Food and Agriculture Organization of the United Nations

2022

Offshore Mariculture Suitability Geospatial analysis

Cabo Verde

NELSON RIBEIRO (CSI)

Abstract

This report outlines a pilot geospatial analysis on offshore mariculture suitability in Cabo Verde for: gilthead seabream, cobia, Atlantic bluefin tuna (ABT) and yellowfin tuna (YFT).

The methodology is assumed from Kapetsky and Aguilar-Manjarrez "*A global assessment of offshore mariculture from a spatial perspective*" (Kapetsky et al., 2013). A short literature review details fisheries, mariculture, and blue economy context and background.

It is assumed that offshore mariculture develops within exclusive economic zones, utilizes cages, and employs species with recognized technologies (or good prospects), and markets. Criteria are defined by technical limits, profitability, and habitat.

Natural conditions are not favourable in the archipelago due to a high exposure to ocean swell and trade winds, and unfavourable depths. In the western most islands of the northern group, Santo Antão and São Vicente, offshore mariculture has the reasonable prospects, in the southern group of Brava, Fogo and Santiago no appropriate areas can be found. Boavista island presents the largest area for seabream.

A large supply-demand deficit is projected for fish products associated to a growing urbanization and middle-class, and a decline in capture fisheries.

Cabo Verde is a dry Sahelian SIDS where fisheries are strategic to the economy. Capture fisheries represent a socio-economic and cultural pilar and small-scale fisheries have important social, cultural, and economic roles. Tourism, transportation, and logistics are other competing blue economy sectors.

Competition for maritime space and catches used as feed, present clear sustainability challenges and it can increase pressure on halieutic resources having adverse socio-economic effects.

A reliable and participated maritime spatial planning (MSP) effort should frame integrated maritime policy (IMP).

Keywords: Offshore aquaculture GIS; Offshore aquaculture zoning; Ocean fish farming zoning; Ocean fish farming potential; Ocean fish farming spatial analysis; mariculture zoning modelling; Mariculture GIS;

Acknowledgements

I would like to express my deepest appreciation to those who provided me the possibility to engage in this research and complete this report, CSI Karl Morteo and ESA Hand-in-Hand team Panagiotis Karfakis.

Special thanks to Marc Taconet FAO Fisheries Division for the contribution in stimulating suggestions, comments, and advice.

I also want to acknowledge CSI Justeen De Ocampo for assisting with the document revision.

Contents

Figures index

INTRODUCTION

This report documents a pilot case Geographical Information Systems analysis under the scope of FAO's Hand-in-Hand Initiative, which targets the assessment of offshore fish mariculture potential areas and species in Cabo Verde's maritime Exclusive Economic Zone. The detailed analysis of competing or conflicting uses is not under the scope of this study and any interventions targeting mariculture investments should be framed by a holistic Maritime Spatial Planning approach.

Research question can be formulated as:

1. *Where are the potential areas and what are the possible species for offshore mariculture in Cabo Verde archipelago?*

The methodology is adopted from Kapetsky and Aguilar-Manjarrez Study "*A global assessment of offshore mariculture from a spatial perspective*" (Kapetsky et al., 2013)

A short literature review briefly details fisheries, mariculture and blue economy context, background, and perspectives. Modelling methodology adds FAO's species distribution for gilthead seabream (Sparus Aurata), Atlantic Bluefin tuna (Thunnus thynnus) and Yellowfin Tuna (Thunnus Albacares). The habitat description and geographic range written in the published FAO Catalogues of Species[1]

Kapetsky and Aguilar assume the definition of offshore aquaculture as: "*taking place in the open sea with significant exposure to wind and wave action, and where there is a requirement for equipment and servicing vessels to survive and operate in severe sea conditions from time to time. The issue of distance from the coast or from a safe harbour or shore base is often but not always a factor*".

The suitability analysis is based on the following key assumptions:

1. Offshore mariculture develops within the exclusive economic zones (EEZs).
2. Uses of cages for fish.
3. Employ species with proven mariculture technologies, or good prospects, and established markets.

[1] more details at http://www.fao.org/fishery/fishfinder

Analytical criteria and thresholds are associated to technical limits on cages, farming profitability, and species habitat.

1. Depths and current – current speeds are associated to cage technical limits and fish feed conversion or growth ratio.
2. Cost limits on travel time/distance to offshore installations.
3. Reliable access to a port.
4. Considered species: Cobia, gilthead seabream (Sparus Aurata), Atlantic Bluefin tuna (Thunnus thynnus) and Yellowfin Tuna (Thunnus Albacares).

The project is developed using open-source GIS software 3.16.14-Hannover and publicly available open-data sources.

This document is structured in 4 main sections: 1. Context and Background, 2. Data Sources, 3. Suitability assessment methodology, 4. Results - Suitability Potential for Offshore Mariculture, with Introduction and Conclusions.

1. CONTEXT AND BACKGROUND

According to OECD-FAO Agricultural Outlook 2021-2030 (OECD & FAO, 2021), fish production, trade, and consumption all diminished in 2020 due to COVID19. The decline in aquaculture production is a consequence of lockdown and restrictions in port access, that impacted capture production and aquaculture supply (inputs seed/feed).

In the 2021–2030-decade, world fish production is projected to grow at 1.2% and aquaculture at 2.0% p.a. Lower growth rates compared to the previous decade reflect policy changes in China, feed cost, reduced productivity gains, and competition for land. By 2030 aquaculture is anticipated to supply 57% of human fish consumption overtaking capture production by 2027.

Sustainability is the major issue to capture fisheries. It is the only large-scale food sector based on wild biodiversity that affects the abundance of fish populations and impacts associated or dependent species (FAO, 2020).

FAO's long-term monitoring of marine fish stocks shows a continuing resource depletion. Overfishing has been targeted by fisheries management, policies, and measures, aiming for sustainable fisheries and ecosystems via science-based policies and regimes for fish utilization and trade.

Sub-Saharan Africa

The population of the Sub-Saharan Africa (SSA) region was 1,106,957.90 in 2019, and with an annual growth rate of 2.5 %, it is projected to reach between 1.5 and 2 billion by 2050. The unemployment rate was around 6.1% for the same year. Although, poverty headcount ratios in percentage of the population have fallen from over 60% in the 1990s to close to 40% in 2019, there are great disparities between countries and subregions (World Bank[2]).

Per capita fish consumption in Africa is projected to decrease as the fast-growing population outpaces the growth in production, weakening the ability to meet SDG targets.

Aquaculture production in SSA is predominantly inland and freshwater. From 2004 to 2014 there was a seven-fold increase in production with an average percent growth rate (APR) of 2%. The first sales value

[2] https://data.worldbank.org/indicator/SP.POP.TOTL?locations=ZG

of the 2014 production was US$1.6 billion, mainly of tilapia and catfishes. Seven countries (the Federal Republic of Nigeria, the Republic of Uganda, the Republic of Ghana, the Republic of Kenya, the Republic of Zambia, the Republic of Madagascar, and the Republic of South Africa) concentrated 93% of production (Satia, 2017).

The sector has experienced a steady growth based on indigenous species, genetic and feed improvement, government, development agency support and a large growing demand.

Some of the commonly identified constraints and risks in existing literature are environmental impacts and health/food safety related, social impacts, land and water competition, employment, and value chain growth. Climate change impacts or social and regional conflicts are also merely mentioned.

Recent fish farming growth has been driven by an increasing importance for improving food security, job creation, economic growth, and resource use. It is supported by external assistance from FAO and other development partners, donor organizations and investors, and growing private sector participation.

Blue Growth and Blue Economy

Oceans are fundamental for addressing many global challenges, including food security, poverty, climate change, provision of energy, natural resources, improved well-being, and medical care.

In the context of the Blue Growth and Blue Economy – adopting a sustainable development viewpoint, e.g. as in the definition used by the World Bank: 'The blue economy is sustainable use of ocean resources for economic growth, improved livelihoods and jobs, and ocean ecosystem health' (Scholaert & European Parliament. Directorate-General for Internal Policies of the Union., 2020) - offshore mariculture suitability assessment must be integrated with socio-economic, environmental, sustainability, and jurisdictional issues and data. This lays the groundwork to a holistic approach to the blue growth in developing countries, and more importantly in SIDS where fisheries represent a fundamental socio-economic and cultural pilar.

FAO’s Blue Growth Initiative (BGI) implies transformative actions with environmental, economic, and social considerations, sometimes requiring reduction in capture fisheries and alternative income-generation, e.g., blue fashion, ocean ecotourism, and fisheries services (certification and ecolabelling).

Blue growth actions can target value chain infrastructure that aims at waste and pollution reduction, preservation of product attributes and quality, better price, and access to export markets.

The European Union blue growth initiative defines its 'key enablers' as maritime spatial planning, data collection, research and innovation, maritime surveillance, and efforts to improve skills.

Maritime spatial planning (MSP) is a central instrument of integrated maritime policy (IMP), which is fundamental when facing increased competition for maritime space. Planning and allocation of areas and use of the maritime space can prevent conflicts, streamline decision making, create good investments in climate, and increase cross-border cooperation an efficient marine environment protection. MSP can also highlight the potential for growth in unused sea areas.

Established blue economy sectors include 'marine living resources' (i.e. fisheries, aquaculture and fish processing and distribution), 'coastal tourism', 'maritime transport, port activities, shipbuilding and repair' and 'marine extraction of oil, gas and minerals'.

The fisheries processing sector includes the preparation and preservation (freezing, drying, cooking, smoking, salting, canning, etc.) and the production (fish fillets, caviar, etc.) of fish, crustacean, and mollusc products.

Small-scale Fisheries

Artisanal and small-scale fisheries provide livelihoods for millions and contribute substantially to household, local and national economies, and economic growth. They guarantee essential nutrition to billions and especially the poorest. It is estimated that small-scale fisheries provide 90% of the employment in the marine fisheries sector (World Bank, 2012 in (FAO, 2020)). Small-scale fisheries have been constantly marginalized in social, economic, and political processes and not given attention in policy.

According to FAO's "The State of the World Fisheries and Aquaculture 2020", estimates of the importance of small-scale fisheries, include:

- Millions of tonnes of fish are unreported.
- 120 million people depend on capture fisheries, 116 million in developing countries, more than 90% in small-scale fisheries, of which 50% are women.
- In developing countries, small-scale fisheries produce more than half the catch, and 90–95 % consumed locally.

- Employment in small-scale fisheries is several times higher per tonne of harvest than in large-scale fisheries.

Cabo Verde

The Republic of Cabo Verde is a dry Sahelian SIDS in Africa composed of 9 inhabited islands, Santo Antão, São Vicente, São Nicolau, Sal, Boa Vista, Maio, Santiago, Fogo, and Brava.

Fisheries are strategic to the country's economic development and play an important role in employment, livelihood, food, and nutrition. Despite an apparently relatively low contribution to the gross domestic product (GDP) 0.87%, it is estimated to represent around 3.7%. Total capture production has fallen a 55% from 37,774 tonnes in 2015 to 17,089 tonnes in 2019. The sector represents around 80 % of exports and in 2017 it was valued at USD 37.6 million (FAO, 2022a). In 2017, per capita fish consumption was estimated at 11.0 kg, about 12 % of total animal protein. There were 6 283 full time fishers in 2018 representing 5.2% of the active population.

Halieutic resources include large oceanic pelagic species (tuna and related species, sharks, etc.), small coastal pelagic (horse mackerel, mackerel), demersal species (groupers, seabream, etc.) and lobsters (depth and surface). Tunas represent two thirds of the resources.

Practices are predominantly long line, followed by the drag net and purse seine. The estimated fleet was 1 691 vessels for 2018, with the majority between 12-24 meters length overall (LOA) and the remainder under 12 meters.

Industrial fishing is largely concentrated in São Vicente, Sal, São Nicolau and Santiago. Santiago and S. Vicente with the largest landed quantities and major urban populations. Industrial and semi-industrial fishing are practiced by tuna bait boats, seiners, and lobster boats, vessels introduced under fisheries support projects.

The sector is of major socioeconomic importance for coastal communities, where most of the population lives. There are 77 identified artisanal fisheries landing sites that contribute to population resilience and reducing migration.

Artisanal fisheries and trading networks are essential to the domestic market (local consumption) and women play a key role in post-harvest. Sales is estimated to be practiced by 3500 women mainly in Praia and Mindelo (major urban centres) in fish markets or door to door, and in the other islands primarily in municipal markets.

Institutional /policy

Ocean or “blue” sectors are both central and strategic in the country development. A charter was adopted to coordinate blue growth policies aiming at economic growth, employment, and environmental sustainability. FAO and the African Development Bank, support the implementation of the national strategic framework for the transition to blue growth. (FAO, 2020)

A fundamental institutional issue is the low presence of institutions in isolated islands and communities, and lack of resources for surveillance and control of fishing activities.[3]

Fishing policies from the Plano Nacional de Desenvolvimento Sustentável 2018-2022 have aimed to protect maritime areas, management, scientific research, surveillance reinforcement, industry diversification and added value, and mechanisms to reduce sector vulnerability and increase resilience.

There are protocols and partnerships with the EU regarding tuna fishing licenses[4] within CPV EEZ, with part of the proceeds channelled to sustainable management promotion, control, and surveillance capacity(EU 2006).

Cabo Verde is also part of Programme EAF-Nansen[5], targeting an ecosystem approach to fisheries management and considers climate and pollution impacts.

