Ocean and Coastal Management 243 (2023) 106764

Contents lists available at ScienceDirect

Ocean and Coastal Management

journal homepage: www.elsevier.com/locate/ocecoaman

Towards blue growth: Multi-use possibilities for the development of emerging sectors in the Brazilian sea

Carlos V.C. Weiss [a,b,*], Jarbas Bonetti [b], Marinez E.G. Scherer [b], Bárbara Ondiviela [a], Raúl Guanche [a], José A. Juanes [a]

[a] *IHCantabria - Instituto de Hidráulica Ambiental de la Universidad de Cantabria, Santander, Spain*
[b] *Federal University of Santa Catarina, Florianópolis, SC, Brazil*

ARTICLE INFO

Keywords:
Spatial synergies
Marine spatial planning
Offshore wind energy
Wave energy
Aquaculture

ABSTRACT

The marine environment has been in the spotlight of economic development due to the growing demand for areas to promote activities associated with the concept of Blue Economy. This is the case of the renewable energy and aquaculture sectors, whose expansion towards offshore is determined by the increase global demand for energy and food, and by exceeding of the carrying capacity of coastal and terrestrial systems. In this context, the multi-use strategy can be an alternative to minimize conflicts between activities and impacts on the surrounding social-ecological environment. This contribution presents a preliminary approach to identify opportunities for individual exploitation and the possibilities of multi-use between wind energy, wave energy and aquaculture in Brazil's Exclusive Economic Zone. Technical, operational, and biological aspects were evaluated, through a Suitability Index validated in previous works, to identify zones with favorable conditions for energy exploitation and farming of six fish species. Additionally, overlaps between conservation areas and multi-use zones were considered to analyze possible spatial conflicts. Zones with multi-use possibilities with different combinations between these sectors were identified: *i)* wave energy and aquaculture presented the largest areas for multi-use, distributed in the south, southeast and northeast; *ii)* possibility of combining wind energy and aquaculture was identified in the northeast; and *iii)* multi-use possibilities in the south for marine energies. Zones with multi-use possibilities were identified in protection and conservation areas, such as the combination of wave exploitation and Greater Amberjack farming, with 63% overlap. Therefore, this case study is a guide for future local studies in the marine region of Brazil, mainly in the selection of sites for analysis. The present contribution represents a starting point for the discussion about multi-use in the country.

1. Introduction

Marine renewable energy sources and offshore aquaculture are key players in the energy transition and food security, respectively, highlighting the important role that Blue Economy will play in the coming decades. On one hand, most countries, especially those committed to the 2030 Agenda, have aimed to renew their energy mix with renewable sources, due to the unsustainability of fossil fuel-based resources (Vidal-Amaro et al., 2015). In turn, due to the exceeding of the carrying capacity of coastal environments, the aquaculture sector faces a lack of areas to meet the demands of a growing world population (Costello et al., 2020). In this context, the need for the expansion of these industries towards offshore arises (*i.e.*, Blue Growth). Nevertheless, the Sustainable Development Goals (mainly 2, 7, 8, 9, 12, 13, 14) and climate change mitigations (*i.e.,* CO_2 policies and reduction targets) have driven the expansion of maritime sectors, such as renewable energy and offshore aquaculture (Stancheva et al., 2022).

The increasing and often conflicting use of marine resources (Kyriazi, 2018), combined with the diversification of the Blue Economy, requires the progressive application of a multi-use approach in Marine Spatial Planning (MSP, Calado et al., 2019; Stancheva et al., 2022). Multi-use can be defined by the joint use of resources in close geographical proximity by one or multiple users (Schupp et al., 2019). The combined exploitation of marine resources may have different characteristics in terms of combination or degree of connection in spatial, temporal, provisioning, and functional dimensions (cf., Schupp et al., 2019). However, the coexistence of different activities represents an

