the country (Benchimol & Francour, 2009). Always with a view to biodiversity, the survey of the seagrass field of Porto Novo with Oktopus inspection system for the current study permits to record of green algae (*Avrainvellea sp*) and red algae (*Asparagopsis taxiformis*) on the field. Seydouba, (2021) recorded the presence of green algae at 8 meters in front of the seagrass *Halodule wrightii* in Gamboa Bay, but without specification of the species. (Vinaccia, 2022a) recorded presence of brown algae *Phaeophyceae* on the same species of seagrass (*H. wrightii*) at the same site (Gamboa bay) but did not specify its extension. And Diouf, (2023) recently mentioned the presence of green algae (*Caulerpa sp*) and brown algae (*Dictyota sp*) drifting on the seagrass meadow, both in Bétenty (Senegal) and Gambo Bay (Cabo Verde). The study of seaweed species composition, distribution and zonation pattern in the rocky shore of the entire Santo Antão Island found 43 species occurrences, and only *Dictyota sp1* is shown on the list with a slight abundance of occurrence, and *Asparagopsis taxiformis* almost of abundance, all in upper intertidal and middle intertidal water (Piñeiro-corbeira et al., 2023). The findings of these various studies of biodiversity (fauna and flora) on seagrass of Cabo Verde confirm the need for deep study on the flora occupation of seagrass meadows.

Knowledge of seagrass of WAMER increased in recent years from 2009 to 2018, with a rise in studies and many papers published (from 4 in 2009 to 13 in 2018) (Vegh et al., 2019). There is more awareness, research and survey around the region, in Cabo Verde, specifically with the accession of the ResilienSea project funded by MAVA foundation with big ambition regarding management, conservation and knowledge of seagrass in WAMER and Cabo Verde particularly (Resilient Seagrasses, 2022). Thanks to the results of this project, which raised knowledge and awareness of seagrass importance, map and seagrass state of different countries and involved many stakeholders for seagrass conservation in Cabo Verde. (Seydouba, 2021) find out one of the improvements in seagrass health of Gamboa Bay, which is increased coverage from $20m^2$ to $6243m^2$ within five years (from 2016 to 2021), also increase of community's knowledge regarding seagrasses importance to the community, ecosystem and climate. Despite this feat, making the most of the little-known seagrass is essential to move forward in the real conservation of that valuable habitat (Nordlund et al., 2018). From the political site, Cabo Verdean authorities, informed of the importance of biodiversity for their country and aware that biodiversity is best preserved under functional natural parks, set 46 PAs (Decree-Law 3/2003) (DNA, 2015) and 3 marines management areas (Vinaccia, 2022). Seagrass conservation will be incorporated in the updated NDC of the country in 2021 with the participation of stakeholders and led by the National Direction of Environment (DNA). With this update NDC, Cabo Verde has ambition to invent its seagrass meadows and develop a strategy for the protection and conservation of these ecosystems by 2024 (Vinaccia, 2022).

6 Conclusions

This work shows the physical description of the seagrass meadow of Porto Novo (Santo Antão Island) and the oceanography setting of the water around the meadow to make the state of the ecosystem services of that special habitat. Using underwater imaging as a sampling method, the seagrass species *Halodule wrightii* was recorded, covering an important area along the coast of Porto Novo laying on deep-water depth of 13 meters. Regarding the ocean conditions, the temperature vertical profile on the seagrass was around 24℃ and 23°C on the rocky field and quietly aligned along the depth in variation in the seagrass field, while the salinity vertical profile was around 35.5 PSU in both fields. The Oxygen Dissolved Optical (ODO) in the seagrass field was 7.4mg/L and abundant up to 2.5 meters depth from the surface, while it was 7.2mg/L and abundant up to 1.5 meters depth from the surface. The chlorophyll-a was 0.4 µg/L in value and abundant up to 7.5 meters depth in the seagrass field, and in the rocky field was 0.2 µg/L in value and abundant up to 6.5 meters depth. The turbidity abundance value was higher (2.5 FNU) in the rocky field than in the seagrass field (2 FNU).