There is no data reported to FAO on aquaculture production, but two commercial aquaculture investments have been located in São Vicente since 2018 with crustacean shrimp semi-intensive farming in the Fazenda de Camarão de Cabo Verde - ACE, locater in Calhau Zone, and an Atlantic bluefin tuna farming pilot from Norwegian Nortuna based in Flamengo beach, São Vicente[6][7][8], that is forecasted to export 500 tons (per year) during a starting phase and a maximum of 10,000 tons/year at a later stage, expanding to both Santo Antão and São Nicolau.

---

[3] Cape Verde’s ‘fish detectives’ try to keep extinction at bay | Environment | The Guardian

[4] Cabo Verde (europa.eu)

[5] Programme EAF-Nansen

[6] Norwegian company developing a tuna aquaculture project in Cape Verde - FurtherAfrica

[7] Cabo Verde — Nortuna

[8] Nortuna autorizada a produzir atum de aquacultura por 50 anos (expressodasilhas.cv)

The archipelago has a combination of natural conditions that impose physical constraints for offshore mariculture. The islands are exposed to north-easterly trade winds, north and south Atlantic swells, and have unfavourable bathymetric circumstances. Inland freshwater fish farming is highly improbable due to the arid climate and non-existence of water resources. Offshore mariculture also faces competing sectors and interests, namely tourism and capture fisheries, in regards to ecosystem sustainability and conflicting areas.

2. DATA SOURCES

The assessment analysis is developed using publicly accessible data.

FAO Map Catalogue data:

1. *FAO aquatic species distribution map of Sparus aurata (Gilthead seabream)*: https://data.apps.fao.org/map/catalog/srv/eng/catalog.search#/metadata/fao-species-map-sbg
2. *FAO aquatic species distribution map of Thunnus albacares (Yellowfin tuna):* https://data.apps.fao.org/map/catalog/srv/eng/catalog.search#/metadata/fao-species-map-yft
3. *FAO aquatic species distribution map of Thunnus thynnus (Atlantic bluefin tuna)*: https://data.apps.fao.org/map/catalog/srv/eng/catalog.search#/metadata/fao-species-map-bft
4. *Regions with HYCOM current speeds at 30m depth between 1 - 10, 10 - 100 and > 100 cm/s for all months in the year* - Based on HYCOM NCODA (HYbrid Coordinate Ocean Model (HYCOM) and Navy Coupled Ocean Data Assimilation (NCODA)) 8.9 km 2004-2008: https://data.apps.fao.org/map/catalog/srv/eng/catalog.search#/metadata/73fee8e5-fcb6-47ad-bef0-365f8bd0368b
5. *Sea Ports* - https://data.apps.fao.org/?share=f-e0d90630-141c-4854-a49c-86113d050bef

Web available data:

6. EEZ - VLIZ Flanders Maritime Institute - *Maritime boundaries geodatabase version 5 (2009)*: http://www.vliz.be/vmdcdata/marbound/download.php
7. Bathymetry – GEBCO – General Bathymetric Chart of the oceans *- Gridded bathymetric data sets are global terrain models for ocean and land 2021* https://download.gebco.net/

3. SUITABILITY ASSESSMENT METHODOLOGY

Suitability assessment methodology is adopted from *A global assessment of offshore mariculture potential from a spatial perspective* (Kapetsky et al., 2013).

Suitability is estimated based on the following assumptions**:**

1. The activity develops within the exclusive economic zones (EEZs)
2. Uses cages for fish, and
3. Employs species with proven mariculture technologies and established markets or identified as having good prospects for future development.

The analytical criteria and thresholds are defined based on technical limits on cages, cost-effective farming, and selected species habitat:

1. Depths (25–100 m).
2. Current speeds (10–100 cm/s).
3. Cost limits on distance from shore to offshore installations (25 nm (46.3 km)).
4. Reliable access to a port.
5. Selected species cobia, Atlantic bluefin tuna, gilthead seabream (sparus aurata) and yellowfin tuna. Favourable grow-out of fish is defined by existing habitat conditions (FAO, 2022b) , and
6. Sea surface temperature for cobia (22–32°C).

Global layers were clipped using the country's EEZ.

3.1 Species

As previously specified, analysed species were selected based on existing habitat, proven farming technologies, and established markets for Cobia (rachycentron canadum)[9], Gilthead Seabream (Sparus Aurata)[10], Atlantic Bluefin Tuna (Thunnus Thynnus)[11] (Ferreira et al., 2012; Mayer et al., 2008; Porporato et al., 2020), or with existing habitat and exhibiting strong potential for full-life-cycle aquaculture forYellowfin Tuna (thunnus albacares) (Margulies et al., 2016)

Favourable offshore grow-out environment is essentially defined by sea surface temperature (SST) requirements. SST affects fish feeding, growth, and the metabolism. Habitat descriptions and species geographic distributions are from the *Compilation of Aquatic Species Distribution Maps of Interest to Fisheries* (FAO, 2022b), derived from the official FAO Catalogues of Species[12].

Cobia (rachycentron canadum)

Cobia is distributed in warm marine waters worldwide displaying a very large potential suitable area. It was originally selected as a representative species for tropical/subtropical waters offshore mariculture in the Kapetsky, Aguilar-Manjarrez and Jenness study. With a fast growth rate and strong market acceptance, it is one of the most suitable warm water fish for offshore mariculture (Kapetsky et al., 2013).

Cobia is a predator that feeds primarily on crabs, squid, and fish.

FAO catalogue data "regions with sea surface temperatures, as defined by 95% confidence intervals, between 22 and 32°C, over entire year"[13] was used for its geographic distribution.

[9] Fisheries and Aquaculture - Cultured Aquatic Species - Rachycentron canadum (fao.org)

[10] Fisheries and Aquaculture - Cultured Aquatic Species - Sparus aurata (fao.org)

[11] Fisheries and Aquaculture - Cultured Aquatic Species - Thunnus thynnus (fao.org)

[12] FAO Catalogues of Species

[13] FAO Map Catalog

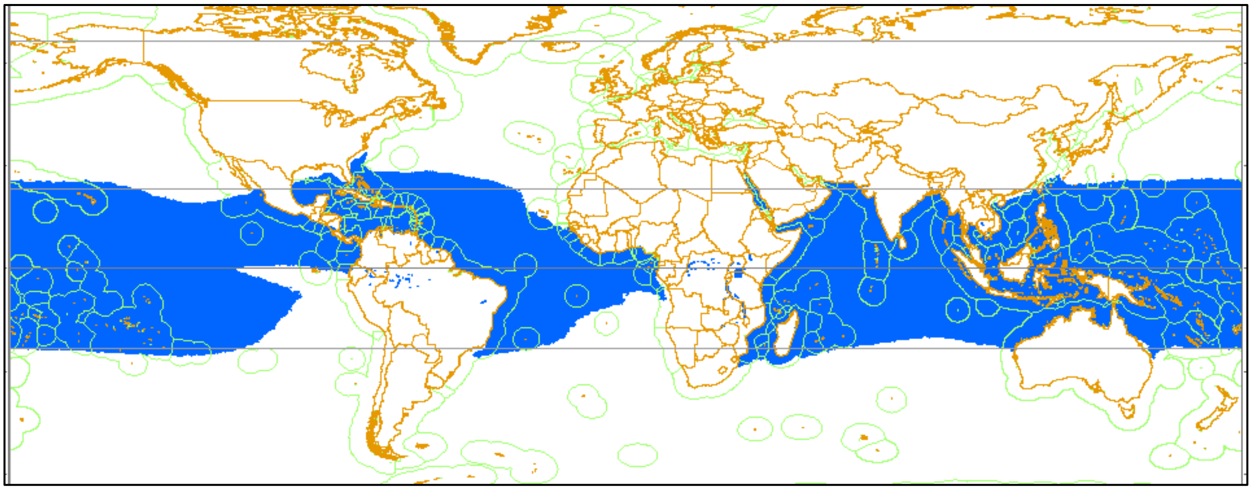

Figure 1 – Cobia geographic distribution

Cobia aquaculture research started in the 1970's, and by the late 90's technology was in place to produce large numbers of juveniles and grow-out in nearshore cage systems, occurring in coastal-nearshore and offshore cages, and utilizing both surface and submerged systems. Feed consists of pellets with high – close to 50% - percentage of crude protein, with a reported FIFO of 1.5:1.

Some of the challenges around cobia culture are:

- Large number of viruses, bacteria, and parasites, common to warm water marine species.
- Production in ponds impact water quality with excess nutrient in the effluent.
- Large-scale production at the various life stages can impact coastal areas and production discharge requires monitoring.
- Grow-out in cage systems impacts - escapees (genetic pollution), disease transmission, and nutrient loading in and around farm sites.
- Higher trophic level carnivores feed contains high crude protein levels, typically obtained from fish meal.

Cobia aquaculture production has had a spectacular 1393.44% growth from 3225 Tons in 2001 to 48 163.46 in 2019, at an average of 73.34% p.a. Production reached a peak in 2012 with 49 930.06 and has floated without a clear trend ever since, evidencing perhaps market maturity.

Gilthead Seabream (sparus aurata)

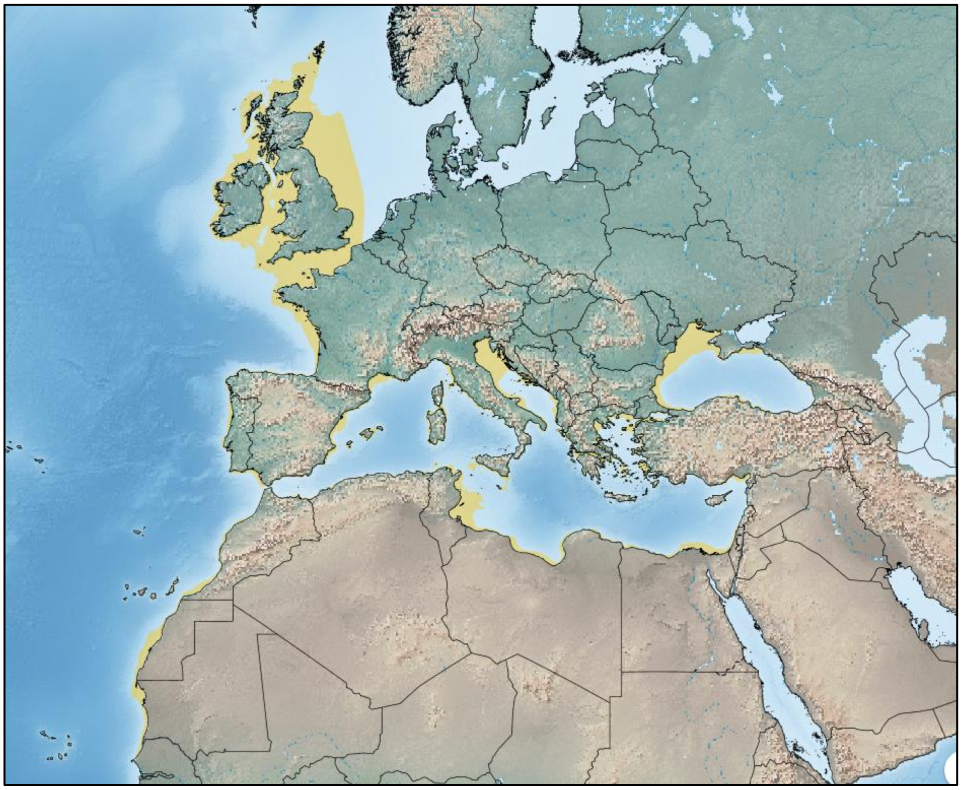

Figure 2 - Gilthead Seabream geographic distribution

The gilthead seabream is a temperate-water fish that is native to Europe, Mediterranean, Black Sea, and western African coast down to the cape vert.

Artificial breeding started in Europe in the early 80's and large-scale production of juveniles was achieved in the same decade. Seabream aquaculture success can be explained by its high adaptability to intensive farming conditions.

Although with a mature market, production data from 2001 to 2019 shows a 214.91% steady increase, representing a 11.3% p.a. growth.

Intensive farming usually integrates all stages: reproduction, larval rearing, pre-fattening and grow-out occurring in sea cages, using both semi-submersible and submersible cages. In intensive grow-out systems the Feed Conversion Ratio (FCR) is usually very favourable (about 1.3:1). Sea cages farming is simple and economical, but not being possible to control temperature usually results in longer rearing period to market size.

Production development in sea cages has led to declining prices and the industry evolved from high margins/low volumes to low margins/high volumes.

The species has a relatively long list of bacterial and viral diseases, and parasites. The potential impact of seabream aquaculture in coastal areas can include:

- Discharges of organic matters, phosphorus, and nitrogen can cause eutrophication.
- Farmed fish escapes impact wild stock genetic pool.
- Transfer of diseases parasites between farmed and wild fish.
- Introduction of non-indigenous species.