---

* Corresponding author. IHCantabria - Instituto de Hidráulica Ambiental de la Universidad de Cantabria, Santander, Spain.
E-mail addresses: dacruzcv@unican.es (C.V.C. Weiss), jarbas.bonetti@ufsc.br (J. Bonetti), marinez.scherer@ufsc.br (M.E.G. Scherer), barbara.ondiviela@unican.es (B. Ondiviela), raul.guanche@unican.es (R. Guanche), juanesj@unican.es (J.A. Juanes).

https://doi.org/10.1016/j.ocecoaman.2023.106764
Received 28 December 2022; Received in revised form 21 July 2023; Accepted 21 July 2023

Abbreviations

Ap	Available wind energy potential
BA	Bahia
C50	50-year return period for current velocity
CAPEX	Capital expenditures
CE	Ceara
Dp	Euclidean distance from the ports
EEZ	Exclusive Economic Zone
Ef	Available wave energy flux
ES	Espírito Santo
Hs50	50-year return period for significant wave height
Hs	Significant wave height
MA	Maranhão
MSP	Marine Spatial Planning
O&M	Operation and maintenance
OPEX	Operational expenditures
PE	Pernambuco
PR	Paraná
RJ	Rio de Janeiro
RN	Rio Grande do Norte
RS	Rio Grande do Sul
SDG	Sustainable Development Goals
SC	Santa Catarina
SI	Suitability Index
SI_{Aqua}	Suitability Index for aquaculture
SI_{AquaS}	Suitability Index for structural survivability of aquaculture cages
SI_{Log}	Suitability Index for offshore logistics of aquaculture, wind, and wave energy activities
SI_{MU}	Suitability Index for multi-use possibilities
SI_{Sp}	Suitability Index for species requirements
SI_{ENet}	Suitability Index for electrical network
SI_{Wave}	Suitability Index for wave energy
SI_{WaveR}	Suitability Index for wave resource
SI_{WaveS}	Suitability Index for structural survivability of wave devices
SI_{Wind}	Suitability Index for wind energy
SI_{WindR}	Suitability Index for wind resource
SI_{WindS}	Suitability Index for structural survivability of wind devices
SP	São Paulo
sst	Sea surface temperature
sal	Salinity
Tp	Peak wave period
Ws50	50-year return period for wind speed
WEC	Wave energy converter
Ws	Wind speed

opportunity to optimize the use of space and reduce conflicts between uses (Bocci et al., 2019; van den Burg et al., 2020), including conservation (Reimer et al., 2023), being a key issue in MSP (Calado et al., 2019). In some countries, the national Marine Spatial Plan reflects this development by fostering multi-use (Schultz-Zehden et al., 2018).

Therefore, ocean multi-use can be a sustainable alternative to meet the challenges of contemporary society. Thus, due to the potential synergies between these emerging maritime sectors (Zanuttigh et al., 2021), different EU-funded projects have assessed the technical and economic implications of the feasibility of combining energy production and aquaculture. MERMAID,[1] H2OCEAN[2] and TROPOS[3] in the FP7-OCEAN-2011 call, conducted between the years 2012 and 2015. Space@Sea,[4] MUSES,[5] Blue Growth Farm[6] and MARIBE[7] under the EU Horizon 2020 research and innovation program, carried out between 2015 and 2022. Most recently, UNITED[8] (2020–2023) and MUSICA[9] (2020–2014) projects were funded in the H2020-BG-2018-2020 call. AQUAWIND[10] (2022–2025) funded under the EMFAF Fund (European Maritime, Fisheries and Aquaculture) and the MULTIFRAME[11] (2020–2023), funded through the Belmont Forum, Future Earth and JPI Oceans 2018–2019 international call.

Despite the comprehensiveness of these initiatives, the analysis of technical, operational, biological, and environmental aspects in an integrated approach to identify zones for multi-use among these sectors received few contributions. For instance, Weiss et al. (2018a) analyzed the opportunities of co-locating aquaculture, wind and wave energy in the Canary Archipelago and Weiss et al. (2020) performed multi-use assessment under climate change scenarios. Projects addressing multi-use have focused on technical issues of experimentation and physical modeling for multipurpose platforms prototypes. Furthermore, research efforts on multi-use are concentrated on the European continent, with no contributions in South America (Xylia et al., 2023). Thus, the importance of assessing the synergistic spatial interactions between these emerging maritime sectors to propose sustainable alternatives for MSP becomes evident, especially for developing countries where ocean planning has not yet started or is in execution.