Four fish species were found in the seagrass field while sixteen were found in the rocky field, making higher biodiversity of the species occurrence in the rocky field than the seagrass field. All species are coastal and reef related species of the country, belonging to the Western and Eastern African regions. This record of fish species occurrence in seagrass meadows of Cabo Verde has never appeared in literature before. The one more record of two different species of algae suspended on the seagrass field of Cabo Verde needs deep understanding.

Regarding the seagrass state of the country and possible conservation measures, knowledge is basic and there is still many lack of information for the total distribution and prediction of seagrass WAMER in general and Cabo Verde particularly. There is no formal regulation for seagrass conservation, and the little known about requires valuable use to improve the situation of that important ecosystem that is threatened all around the world with not much interest.

The limitation of this work is that physical sampling and survey on the field may provide more details on the shoot density, biomass, sediment and species of algae present on the field. Furthermore, the malfunction of the PlasPi cameras did not allow them to take videos and photos for long-term observation of the field. Because of this, only the data provided by Oktopus inspection system is used to analyze the nekton diversity on the seagrass field. This provides information as an instantaneous video only for the presence and absence of the species on the field.

7 Recommendations

This study recommends a deep study of the seagrass field of Porto Novo (Santo Antão) first to observe the state of the seagrass field and how it is progressing for the monitoring plan. Also, a complete ecological habitat study is needed to deeply understand the ecosystem services and function of the full coverage of the seagrass area, including consideration of the fish species occurring and how those species use that habitat. Such information will provide essential knowledge on species biodiversity and potential fishery resources for the island community and the country.

Using an imaging method with a high-quality resolution observation camera system, such as a remote camera, is highly recommended. This will allow long-term observation of the organism and their interaction with their habitat without human interference to know which animals use the seagrasses and how they use it, at which period of the year are abundant and learn more about other services and functions of the habitat regarding the biodiversity of the species occurrence.

Understanding the biological system of the seagrass field will permit sustainable management of the ecosystem and marine resources of the region, ultimately resulting in potential climate change mitigation effects at a local level.

Finally, it is crucial to orientated future research efforts on how to use the current knowledge of the seagrass fields of Cabo Verde in general and Santo Antão, in particular, to improve the assessment, conservation and management of the marine ecosystem for the sake of ocean health and community good of the Republic of Cabo Verde.

8 References

Resilient seagrasses, 1 (2022).

Allen, D. M. (2009). *Estuarine and Coastal Nekton, Estuarine and Coastal Nekton*.

Bandeira, S., & Björk, M. (2001). Seagrass research in the eastern Africa region emphasis on diversity, *South African Journal of Botany*, *67 420-425*(ISSN 0254-6299), 6.

Benchimol, C. F., & Francour, P. (2009). *The preservation of marine biodiversity in West Africa, the Case of Cape Verde Islands : proposal of a new biodiversity policy management. The preservation of marine biodiversity in West Africa, the Case of Cape. May 2014*.

Beschreibung, A. (2009). *Oktopus Inspektionskamera Inspektionskamera* (T. Ä. Vorbehalten (Ed.); Version 3). Oktopus GmbH Wischhofstr.:1-3 Geb. G13 24148 Kiel Tel.:0431 72093 50 Fax:0431 72093 56.

Bicknell, A. W. J., Godley, B. J., Sheehan, E. V., Votier, S. C., & Witt, M. J. (2016). Camera technology for monitoring marine biodiversity and human impact. In *Frontiers in Ecology and the Environment* (Vol. 14, Issue 8, pp. 424–432). Wiley Blackwell. https://doi.org/10.1002/fee.1322

Borges, J. C. (2022). anuario-2020-10102022. In *INECV*. www.ine.cv, Visited in june 2023

Brasier, M. D. (1974). Historic of seagrass community. *Paleontology*, *18*, 22.