Atlantic Bluefin Tuna (Thunnus Thynnus)

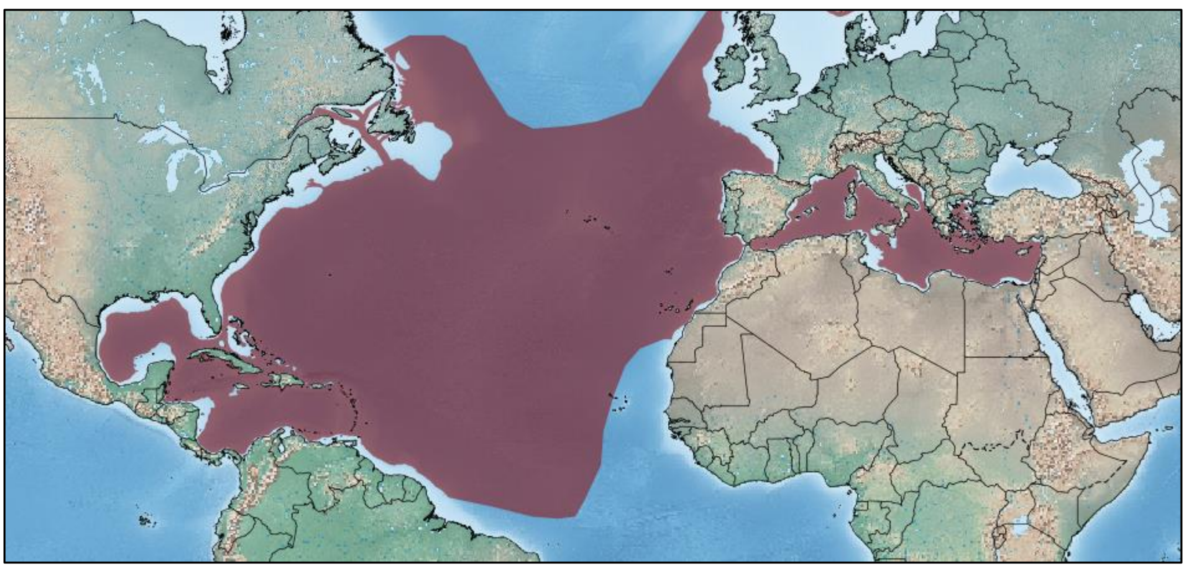

Figure 3 - Atlantic Bluefin Tuna geographic distribution

Atlantic bluefin tuna (ABT) are a large pelagic marine fish species siting at the top of the food chain. It is found in north Atlantic and Pacific Ocean temperate waters and migrate over long distances between temperate waters where it feeds, and tropical waters where its spawns.

ABT has great market awareness and strong demand, and it is positioned as a high value aquaculture species. From the middle of the 1990s, a capture-based aquaculture and “fattening” system was developed where a school of juveniles were caught and grow-out, and fattening occurs in cages where it's heavily fed oily pelagic fishes. Farming is motivated by a highly specialized Japanese market where commercial value depends on desirable fat contents. This industry resulted in overexploitation of stocks and imposed strong regulation.

The major challenge with ABT farming is sustainability. This is due to a very high feed conversion ratio FiFo[14] (somewhere between 7.6 and 15:1)(Aguado-Giménez & García-García, 2005; Cyrus Ma, 2016; WWF, 2020), and farming utilizes fishes as feed or fish oil/meal, which leads to overfishing of small pelagic species**.** (Aguado-Giménez & García-García, 2005; Cyrus Ma, 2016; Jusup et al., 2011; WWF, 2020).

14 The FIFO ratio (or Fish In – Fish Out ratio) is a conversion ratio applied to aquaculture, where the first number is the mass of harvested fish used to feed farmed fish, and the second number is the mass of the resulting farmed fish.

Yellowfin Tuna (thunnus albacares)

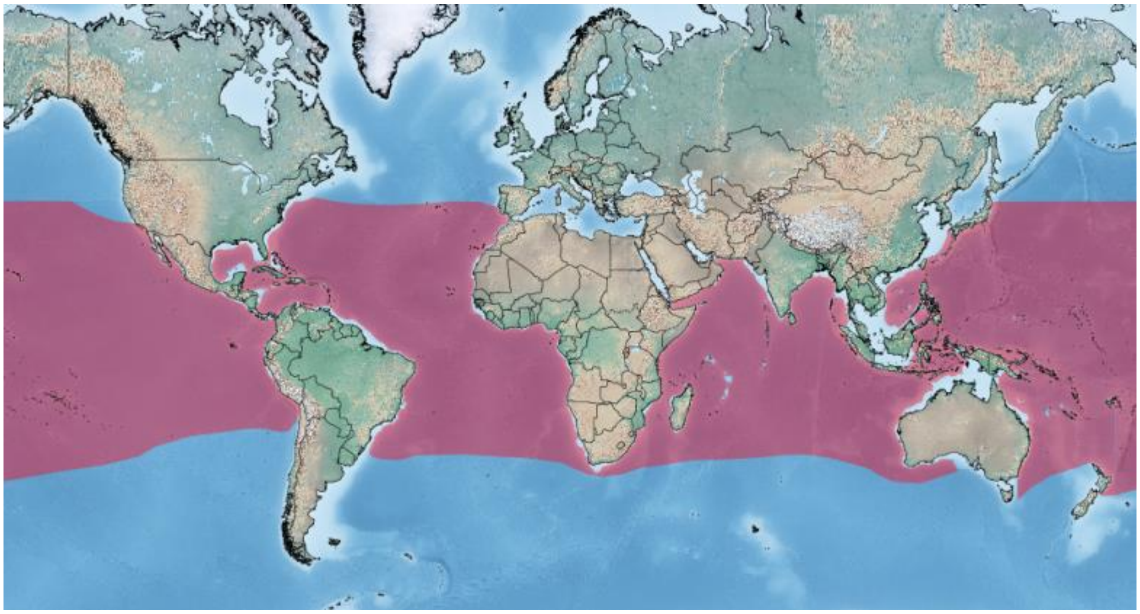

Figure 4 - Yellowfin Tuna geographic distribution

The yellowfin tuna (YFT) (*Thunnus albacares*) is a large epipelagic, oceanic carnivorous fish species that preys on fish, cephalopods, and crustaceans living at temperatures of 18 to 31°C from approximately 40°N to 35°S worldwide, but not present in the Mediterranean Sea.

YFT are highly migratory and strong schoolers where size at maturity depends on region and near- and offshore. Reproduction happens year-round. It is more frequent with warmer waters during the summer when it is at least 26°C, which is the lower limit for reproducing. Juveniles have a fast growth rate, reaching around 3.4 kg at 18 months and 63.5 kg in 4 years.

Research shows a strong potential for the YFT as a candidate species for full-life-cycle aquaculture (Margulies et al., 2016). The Inter-American Tropical Tuna Commission (IATTC) research maintains a hatching population since 1996. Larval and early juvenile stages are characterized by fast growth and high metabolic requirements, but with high mortality. Improving protocols can lead to increase in survival, the development of artificial diets, and sea cage rearing of juveniles. These can then support the development of full-life-cycle aquaculture of YFT.

Predictable challenges for YFT breeding:

- It can host parasites including protozoans, digenea (flukes), didymozoidea (tissue flukes), monogenea (gillworms), cestoda (tapeworms), nematode (roundworms), acanthocephalan (spiny-headed worms), copepods, isopods, as well as other fish.
- High feed conversion rates.

3.2 Depth processing

This subsection describes the processing steps needed for defining the depth constraint:

1. Clipping - depth raster GEBCO – General Bathymetric Chart of the Oceans clipping for the area of interest.
2. Selection of depth range - raster calculator – selection of depth range [-100m,-25m] and creation of a new raster layer.
3. Polygonizing [-100,-25] raster – conversion from raster to vectorial format for further geoprocessing.
4. Combining multipolygon [-100,-25] – creation of a single depth range polygon to use it as a final constraint layer.

3.3 Geoprocessing - outputs

Data layers representing suitable zoning for each species are obtained by overlaying the exclusive criteria or constraints, with the following steps:

1. Polygon intersection: a single depth-current-species polygon is created defining the areas where all the constraints are suitable.
2. Clipped distance from port (25 nm) – a final step clips the suitable areas using a 25 nautical miles distance buffer from the ports.
    - Porto Novo, Tarrafal São Nicolau and Poprto do Inglês Ports were added to FAO major maritime ports data.

Map outputs are later generated for each species and islands where suitable areas are identified.

4. RESULTS - SUITABILITY POTENTIAL FOR OFFSHORE MARICULTURE

The section presents offshore mariculture suitability analysis results by species.

Considering the large size of the EEZ, suitable areas are very limited. This is essentially due to unfavourable depths and current speed conditions that are derived from short shelf bathymetry and strong exposure to wind and ocean swell.

In the case of cobia farming, adequate water temperatures are found in some of the southern *Sotavento* islands. However, the constraints and the species habitat intersection does not identify suitable areas.

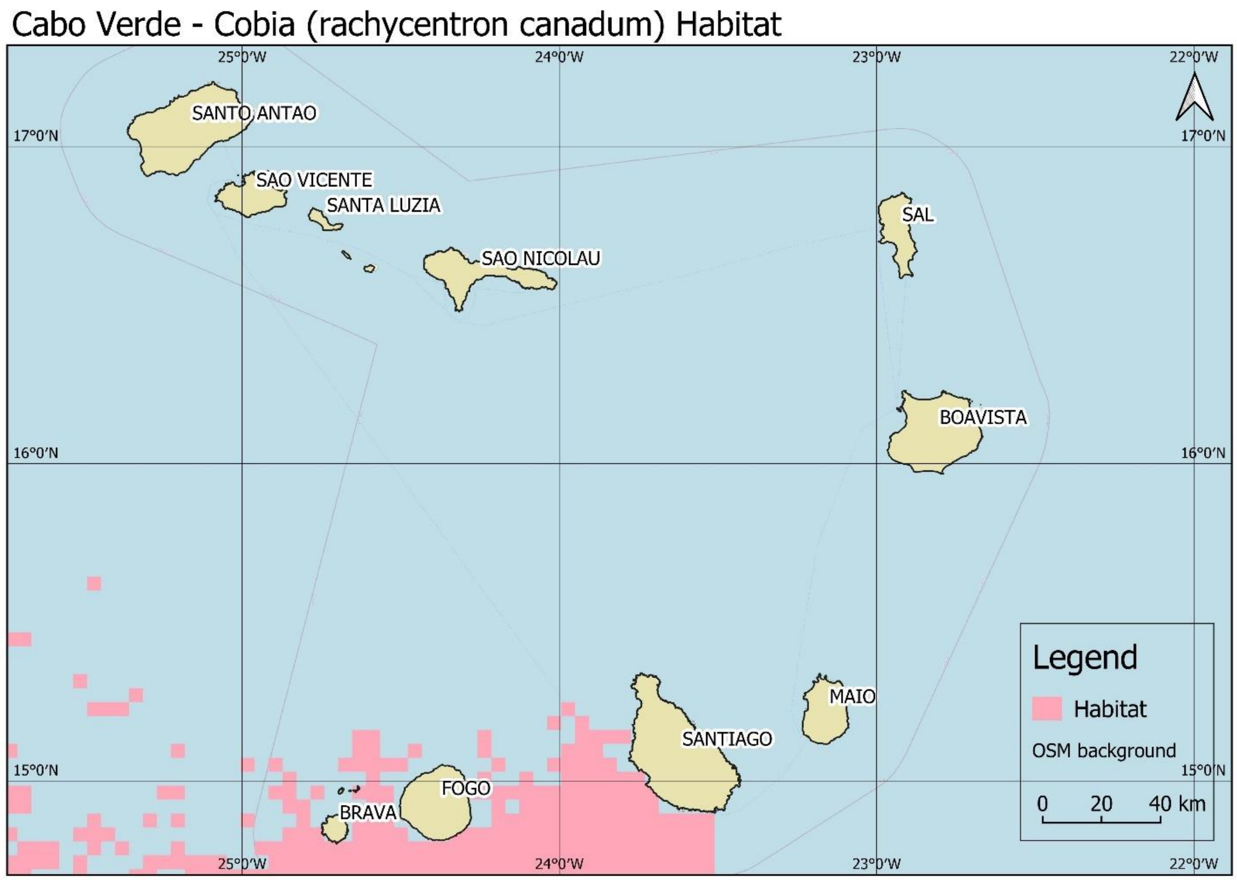

Figure 5 - Cobia Habitat

The *Sotavento* group of Brava, Fogo, and Santiago Islands exhibit no suitable areas for any of the analysed species offshore mariculture.

4.1 Gilthead seabream

The gilthead seabream can be found in all the archipelago's islands. The Eastern sandy and less mountainous islands of Sal, Boavista and Maio, show wider habitable areas due to more favourable depths.