Therefore, the aim of this study is to identify, through a systematic assessment, the opportunities for exploitation of wind energy, wave energy and aquaculture and the possibilities of multi-use among these activities from a spatial perspective. The case study is the Exclusive Economic Zone (EEZ) of Brazil, an area of great biodiversity that presents high potential for the development of these activities and lacks a comprehensive assessment for planning the emerging maritime sectors. The case study addresses national protected and priority conservation areas to identify possible spatial conflicts with multi-use zones.

2. Study area

The Brazilian EEZ corresponds to an area of approximately 3.6 million square kilometers, extending 200 nautical miles beyond the territorial sea (Silva et al., 2016). This case study was chosen for three main reasons: *i)* High potential for the development of the assessed sectors; *ii)* Increasing pressure from the offshore wind sector; *iii)* Concrete initiatives to develop national MSP.

The study area presents a high potential for energy generation given the wave and wind energy resource available, as verified in different studies (*e.g.,* de Oliveira et al., 2021; Vizonha and Schaeffer, 2021). In turn, Brazil presents zones with potential for the farming of all six species analyzed in this work, as pointed out by Weiss et al. (2018c) in a global study. The second reason is supported by the expressive increase of offshore wind projects in the Brazilian EEZ; 66 projects have applied for environmental licenses in the last three years, with exponential growth until 2022 (IBAMA, 2022a). In contrast to the offshore wind

---

[1] https://cordis.europa.eu/project/id/288710.

[2] https://cordis.europa.eu/project/id/288145.

[3] https://cordis.europa.eu/project/id/288192.

[4] https://doi.org/10.3030/774253.

[5] https://doi.org/10.3030/727451.

[6] https://doi.org/10.3030/774426.

[7] https://doi.org/10.3030/652629.

[8] https://doi.org/10.3030/862915.

[9] https://doi.org/10.3030/862252.

[10] https://aquawind.eu/.

[11] https://www.submariner-network.eu/multi-frame.

industry expansion scenario, wave energy converters (WECs) are still in the development and validation stage, expected to advance in the coming years (IEA-OES, 2022). Offshore fish farming has not yet established as a consolidated commercial activity in the country. The activity is conditioned to small net cage farms in sheltered coastal areas (Valenti et al., 2021). One-off experiments offshore aquaculture has been made in the country, such as in northeastern Brazil with Cobia farming, using floating high-density polyethylene cages (HDPE; Cavalli, 2022).

The first two reasons support the eminent need for a national MSP. Concrete initiatives emerged in 2022, through a public call from the National Development Bank with the Secretariat of the Interministerial Commission on Marine Resources, to perform a technical study to characterize and map the current and potential uses of the marine environment (RFI n° 013/2022). This Pilot Project will be developed in the South Marine Region of Brazil. Until then, only punctual initiatives have been performed, mainly in the academic field (Gandra et al., 2018).

3. Methodology

3.1. Overview

This study analyzed the individual opportunities and multi-use possibilities for wind energy, wave energy and aquaculture sectors. Technical, operational, and biological aspects were evaluated, through a Suitability Index (SI), to identify zones with favorable conditions for energy exploitation and farming of six fish species. The availability and quality of energy resource and the distances from main onshore electrical network were considered to identify suitable zones for energy harvesting and later distribution. The survivability of aquaculture and energy structures was analyzed to identify zones with best conditions from the durability and integrity of the facilities point of view. The possibility of carrying out offshore logistical activities were analyzed to identify zones with favorable conditions for the installation, O&M of these activities. The biological requirements for aquaculture considered limiting factors to identify suitable zones for fish growth. Analysis of the overlap between multi-use zones with protected and priority conservation areas is performed to identify possible spatial conflicts (Fig. 1).