Brodeur, R. D., & Pakhomov, E. A. (2019). Nekton. *Encyclopedia of Ocean Sciences*, 582–587. https://doi.org/10.1016/B978-0-12-409548-9.11460-5

Cheikh, M. A. S., Bandeira, S., Soumah, S., Diouf, G., Diouf, E. M., Sanneh, O., Cardoso, N., Kujabie, A., Ndure, M., John, L., Moreira, L., Radwan, Z., Santos, I., Ceesay, A., Vinaccia, M., & Potouroglou, M. (2022). Seagrasses of West Africa: New Discoveries, Distribution Limits and Prospects for Management. *Diversity*, *15*(1), 5. https://doi.org/10.3390/d15010005

Creed, J. C., Engelen, A. H., D’Oliveira, E. C., Bandeira, S., & Serrão, E. A. (2016). First record of seagrass in Cape Verde, eastern Atlantic. *Marine Biodiversity Records*, *9*(1), 4. https://doi.org/10.1186/s41200-016-0067-9

Diouf, G. D. (2023). *Master Thesis: comparative study of seagrass meadows between Cabo Verde and Senegal : highlight to seagrass structure.* ISEGMAR/UTA/WASCAL/ Cabo

Verde. 72.

DNA, N. D. for the E. (2015). *Fifth national report on the status of biodiversity* (Issue August).

Duarte, C. M., Borum, J., Short, F. T., & Walker, D. I. (2008). Seagrass ecosystems: Their global status and prospects. *Aquatic Ecosystems: Trends and Global Prospects*, *November 2017*, 281–294. https://doi.org/10.1017/CBO9780511751790.025

Freitas, R. (2014). The coastal ichthyofauna of the Cape Verde Islands : a summary and remarks on endemism. *Sociedade Caboverdiana de Zoologia*, *5*(1), 1–13.

Freitas, R., Falcon, J. M., Gonzalez, J.A Burnett, K. A., Dureuil, M., Caruso, J. H., Hoving, H. J. T., & Brito, A. (2018). *New and confirmed records of fishes from the Cabo Verde archipelago based on photographic and genetic data*. *1996*, 67–83.

Grose, S. O., Pendleton, L., Leathers, A., Cornish, A., & Waitai, S. (2020). Climate Change Will Re-draw the Map for Marine Megafauna and the People Who Depend on Them. In *Frontiers in Marine Science* (Vol. 7). Frontiers Media S.A. https://doi.org/10.3389/fmars.2020.00547

Hanisch, E., Johnston, R., & Longnecker, N. (2019). Cameras for conservation: wildlife photography and emotional engagement with biodiversity and nature. *Human Dimensions of Wildlife*, *24*(3), 267–284. https://doi.org/10.1080/10871209.2019.1600206

Hayes, M. A., McClure, E. C., York, P. H., Jinks, K. I., Rasheed, M. A., Sheaves, M., & Connolly, R. M. (2020). The differential importance of deep and shallow seagrass to nekton assemblages of the great barrier reef. *Diversity*, *12*(8). https://doi.org/10.3390/D12080292

Hazevoet, C. J., Monteiro, V., López, P., Varo, N., Torda, G., Berrow, S., & Gravanita, B. (2010). *Recent data on whales and dolphins (Mammalia: Cetacea) from the Cape Verde Islands, including records of four taxa new to the archipelago*.

Hoving, H. J. T., & Freitas, R. (2022). Pelagic observations of the midwater scorpionfish Ectreposebastes imus (Setarchidae) suggest a role in trophic coupling between deep-sea habitats. *Journal of Fish Biology*, *100*(2), 586–589. https://doi.org/10.1111/jfb.14944

Instituto Nacional de Estatistica. (2021). *Cabo Verde Statistical Year book 2015*. *1*, 227. http://www.ine.cv/ last visit in 5th Octobre 2023.