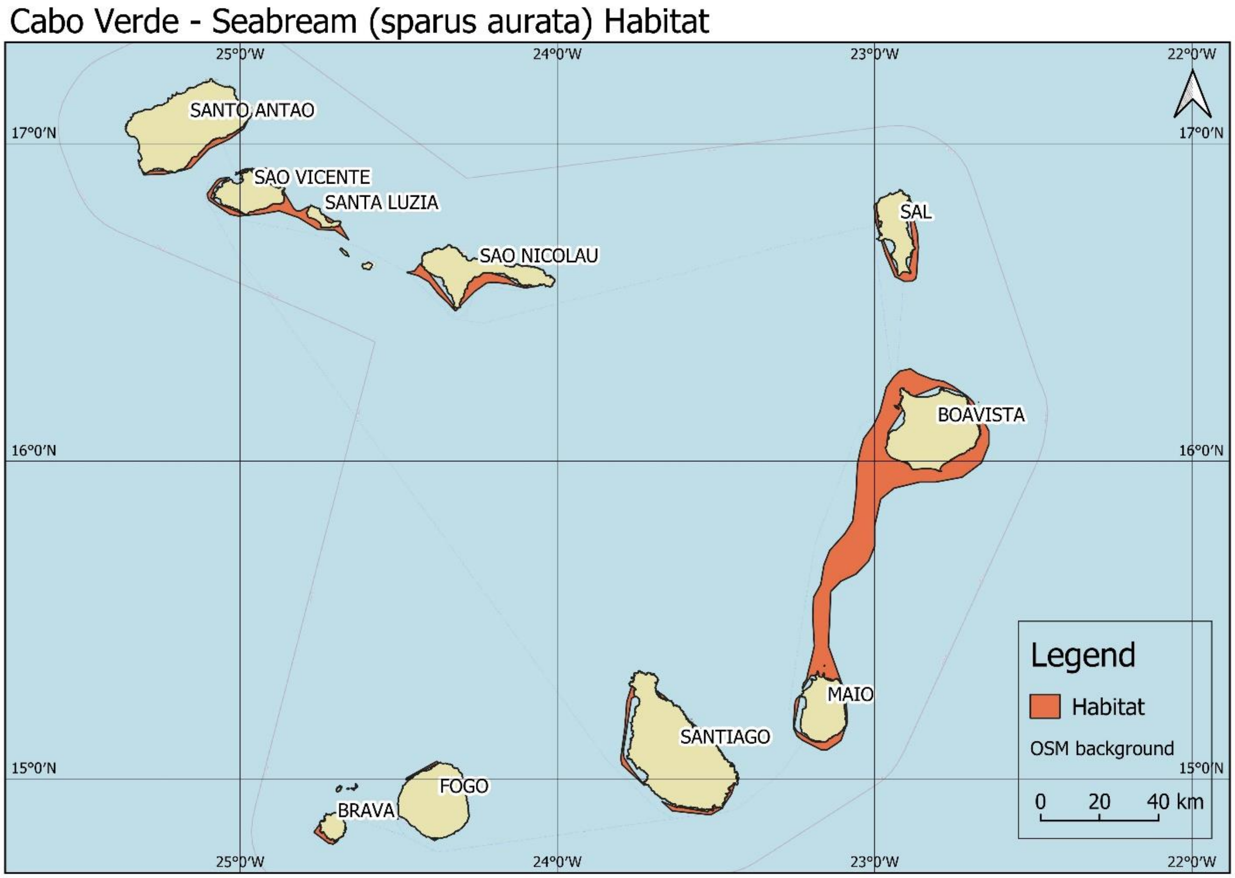

Figure 6 - Seabream Habitat

Although with great variations in extension, the suitable conditions for seabream offshore mariculture can be identified in six of the nine inhabited islands: Boavista, Maio, Sal, São Vicente, Santo Antão e São Nicolau.

Cabo Verde - Boavista - Seabream (Sparus Aurata) mariculture zoning

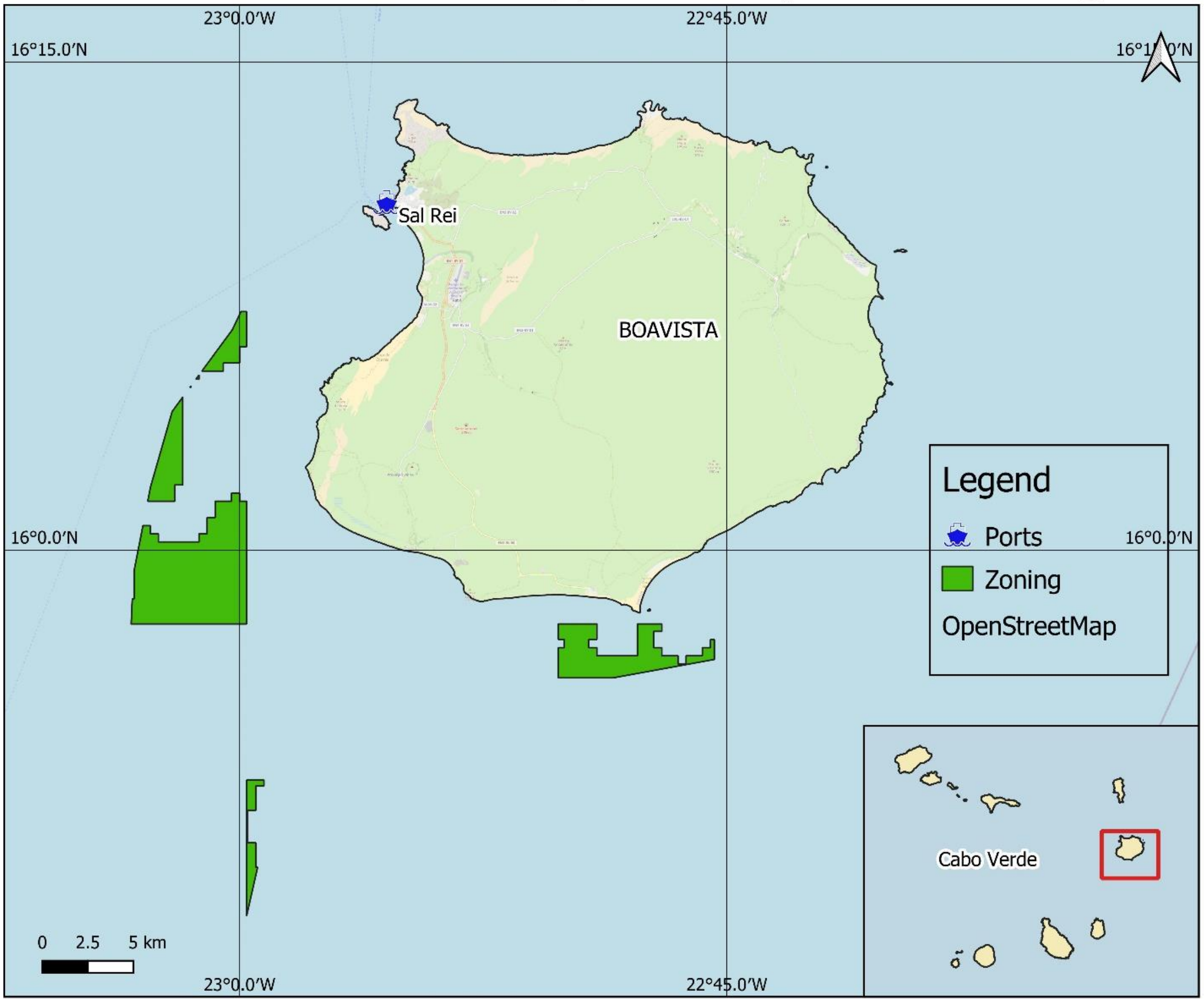

Figure 7 - Seabream Boavista

Located south and west of Boavista Island there are the largest suitable areas in the archipelago, with around 60 square kilometres.

Cabo Verde - Ilha do Maio - Seabream mariculture zoning

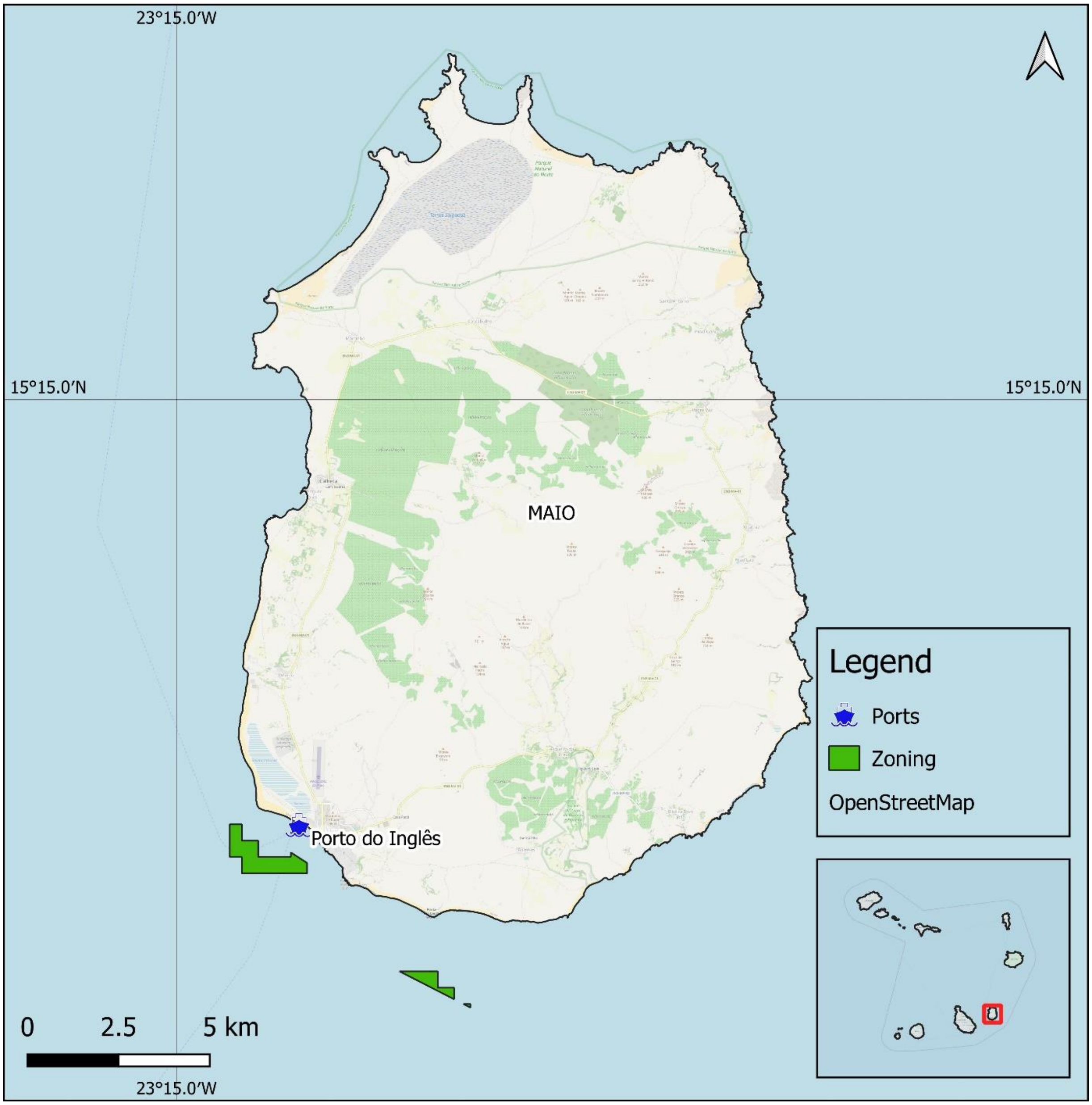

Figure 8 - Seabream Maio

Although with good bathymetric conditions in the context of the archipelago, a small suitable area (less than 2 square Km in total) is defined on Maio's southwest coast.

In the topic of ports, mariculture can conflict with other blue economy sectors, maritime transportation, and port logistics, but also find good inshore/offshore operation connectivity. With little touristic infrastructures and one of the most arid, Maio Islands is highly dependent on artisanal fisheries, another potential competing use of maritime space.

The analysis included Maio's Porto do Inglês as a major maritime port, considering its current expansion and modernisation[15].

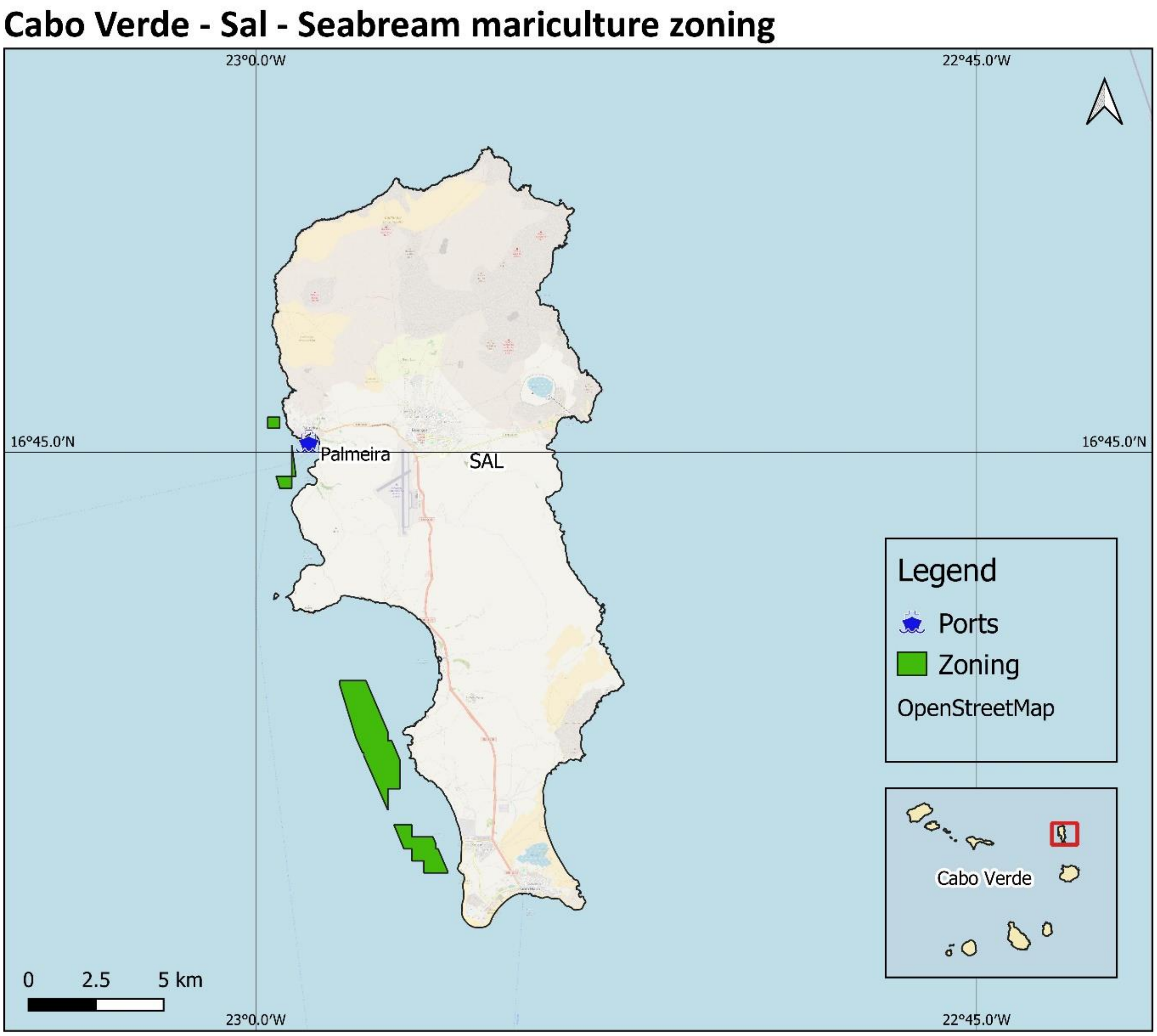

Figure 9 - Seabream Sal

Sal Island west coast presents around 7 square kilometres of suitable area; besides capture fisheries and port logistics, another possible conflicting sector is tourism which is the island's main economic activity.