3.2. Data

Long-term data series with spatial resolutions between 0.017 and 0.3° and temporal resolutions of hours, days, and weeks were used (Table 1). The data were interpolated by the Kriging method (Ghiasi and Nafisi, 2015) on a 0.15° grid.

3.3. Suitability Index (SI) assessment

The spatial analysis of favorable conditions for wind and wave exploitation and aquaculture was based on the methodologies developed by Weiss et al. (2018a,b, c). Zones with opportunities for the development of these emerging maritime sectors, as well as multi-use possibilities, have been recognized through the SI. This index expresses, for a given area, the probability of being in favorable conditions for the development of these activities. Five aspects related to exploitation devices, technical-economic factors, met-ocean and environmental conditions were analyzed to determine the opportunities and feasibility for individual and combined exploitation of these activities. The favorable conditions were determined by the thresholds defined for each aspect of evaluation, according to international standards, reference wind turbines, generic wave devices and generic aquaculture cages (Table 2).

For an accurate and comprehensive analysis, thresholds and evaluation criteria examined by Weiss et al. (2018a,b, c) were adapted to the specific characteristics of the study area and new aspects were considered. The fish species analyzed in this study were selected according to the global results presented by Weiss et al. (2018c), and for their high commercial potential and farming trajectory. Brazilian public ports were considered for the offshore logistics activities of the multi-use. The coastal electrical network of the Brazilian Interconnected System was considered for energy distribution, in particular the location of coastal electrical substations. In the case of the structural survivability assessment for aquaculture, the high exposure scenario was considered due to the sea conditions of the study area (Standard Norge, 2009).

3.3.1. Energy resource

For the wind resource assessment, the *Ap* and *Ws* were considered. *Hs* was used as a safety factor in the operation of the turbines. On the other hand, *Ef*, *Tp* and *Hs* were analyzed to identify zones with favorable conditions for exploitation of wave resource. The SI for the wind and wave resources were obtained by integrating the percentage of time that the cited aspects remained in the conditions defined by the thresholds in Table 2. The calculation used to obtain the wind and wave resource index (SI_{WindR},SI_{WaveR}) is shown in Eqs. (1) and (2), respectively. For the wind resource, all zones with more than 50% of the time with *Ap* above 400 W/m^2 was considered as favorable ($SI = 1$).

$$SI_{WindR} = min\left(\left(\frac{t_{Ap}}{\bar{t}}\right)\begin{cases} 1 & for\ \frac{t_{Ap}}{\bar{t}} \geq 0.5 \\ \frac{t_{Ap}}{\bar{t}} & for\ \frac{t_{Ap}}{\bar{t}} < 0.5 \end{cases}, \frac{t_{Ws}}{\bar{t}}, \frac{t_{Hs}}{\bar{t}}\right) \tag{1}$$

where *min* is the minimum value found among the analyzed aspects at a given point in the analysis grid. t_{Ap}, t_{Ws} and t_{Hs} are the time, at the temporal resolution of the evaluated variable, that the variable (A_p, W_s and H_s) remained at the conditions defined in the thresholds throughout time series ($\bar{t}$).

$$SI_{WaveR} = \frac{\left(\left(\frac{t_{Ef}}{\bar{t}} * 2\right) + \frac{t_{Hs}}{\bar{t}} + \frac{t_{Tp}}{\bar{t}}\right)}{4} \tag{2}$$

where t_{Ef}, t_{Hs} and t_{Tp} are the time, at the temporal resolution of the evaluated variable, that the variable (Ef, H_s and T_p) remained at the conditions defined in the thresholds throughout time series ($\bar{t}$).