Martínez-Garrido, J., Creed, J. C., Martins, S., Almada, C. H., & Serrão, E. A. (2017). First record of Ruppia maritima in West Africa supported by morphological description and phylogenetic classification. *Botanica Marina*, *60*(5), 583–589. https://doi.org/10.1515/bot-2016-0128

Nordlund, L. M., Jackson, E. L., Nakaoka, M., Samper-Villarreal, J., Beca-Carretero, P., & Creed, J. C. (2018). Seagrass ecosystem services – What's next? *Marine Pollution Bulletin*, *134*, 145–151. https://doi.org/10.1016/j.marpolbul.2017.09.014

OECD. (2022). Sustainable Ocean Economy Country Diagnostics of Cabo Verde. *Development Co-Operation Directorate, OECD Publishing, Paris*, 63.

Omollo, D. J., Wang'ondu, V. W., Githaiga, M. N., Gorman, D., & Kairo, J. G. (2022). The Contribution of Subtidal Seagrass Meadows to the Total Carbon Stocks of Gazi Bay, Kenya. *Diversity*, *14*(8). https://doi.org/10.3390/d14080646

Orth, R. J., Carruthers, T. J. B., Dennison, W. C., Duarte, C. M., Fourqurean, J. W., Heck, K. L., Hughes, A. R., Kendrick, G. A., Kenworthy, W. J., Olyarnik, S., Short, F. T., Waycott, M., & Williams, S. L. (2006). A global crisis for seagrass ecosystems. In *BioScience* (Vol. 56, Issue 12, pp. 987–996). https://doi.org/10.1641/0006-3568(2006)56[987:AGCFSE]2.0.CO;2

Pimiento, C., Leprieur, F., Silvestro, D., Lefcheck, J. S., Albouy, C., Rasher, D. B., Davis, M., Svenning, J.-C., & Griffin, J. N. (2020). *Functional diversity of marine megafauna in the Anthropocene*.

Piñeiro-corbeira, C., Arenas, F., Dolbeth, M., & Vale, C. G. (2023). Species composition, distribution, and zonation patterns in the intertidal seaweed assemblages from Santo Antão, Cape Verde. *Regional Studies in Marine Science*, *63*, 102999. https://doi.org/10.1016/j.rsma.2023.102999

Pires, S., Vasconcelos, P., Freitas, R., B Neves, J. L., Vicente, S., & Verde, C. (2020). Cone snails on the North-Western Cabo Verde Islands: contribution to their ecology. *Zoologia Caboverdiana*, *8*, 49–57. www.scvz.org

Purser, A., Hoge, U., Lemburg, J., Bodur, Y., Schiller, E., Ludszuweit, J., Greinert, J., & Wenzhöfer, F. (2020). PlasPI marine cameras: Open-source, affordable camera systems for time series marine studies. *HardwareX*, *7*. https://doi.org/10.1016/j.ohx.2020.e00102

Rampf, M. (2021). *CV-ENG*. www.vozdacrianca.org, Visited in february 2023

Raposa, K. B. (2009). Ecol-Profile-CH10-Nekton. In K. B. Raposa & M. L. Schwartz (Eds.), *An Ecological Profile of the Narragansett Bay National Estuarine Research Reserve* (p. 180).

Search FishBase. (2023). https://fishbase.mnhn.fr/search.php, July 2023

Seydouba, S. (2021).Master thesis: *assessing the role of seagrasses as a socio-ecological system*. ISEGMAR/UTA/WASCAL Cabo Verde. 92.

Touron-gardic, G., Argyriou, A., Meredith, T., Bachiller-jareno, N., Rusten, O., Teeuw, R., Lundgren, A., Donald-mccann, J., Deane, K., Trégarot, E., Dème, H. B., Failler, P., & Araujo, A. (2022). *Evaluation monétaire des services écosystémiques fournis par les herbiers marins en Afrique de l'Ouest : étude de cas au Sénégal, Cabo Verde et Guinée-Bissau*.