[15] https://www.seth.pt/projetos/ampliacao-e-modernizacao-do-porto-ingles-na-ilha-do-maio/

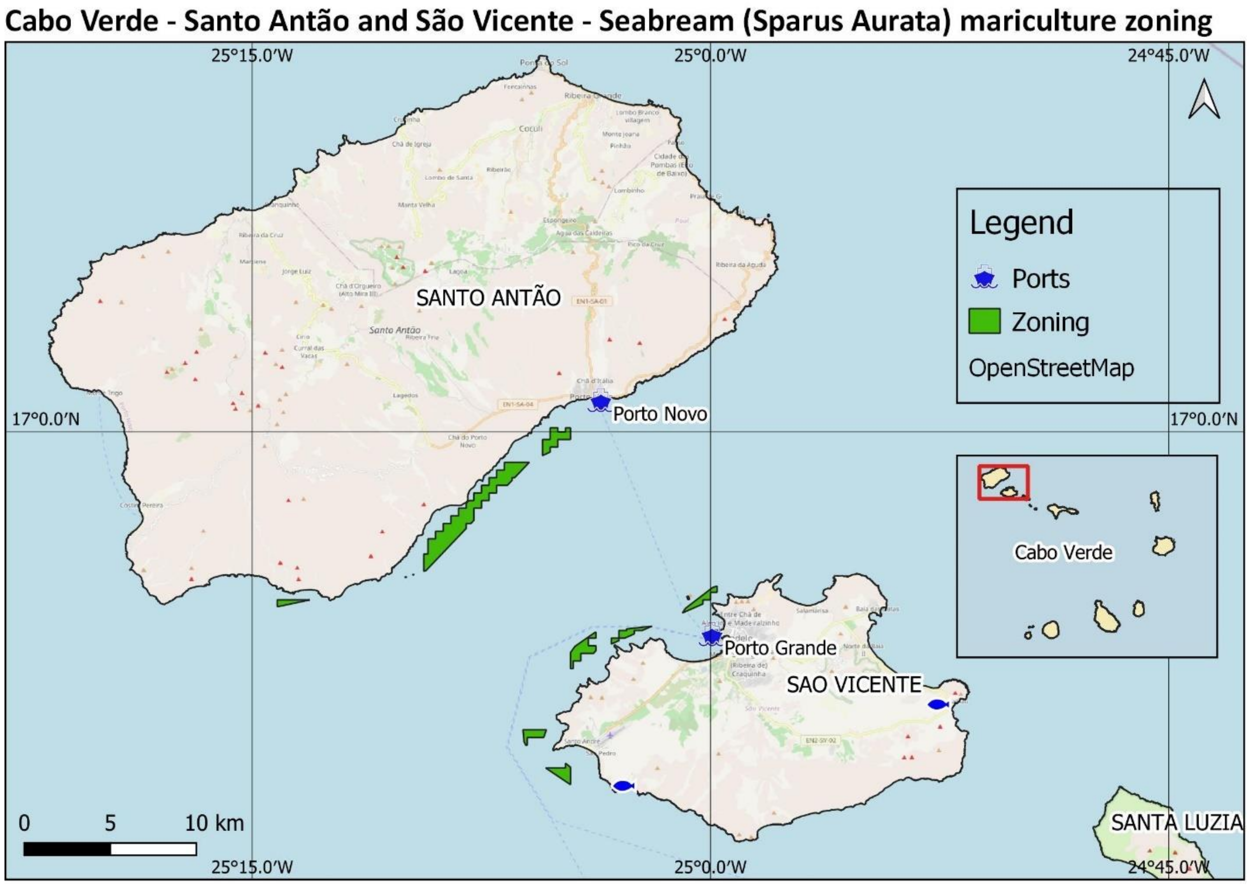

Figure 10 - Seabream Santo Antão/ São Vicente

Both islands display reasonable extents of suitable conditions for seabream farming with a total of around 12 square kilometres.

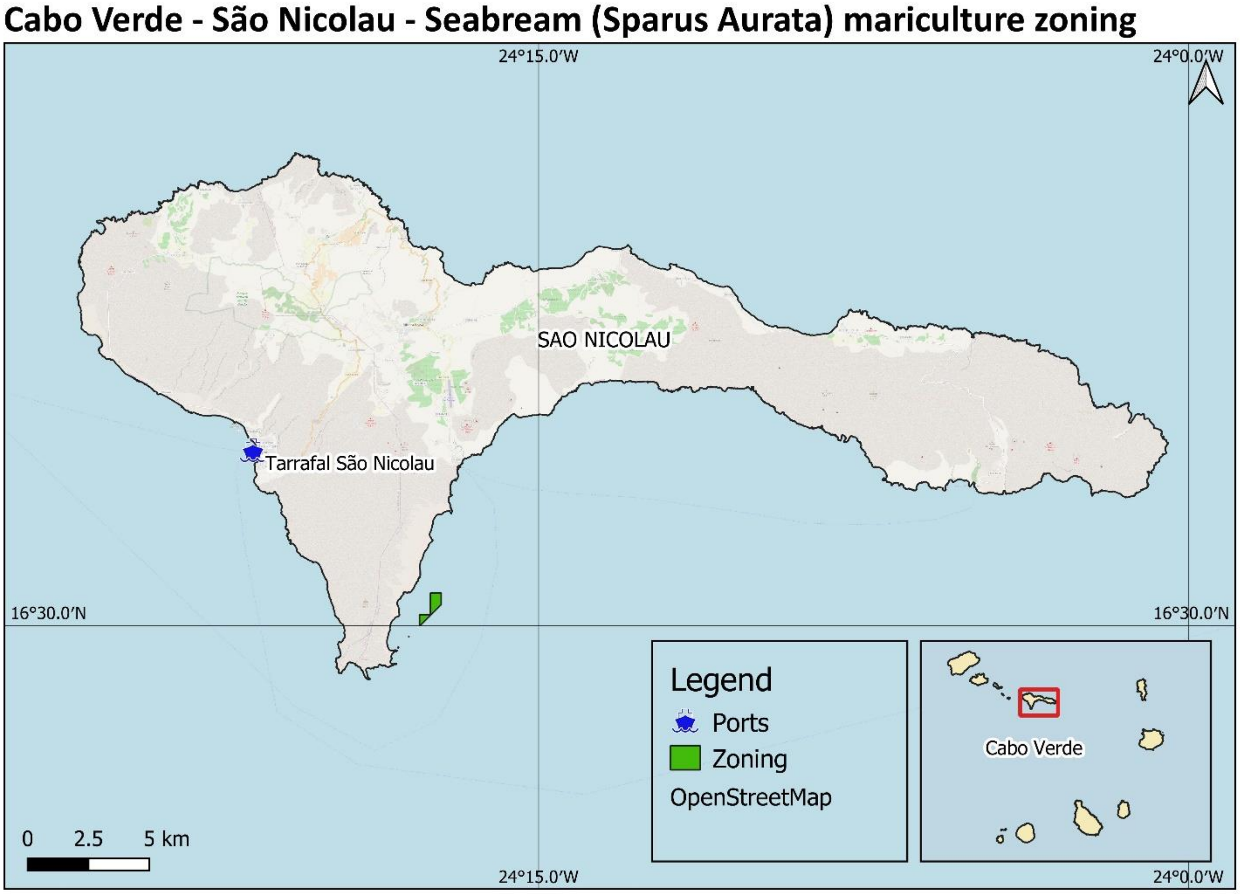

Figure 11 - Seabream São Nicolau

Current speeds strongly limit São Nicolau mariculture suitable areas. Seabream farming appears to have very limited prospects to the southeast with less than 0.5 square kilometres in area.

4.2 Atlantic Blue Fin Tuna

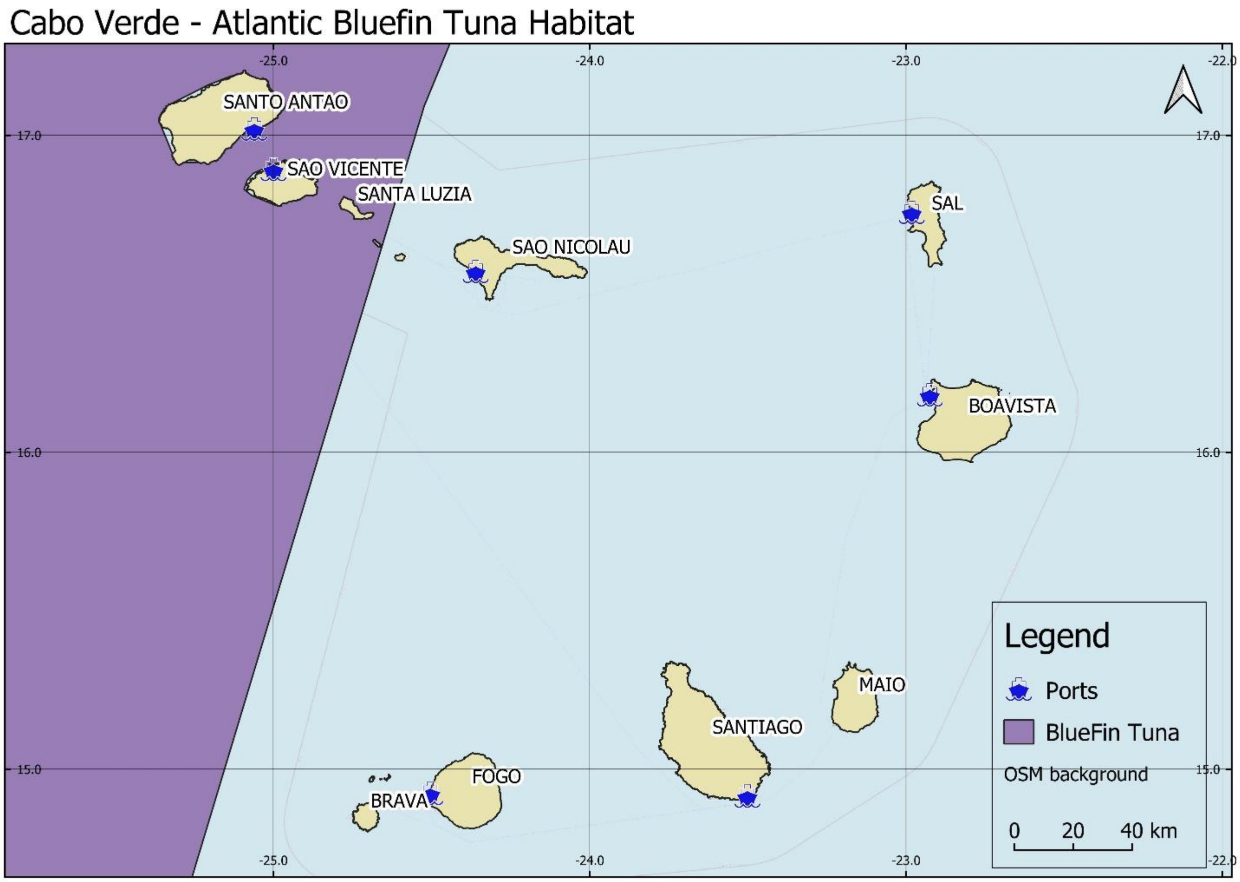

Figure 12 - Atlantic Bluefin Tuna Habitat

The species finds most appropriate habitat conditions in the westmost islands of São Vicente and Santo Antão.