3.3.2. Electrical network

The distance from power substations was considered to identify zones for the operation of wind and wave farms. The Electrical Network index (SI_{ENet}) was established by parameterizing the Euclidean distance, calculated from the location of electrical substations for the study area. Maximum SI was assigned for zones close to substations and SI of 0.2 for zones with distance equal to the threshold (*thld*) defined in Table 2 (Eq. (3)).

$$f(x) = \begin{cases} \left(\left(\frac{-0.8}{\min - thld}\right) * (min - x)\right) + 1 & for\ x \leq thld \\ \frac{0.2\ (x - max)}{thld - max} & for\ x\ > thld \end{cases} \tag{3}$$

where *min* and *max* are the minimum and maximum values found in the study area for the variable *x*.

3.3.3. Structural survivability

The assessment of the severity of the study area for energy and aquaculture structures considered bathymetry and slope to analyze seabed conditions and extreme sea conditions (*Ws50*, *Hs50* and *C50*). For slope, zones with less than 25% was excluded ($SI = 0$). The bathymetry was parameterized linearly according to depth, where a maximum value of SI was assumed for depths of 0–50 m, and every 50 meters SI was reduced by 0.1. The calculation of the 50-year return period used the Peak Over Threshold method, assuming the frequency using a Poisson process, and the intensity using a Generalized Pareto Distribution (Méndez et al., 2006). The extreme conditions for *Ws50*,

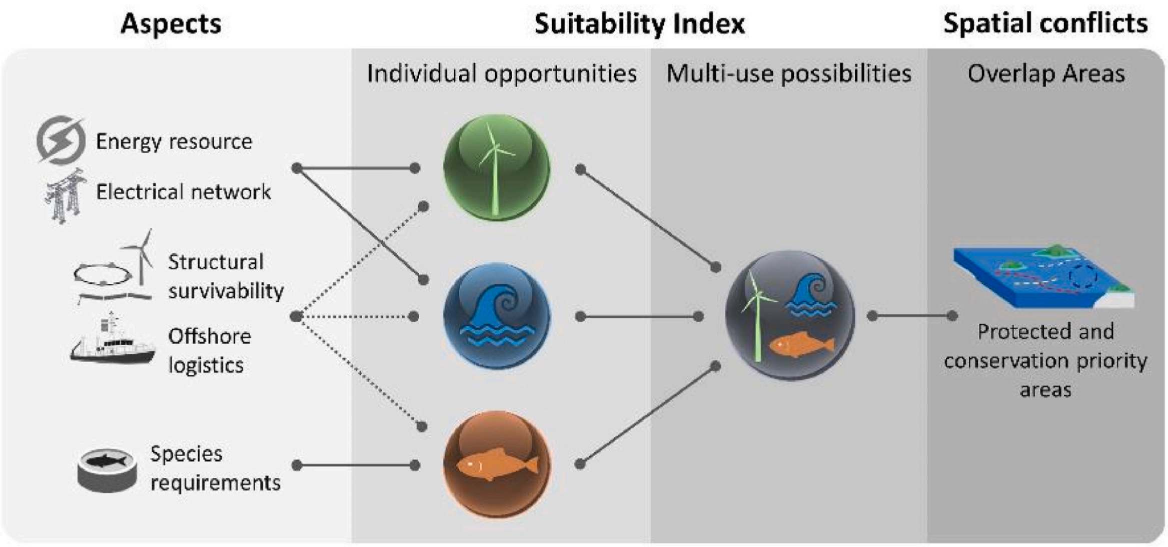

Fig. 1. Conceptual framework with the aspects considered in the Suitability Index for the identification of zones with opportunities for individual exploitation and possibilities of multi-use of wind energy, wave energy and aquaculture activities. Additionally, an evaluation of possible spatial conflicts with conservation areas is performed.

Table 1
Variables, source of information, resolutions and available periods of the data used.