Unsworth, R. K. F., & Butterworth, E. G. (2021). Seagrass meadows provide a significant resource in support of avifauna. *Diversity*, *13*(8). https://doi.org/10.3390/d13080363

Vegh, T., Potouroglou, M., Ahmed, M., Cheikh, S., Diagana, M., Vinaccia, M., Bryan, T., Karim, A., Abdou, S., Kane, S., Guisse, A., Regalla, A., Sarr, A., Doumbouya, A., Kide, A., Pinto, A., Ndiaye, B., Almeida, C., Seck, D., … Melo, T. (2019). *Editors Technical support Contributing Authors*.

Vinaccia, M. (2022). Meadows of knowledge: Putting West Africa on the global seagrass map, 80 (2022). https://www.grida.no/publications/884, visited in July 2023

Walters, M., & Scholes, R. J. (2017). *The GEO Handbook on Biodiversity Observation Networks* (W. Michele & S. Robert J. (Eds.); Springer O). https://doi.org/10.1007/978-3-319-27288-7

Wölfl, A. C., Snaith, H., Amirebrahimi, S., Devey, C. W., Dorschel, B., Ferrini, V., Huvenne, V. A. I., Jakobsson, M., Jencks, J., Johnston, G., Lamarche, G., Mayer, L., Millar, D., Pedersen, T. H., Picard, K., Reitz, A., Schmitt, T., Visbeck, M., Weatherall, P., & Wigley, R. (2019). Seafloor mapping - The challenge of a truly global ocean bathymetry. In *Frontiers in Marine Science* (Vol. 6, Issue JUN, p. 16). Frontiers Media S.A. https://doi.org/10.3389/fmars.2019.00283

Zinzindohoue, C. G. F. (2021). Master thesis: *Development of low-cost instrumentation for advanced underwater ecology observations*. 72. ISEGMAR/UTA/WASCAL. Cabo Verde.

Appendix

Appendix 1: Interview questions

Interview questions:

I- Seagrass situation in Cabo Verde

1.1 How many seagrasses hotspots exist in Cabo Verde since the first record in 2016 (Creed et al, 2016)?

1.2 What is the general condition of the seagrasses discovered so far?

1.3 How many species of seagrass have been discovered so far?

1.4 Which species of seagrass occur the most and which one is more valuable in Cabo Verde?

1.5 How do Cabo Verde seagrass beds relate to other Macaronesian islands?

II- Biodiversity around seagrass in Cabo Verde

2.1 Is there floral and faunal diversity around the seagrasses?

2.2 Which species are there if yes?

Fauna:

Flora:

2.3 Are there abundant?

III- Importance of seagrass to Cabo Verde

3.1 Are the various (all) known functions of seagrass applied here to the Cabo Verde?

3.2 If not, all are verified, which ones are not verified in Cabo Verde?

3.3 What consideration is given to the seagrasses of Cabo Verde? (Population, stakeholder, scientists)

3.4 Is there any protection, conservation, or restoration plan or action taken regarding seagrasses in Cabo Verde?

3.5 If yes, which one, and how does it work?

Appendix 2: Some photos of the fielwork

Figure 20: Generator use to power the okptopus inspection system

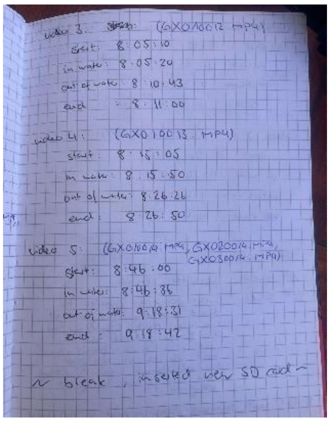


Figure 21: Camera deployment protocol during the fieldwork

Figure 22: Seagrass species *Halodule wrightii* extract from GoPro video for identification