Cabo Verde - Santo Antão and São Vicente - Atlantic Bluefin Tuna mariculture zoning

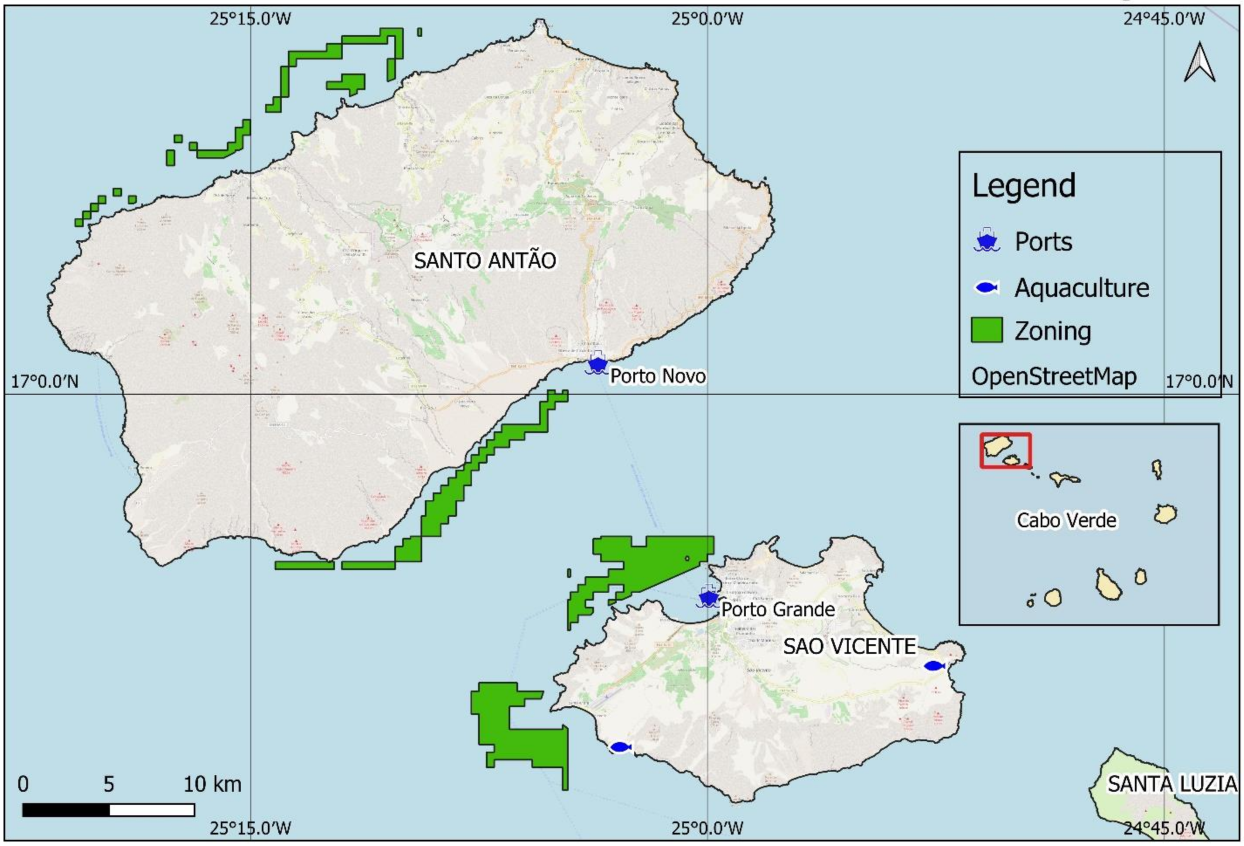

Figure 13 – Atlantic Bluefin Tuna Santo Antão and São Vicente

The largest suitable areas for ABT farming in the country (20 and 17.7 square kilometres) can be found in São Vicente. Unsurprisingly, Nortuna[16] has started an ABT fish farming operation in Flamengo Beach on the southwest coast.

Santo Antão also shows good prospects with roughly 28.6 square kilometres of potential areas both to the north and south of the islands.

---

[16] https://www.nortuna.com/cabo-verde

4.3 Yellow fin tuna

Of the considered species, the YFT has the most widespread habitat. It also happens to be the country's major capture production of the pelagic species and its main export.

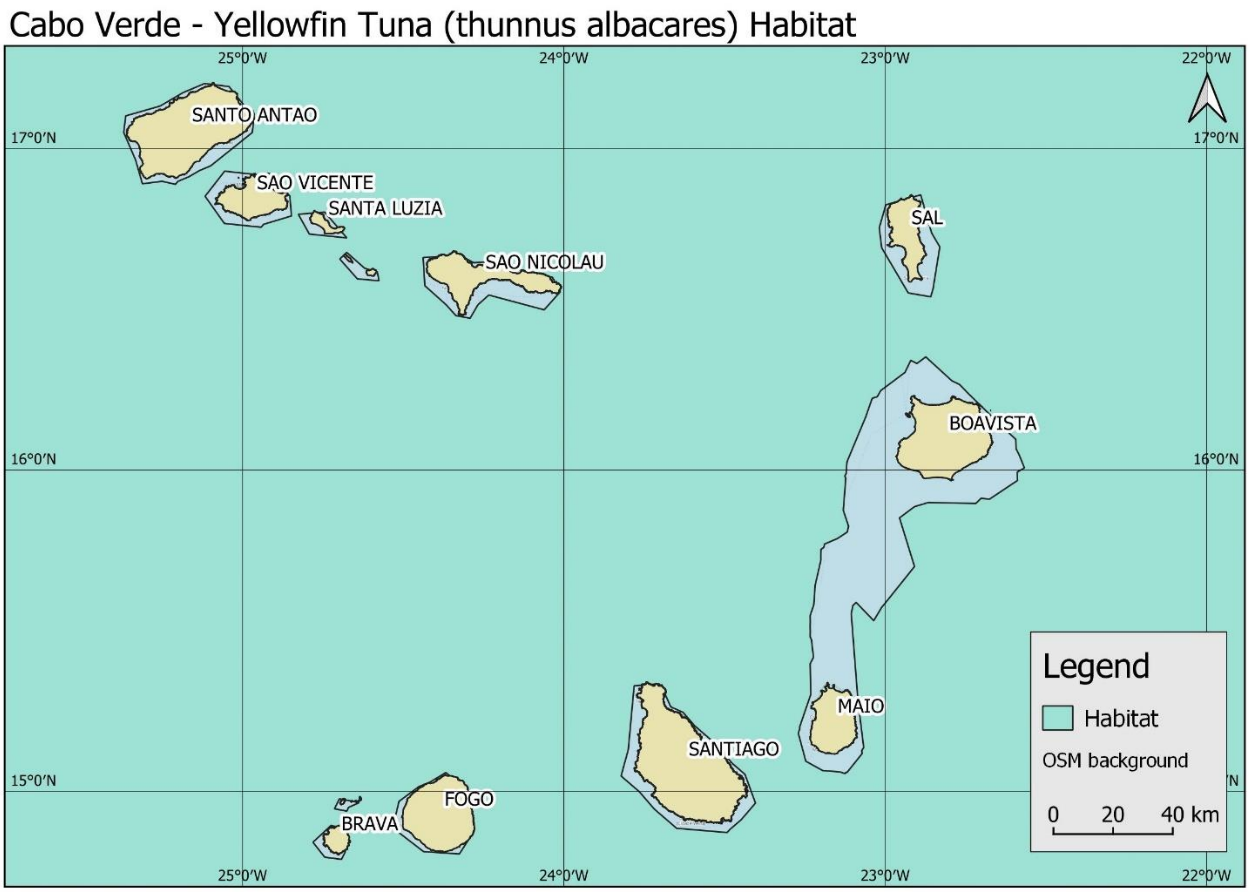

Figure 14 - Habitat Yellowfin Tuna

Although, it can be found in most of the country's economic exclusive zone, the southern group of *Sotavento* has less favourable farming conditions. Brava, Fogo and Santiago do not have suitable depths or currents speed. The region between Boavista and Maio Islands does not appear as an adequate habitat for the YFT.

Northwest islands of Santo Antão, São Vicente and São Nicolau have the most suitable conditions.

Cabo Verde - Boavista - Yellowfin Tuna mariculture zoning

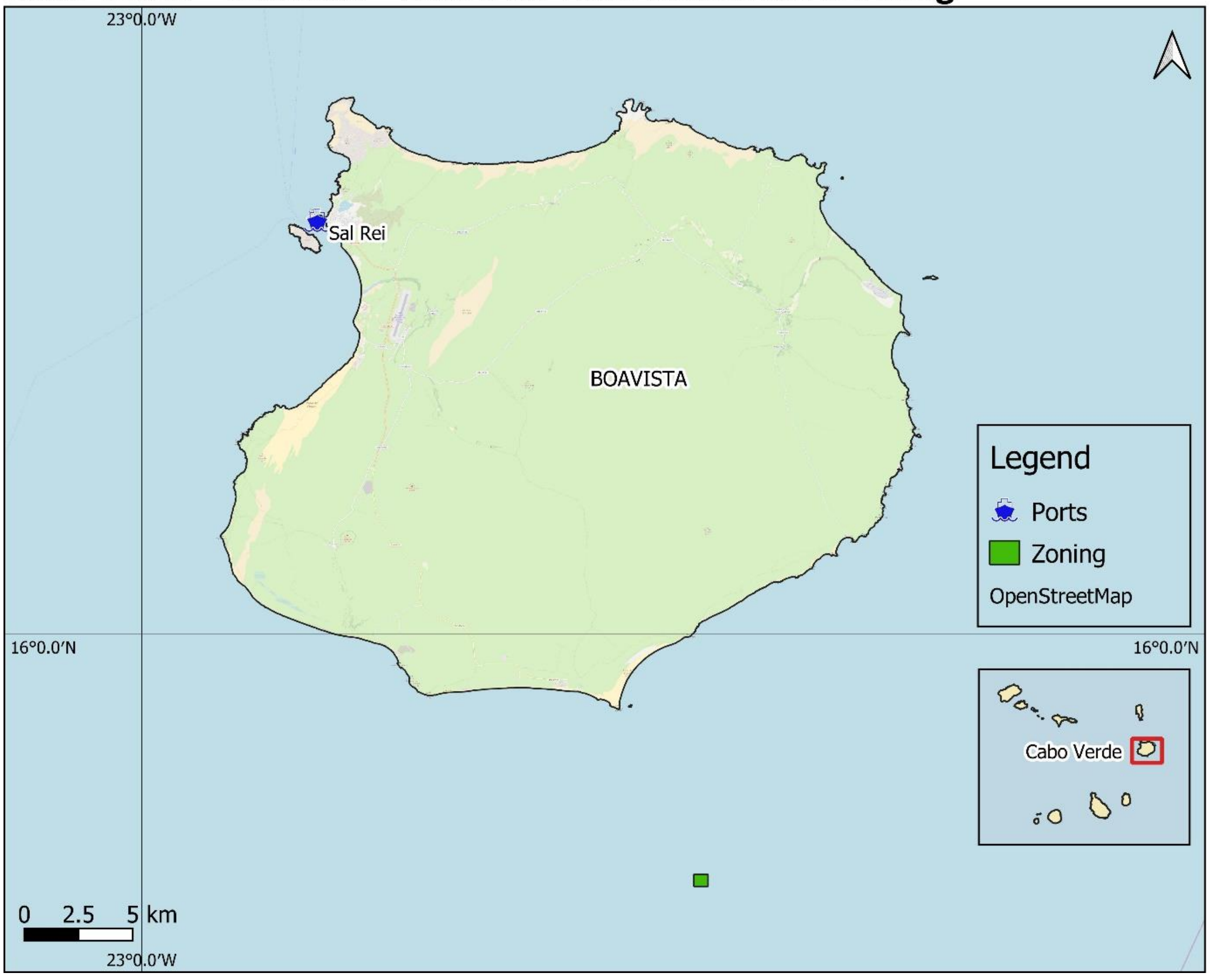

Figure 15 - Boavista YFT mariculture zoning

To the south of the island there is a very limited area of under 0.5 square km.

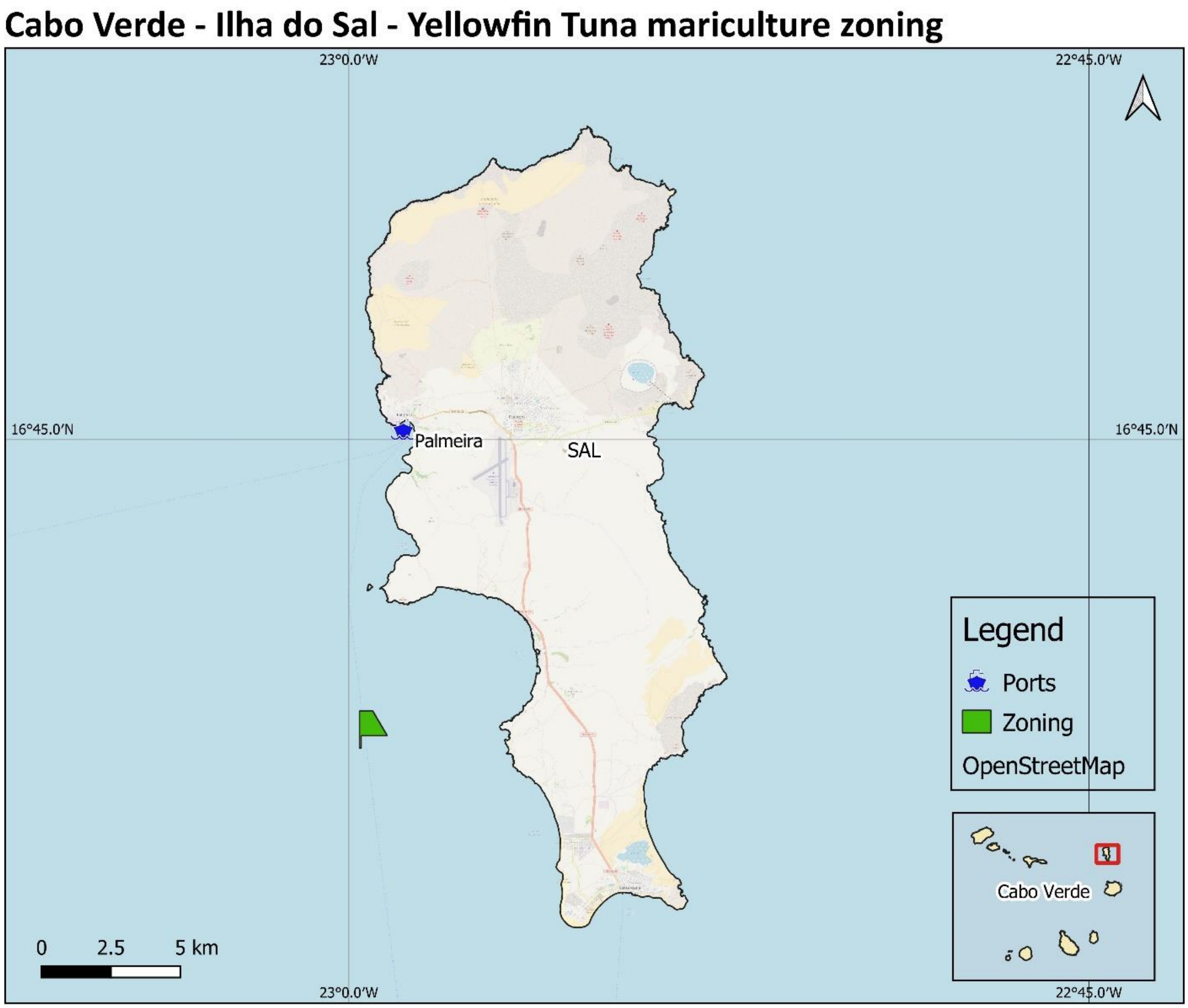

Figure 16 - Sal YFT mariculture zoning

A small extension on the west coast of Sal Island that is less than one square kilometre is considered suitable.

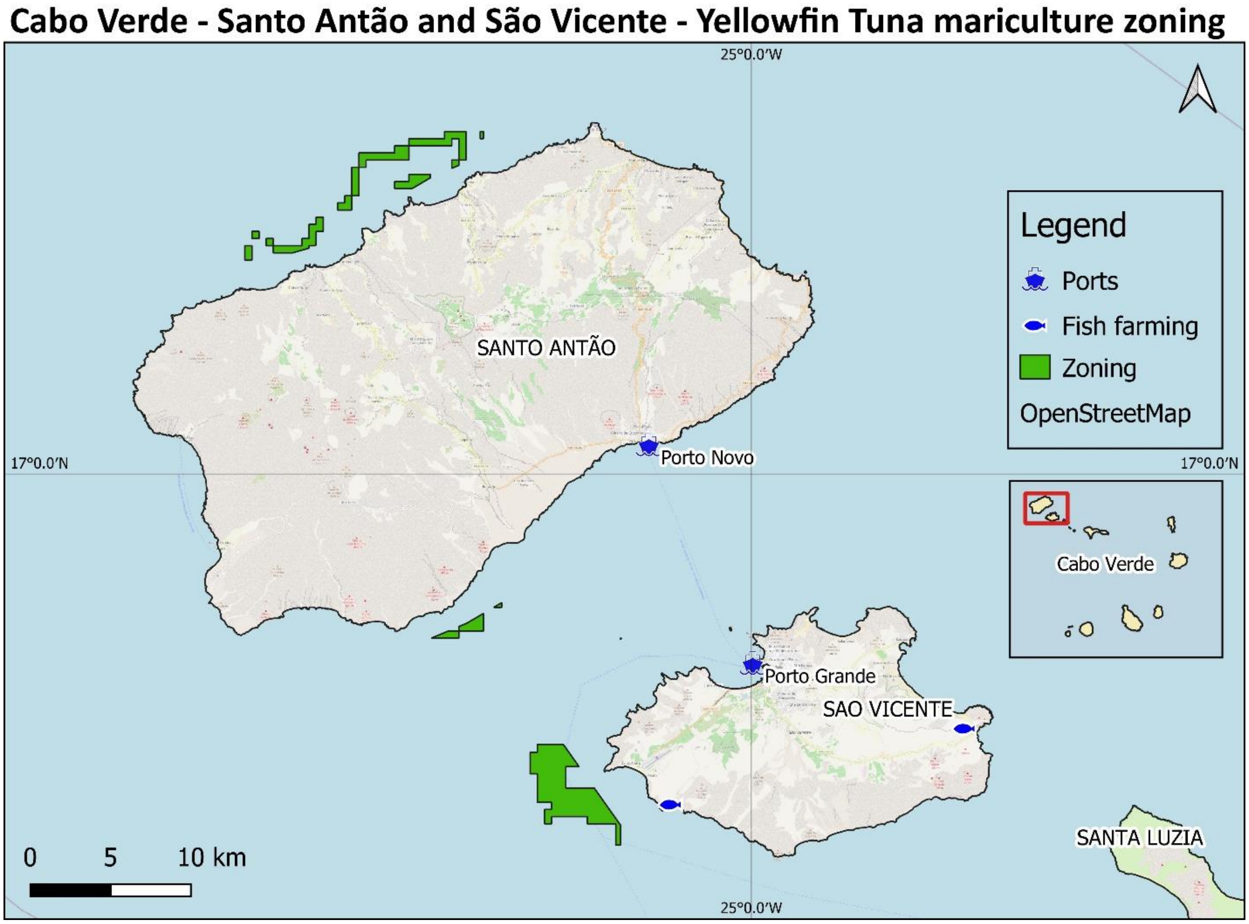

Figure 17 - Santo Antão and São Vicente YFT mariculture zoning

Northwest islands of Santo Antão and São Vicente are the most favoured and exhibit the largest suitable areas. West of São Vicente Island there is the largest area (approx. 15.398 km²) in the archipelago, and Santo Antão has scattered areas totalling around 12 square kilometres.

Cabo Verde - São Nicolau - Yellowfin Tuna mariculture zoning

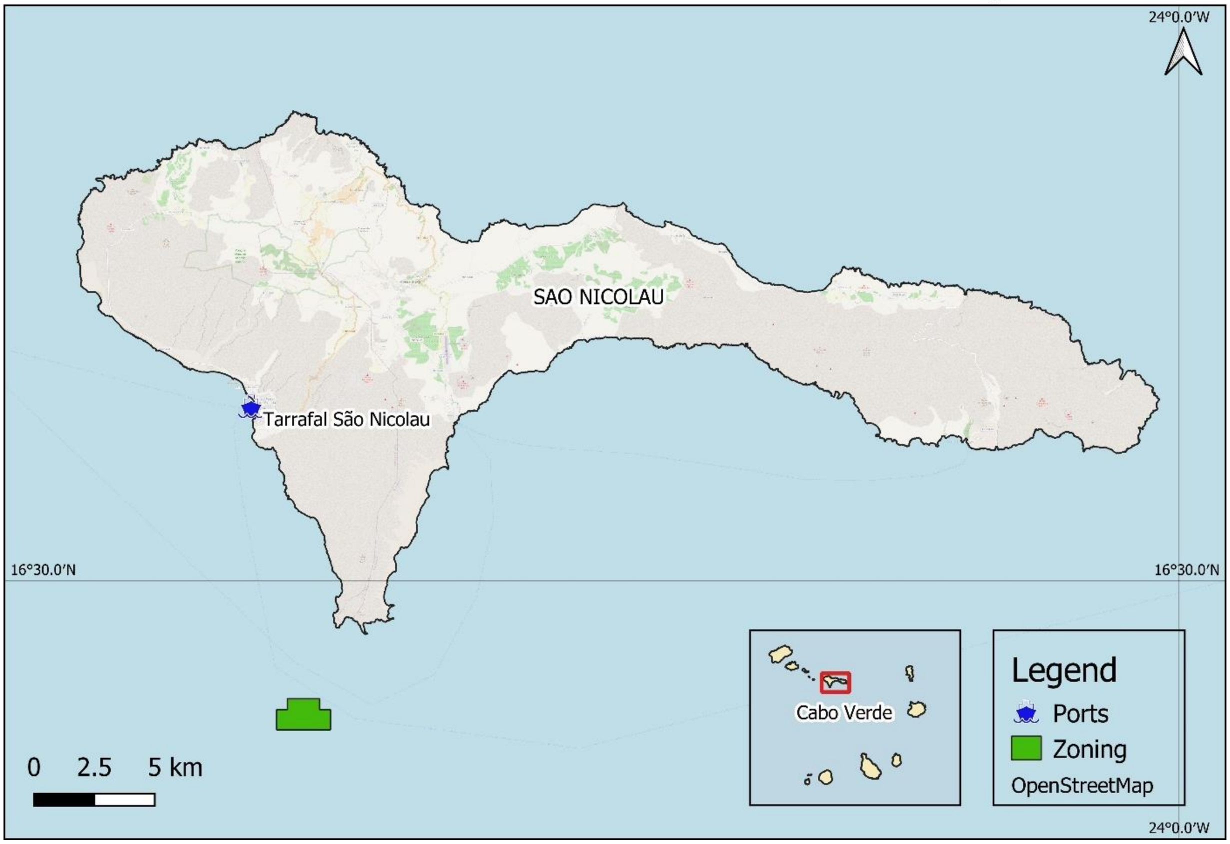

Figure 18 - São Nicolau YFT mariculture zoning

A medium suitable area of approximately 2.6 km² can be found south of São Nicolau Island.

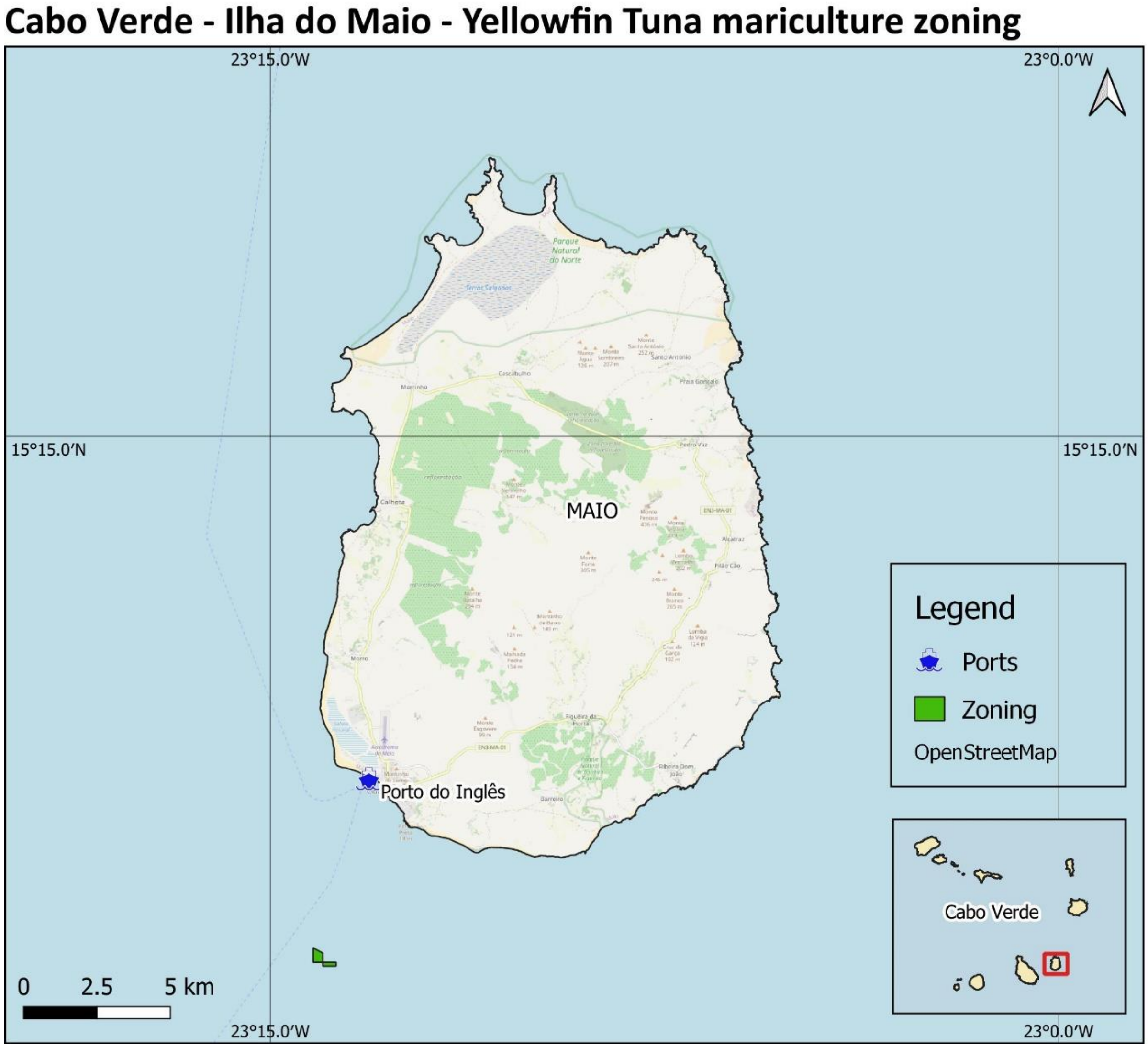

Figure 19 - Maio Island YFT mariculture zoning

Suitable zones around Maio Island are less than 0.5 square kilometres.