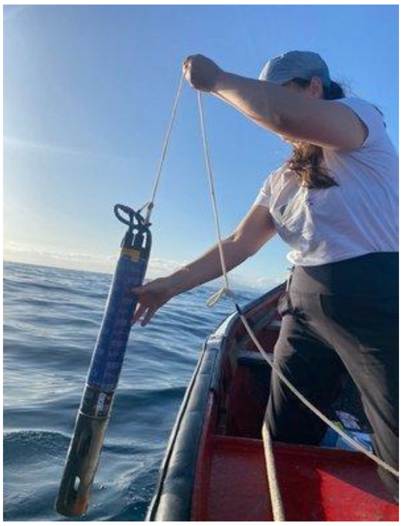
Figure 23: Green and brown algae suspend on the seagrass *Halodule wrightii* of Porto Novo (Santo Antão)

Figure 24: Fishing boat use for data collection in Santo Antão

Figure 25: Plaspi with high stand frame about to be deployed

Figure 26: Oktopus underwater system about to be deployed

Figure 27: Line use for Okptopus deployment at different depth

	
Figure 28: Scuba diver deploying PlasPi device in Praia de Vulcão (november 2022). Source: COAST project	**Figure 29**: Multiparameter sonde deployment in Santo Antão coast. Source: COAST project

<u>Appendix 3</u>**:** Some plots for data visualization

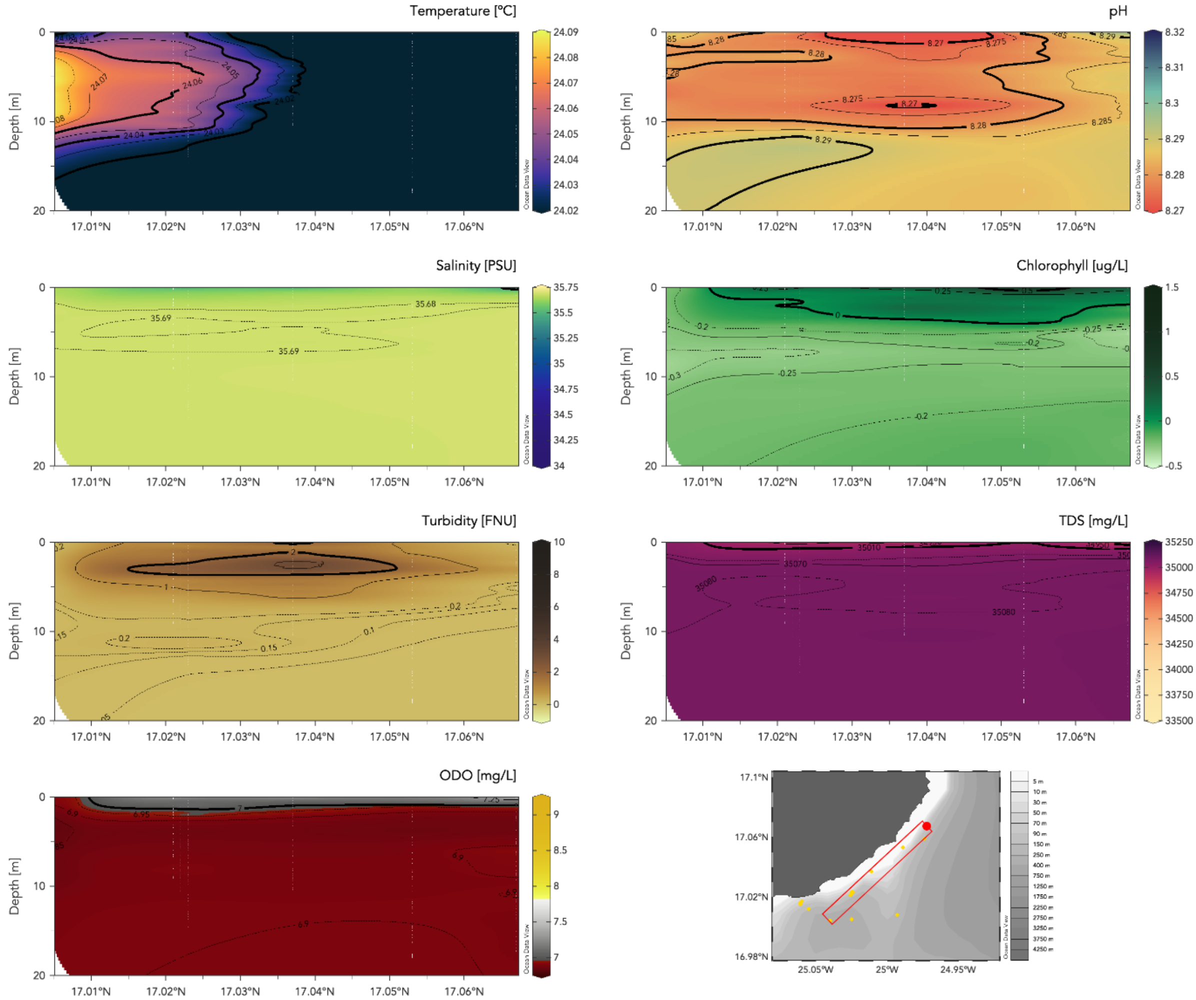


Figure 30: Oceanographic setting trend of seagrass from ODV

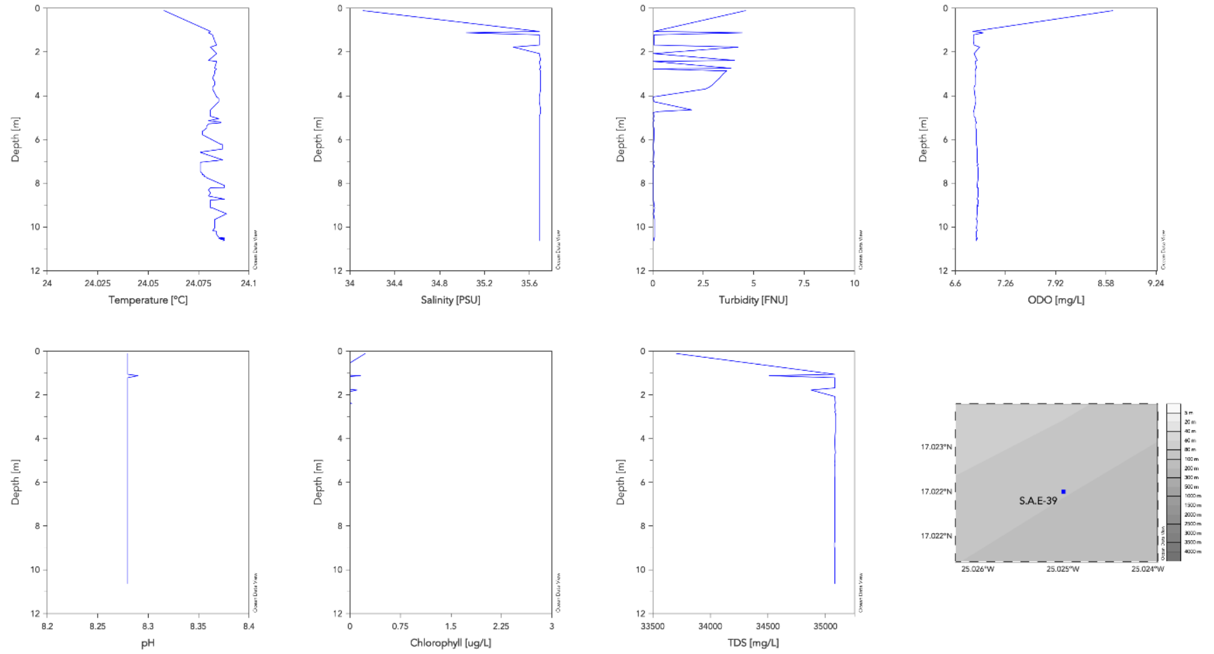


Figure 31: Line plot trend of oceanographic setting view of seagrass

Data availability

Data from this research are kept under the COAST project and WASCAL Cabo Verde. Some part of it can be assessable by me with the agreement of WASCAL Cabo Verde and COAST project.

www.uta.cv