CONCLUSIONS

This section presents the working paper conclusions, results, and recommendations.

The paper documents a geographic information systems pilot case exercise that targets the assessment of offshore fish mariculture suitability in Cabo Verde. It consists of desk research analysis using publicly available global data layers.

The methodology is adopted from *"A global assessment of offshore mariculture potential from a spatial perspective*" study (Kapetsky et al., 2013). It is based on a set of assumptions, analytical criteria, and thresholds, associated to cages technical limits, farming profitability, and species habitat. Results interpretation must consider that assumptions, criteria, and thresholds are subject to change as mariculture technology, techniques, and methods evolve.

Considered species are selected based on existing habitat, proven farming technologies, and established markets or demonstrated potential for full-life-cycle aquaculture - for Cobia (rachycentron canadum), Gilthead Seabream (Sparus Aurata), Atlantic Bluefin Tuna (Thunnus Thynnus), Yellowfin Tuna (thunnus albacares).

Geographical information systems modelling is contingent on input data quality and characteristics, e.g.: current speed data spatial resolution is around 8.9 km which it is not ideal for detailed high-scale analysis.

A large potential demand is projected for fish farming products in the sub-Saharan African (SSA) region, due to expanding supply demand deficit, explained by fast-growing urban population and middle-class purchase power, and stagnation or decline in capture fisheries production. Per capita fish consumption is anticipated to decrease in Africa and especially in the SSA region.

Aquaculture and mariculture had spectacular growth in the last two decades posing long-term sustainability questions. Large-scale production growth policies should not overlook the fact that capture fisheries are of key importance to a large majority of coastal communities in the developing world and should have a deep understanding of how production connects with consumption, in terms of output access and affordability.

Cabo Verde has in place a blue growth charter that is targeting resource protection, management, research, surveillance, diversification, and added value.

In the context of the blue economy, offshore mariculture suitability assessment must be integrated with socio-economic, environmental, sustainability, and jurisdictional issues and data, laying ground to a holistic approach to blue growth. Investment interventions and policies must recognize that small-scale fisheries provide livelihoods to tens of millions and contribute significantly to household, local and national economies. Artisanal fisheries guarantee essential nutrition to billions and especially for the poorest, and it is estimated that small-scale fisheries provide 90%of the employment in the marine fisheries sector.

Cabo Verde is a dry Sahelian SIDS where fisheries are strategic to the economy. Fisheries provide around 80% of the country exports and contributes to national nutrition and food security. Capture fisheries are in decline after decades of growth, with industrial investments adding pressure to stocks. Artisanal fisheries are of vital importance on direct and indirect employment, coastal communities' resilience, supplying the internal market, and fundamental to food security and nutrition.

Aquaculture is practically inexistant. An ABT pilot project (Nortuna) and shrimp inland farming operate in São Vicente but suitable areas do not thrive. Natural conditions determine strong physical limitations for offshore mariculture, such as unfavourable depths and ocean swells and trade winds exposure can impose adverse current conditions. Besides limited areas, there are also competing blue economy sectors, most importantly tourism and capture fisheries.

From the analysed species, Seabream, ABT and YFT found suitable conditions. Seabream has proven technology and a mature market but consist low margins and large volumes industry. ABT presents difficult sustainability challenges that derive from an extremely high feed conversion ratio and Japanese markets requirements. With large-scale production potentially leading to overfishing (mackerel and horse mackerel most likely candidates), impacting on direct capture fisheries for human consumption, and dependent wild species like the YFT. YFT has good prospects of becoming a species for full life-cycle aquaculture, but challenges should come identic to the ABT. Besides, they can also host a of parasites and intensive fish farming densities are particularly favourable to the proliferation of parasites and diseases.

Offshore mariculture impacts should be taken into consideration. These include organic maters, genetic pool impacts, transfer of disease and parasites, chemicals and pharmaceuticals, and introduction of non-indigenous species.

Results summary

In conclusion, the northern islands group, *barlavento,* and specially the western most islands of Santo Antão and São Vicente, display the strongest prospects. In the *sotavento* southern group, Brava, Fogo, and Santiago Islands do not appear to have any suitable areas.

In the case of cobia farming, although adequate water temperatures are found in some of the southern *Sotavento* islands group, constraints and habitat intersection does not identify suitable areas.

The gilthead seabream (sparus aurata) can be found in all the archipelago's islands. Eastern, sandy, and less mountainous islands of Sal, Boavista and Maio show wider habitat areas probably due to favourable depths. Suitable conditions can be identified in six of the nine inhabited islands, with large variations in potential areas: Boavista, Maio, Sal, Santiago, Santo Antão e São Nicolau. Boavista presents the largest zones (around 60 square km), Sal, Santo Antão and São Vicente medium size areas, and marginal areas in São Nicolau.

The ABT finds habitat conditions in the westmost islands, São Vicente and Santo Antão. Major suitable areas are in São Vicente (20 and 17.7 square kilometres). Unsurprisingly, Nortuna has started an ABT fish farming operation in Flamengo Beach on its southwest coast. Santo Antão also shows suitable areas, with around 28.6 square kilometres both to the north and south of the island.

The YFT habitat is widespread. It's the major capture fisheries production species and country's largest export. Southern group "sotavento" shows challenging conditions for mariculture, while Brava, Fogo and Santiago have unsuitable depths or currents speed. Very limited areas can be found in Boavista and Sal. West of São Vicente presents the largest suitable area in the archipelago (approx. 15.4 km^2) and Santo Antão scattered areas that sum around 12 square kilometres. São Nicolau has the third largest zone with 2.6 square kilometres while in Maio is minimal.

Closing Remarks

Although opportunities for offshore mariculture exist, a blue economy growth perspective suggesting that large-scale mariculture can replace capture fisheries has to be avoided. Policies and planned interventions must consider the social, cultural, and economic roles that capture small-scale artisanal fisheries to provide for Small Island Developing States.

Large offshore mariculture investments can, to some level, provide jobs and income opportunities to vulnerable communities. However, when targeting high-value output markets, its products are most likely inaccessible to local poor. A direct connection with local food security and nutrition is highly doubtful ((Brugere et al., 2021, Farmery et al., 2021).

Artisanal small-scale near-shore fisheries provide most of the seafood to lower-income households in the global south, while competing maritime space and wild stock catches used as feed, can contribute to further depletion of crucial resources for food security and nutrition, and have adverse socio-economic effects. Offshore mariculture and capture fisheries have similar spatial constraints, e.g. specific depth ranges and proximity to the coast, and in the case of Cabo Verde these areas do not abound.

Caution and examinations are needed for interventions targeting offshore mariculture. Large carnivorous species fed, directly or indirectly, nutrient-rich small-fish presents medium to long term sustainability challenges. Besides potential ecosystem impact and unforeseen socio-economic consequences, there are other environmental impacts. Intensive offshore mariculture are open systems with direct exchanges to the surrounding environment. This includes feed residues, faecal matter, pesticides, antibiotics, hormones, [1] (Wang et al., 2022; Zhang et al., 2021) et al., 2021), contamination by pathogens and parasites, and fish escapes impacting the local genetic pool or introducing invasive species.

In face of complex potential interactions and outcomes, a reliable, participated, maritime spatial planning (MSP) effort must frame an integrated maritime policy (IMP). These are essential instruments to manage competition for maritime space, preventing conflicts, streamlining decision making, creating a good environment for investors, increasing effective marine environment protection, and in short, guarantee a sustainable use of the extremely critical maritime resources for the SIDS.

BIBLIOGRAPHY

Aguado-Giménez, F., & García-García, B. (2005). Growth, food intake and feed conversion rates in captive Atlantic bluefin tuna (Thunnus thynnus Linnaeus, 1758) under fattening conditions. *Aquaculture Research*, *36*(6), 610–614. https://doi.org/https://doi.org/10.1111/j.1365-2109.2005.01210.x

Brugere, C., Troell, M., & Eriksson, H. (2021). More than fish: Policy coherence and benefit sharing as necessary conditions for equitable aquaculture development. *Marine Policy*, *123*, 104271. https://doi.org/10.1016/J.MARPOL.2020.104271

Cyrus Ma. (2016). *Bluefin Tuna Thunnus thynnus Mediterranean Sea*. https://seafood.ocean.org/wp-content/uploads/2016/12/Tuna-Bluefin-Mediterranean-Farmed.pdf

FISHERIES PARTNERSHIP AGREEMENT between the European Community and the Republic of Cape Verde, (2006) (testimony of European Union). 15/02/2022https://ec.europa.eu/oceans-and-fisheries/fisheries/international-agreements/sustainable-fisheries-partnership-agreements-sfpas/cabo-verde_en#:~:text=Cabo%20Verde%20The%20current%20fisheries%20partnership%20agreement%20between,expiration%20of%20the%20previous%20protocol%20in%20December%202018.

FAO. (2020). *The State of the World Fisheries and Aquaculture*.

FAO. (2022a, February 8). *Fishery and Aquaculture Country Profiles. Cabo Verde.* . Country Profile Fact Sheets. Fisheries and Aquaculture Division. https://www.fao.org/fishery/en/facp/cpv?lang=en

FAO. (2022b, February 15). *Compilation of Aquatic Species Distribution Maps of Interest to Fisheries*. Maps Collections Fact Sheets. https://www.fao.org/fishery/en/collection/fish_dist_map

Ferreira, J. G., Saurel, C., & Ferreira, J. M. (2012). Cultivation of gilthead bream in monoculture and integrated multi-trophic aquaculture. Analysis of production and environmental effects by means of the FARM model. *Aquaculture*, *358–359*, 23–34. https://doi.org/10.1016/j.aquaculture.2012.06.015

Jusup, M., Klanjscek, T., Matsuda, H., & Kooijman, S. A. L. M. (2011). A Full Lifecycle Bioenergetic Model for Bluefin Tuna. *PLoS ONE*, *6*(7), 21903. https://doi.org/10.1371/journal.pone.0021903

Kapetsky, J. M., Aguilar-Majarrez, J., & Jenness, J. (2013). A global assessment of offshore mariculture potential from a spatial perspective. In *FAO Fisheries and Aquaculture Technical Paper* (Issue N°. 549, pp. 0–181). Food and Agriculture Organization of the United Nations.

Margulies, D., Scholey, V. P., Wexler, J. B., & Stein, M. S. (2016). Research on the Reproductive Biology and Early Life History of Yellowfin Tuna Thunnus albacares in Panama. *Advances in Tuna Aquaculture: From Hatchery to Market*, 77–114. https://doi.org/10.1016/B978-0-12-411459-3.00004-7

Mayer, P., Estruch, V., Blasco, J., & Jover, M. (2008). Predicting the growth of gilthead sea bream (Sparus Aurata L.) farmed in marine cages under real production conditions using temperature- and time-dependent models. *Aquaculture Research*, *39*, 1046–1052. https://doi.org/10.1111/j.1365-2109.2008.01963.x

OECD, & FAO. (2021). *OECD-FAO Agricultural Outlook 2021-2030 - 8 Fish* (pp. 190–201). OECD. https://doi.org/10.1787/19428846-en

Porporato, E. M. D., Pastres, R., & Brigolin, D. (2020). Site Suitability for Finfish Marine Aquaculture in the Central Mediterranean Sea. *Frontiers in Marine Science*, *6*. https://doi.org/10.3389/fmars.2019.00772

Satia, B. P. (2017). Regional review on status and trends in aquaculture development in sub-Saharan Africa. In *FAO Fisheries and Aquaculture Circular* (Vol. 4, Issue No. 1135/4).

Scholaert, Frederik., & European Parliament. Directorate-General for Internal Policies of the Union. (2020). *The blue economy : overview and EU policy framework : in-depth analysis.* https://www.europarl.europa.eu/RegData/etudes/IDAN/2020/646152/EPRS_IDA(2020)646152_EN.pdf

Wang, X., Lin, Y., Zheng, Y., & Meng, F. (2022). Antibiotics in mariculture systems: A review of occurrence, environmental behavior, and ecological effects. *Environmental Pollution*, *293*. https://doi.org/10.1016/j.envpol.2021.118541

WWF. (2020). *Is Farmed Fish Sustainable*. WWF Our News. https://www.wwf.org.hk/en/?24004/Is-Farmed-Fish-Sustainable

Zhang, R., Du, J., Dong, X., Huang, Y., Xie, H., Chen, J., Li, X., & Kadokami, K. (2021). Occurrence and ecological risks of 156 pharmaceuticals and 296 pesticides in seawater from mariculture areas of

Northeast China. *Science of The Total Environment*, *792*, 148375.
https://doi.org/10.1016/J.SCITOTENV.2021.148375