Variable	Sources of Information	Temporal Resolution	Spatial Resolution	Available Period
Wind	Saha et al. (2010)	Hourly	0.3°	1979–2010
	Saha et al. (2014)		0.2°	2011–2015
Waves	Perez et al. (2017)	Hourly	0.25°	1979–2015
	Reguero et al. (2012)		0.25°	1979–2015
Currents	NCAR (2016)	Hourly	0.25°	1979–2010
Bathymetry	Amante and Eakins (2009)	Punctual	0.017°	2015
Salinity	Copernicus, 2016	Weekly	0.25°	1993–2013
Water temperature	Donlon et al. (2012)	Daily	0.25°	1985–2013
Ports	ANTAQ (2022)	Punctual	Punctual	2021
Electrical network	ONS (2018)	Punctual	Punctual	2018
Wind farm locations	IBAMA (2022a)	Punctual	Punctual	2022
Protected areas	MMA (2023)	Punctual	Punctual	2023
Priority areas for biodiversity conservation	MMA (2018)	Punctual	Punctual	2018

Hs50 and *C50* were parameterized according to Eq. (3), assuming that the thresholds defined for the survival of the structures correspond to 0.2 of the SI.

The structural survivability SI were obtained according to Eq. (4) for wind energy (SI_{WindS}) and Eq. (5) for wave energy (SI_{WaveS}) and aquaculture (SI_{AquaS}).

$$SI_{WindS} = (min((bathymetry), (W_s50), (H_s50), (C50))) - slope \tag{4}$$

$$\begin{matrix} SI_{WaveS} \\ SI_{AquaS} \end{matrix} = (min((bathymetry), (H_s50), (C50))) - slope \tag{5}$$

where *min* is the minimum value found among the analyzed aspects at a given point in the analysis grid.

3.3.4. Offshore logistics

The logistical activities assessment considered *Ws* and *Hs* to analyze the navigation conditions and the distance to the nearest ports. For site accessibility, the percentage of time that *Ws* and *Hs* remained according to the thresholds defined for each activity was evaluated (Table 2). The Euclidean distance from the ports (*Dp*) was parameterized according to Eq (3).

Assuming that O&M activities will be carried out jointly, the offshore logistic index for wind energy, wave energy and aquaculture activities (SI_{Log}) was calculated according to Eq (6).

$$SI_{Log} = min\left(\frac{t_{Ws}}{\bar{t}}, \frac{t_{Hs}}{\bar{t}}, (Dp)\right) \tag{6}$$

where *min* is the minimum value found among the analyzed aspects at a given point in the analysis grid. t_{Ws} and t_{Hs} are the time, at the temporal resolution of the evaluated variable, that the variable (*Ws* and *Hs*) remained at the conditions defined in the thresholds throughout time series ($\bar{t}$).

3.3.5. Species requirements

The species requirements assessment was based on two limiting factors for fish growth, temperature, and salinity. The percentage of the time that these two variables (sea surface temperature, *sst* and salinity, *sal*) remained between the optimal thresholds for fish growth was calculated (Table 2). The SI for the species requirement (SI_{Sp}) was generated according to Eq. (7).

$$SI_{Sp} = min\left(\frac{t_{sst}}{\bar{t}}, \frac{t_{sal}}{\bar{t}}\right) \tag{7}$$

where *min* is the minimum value found among the analyzed aspects at a given point in the analysis grid. t_{sst} and t_{sal} are the time, at the temporal resolution of the evaluated variable, that the variable (*sst* and *sal*) remained at the conditions defined in the thresholds throughout time series ($\bar{t}$).

Table 2
Aspects, thresholds, source of information and criteria for renewable energies and aquaculture activities.

Aspects	Thresholds			Sources of information	Criteria (0–1)
	Wind	Wave	Aquaculture		
Energy resource					
Available wind energy potential (*Ap*, W/m^2)	≥400	_	_	Aymamí et al. (2011); Babarit et al. (2012); Bak et al. (2013); de Andres et al. (2015a); de Andres et al. (2015b); Jonkman et al. (2009); Jonkman et al. (2012); Roberson et al. (2016)	% of time
Wind speed (120 m high) (*Ws*, m/s)	4≤ *Ws* ≤25	_	_		
Significant wave height (*Hs*, m)	≤5	1≤ *Hs* ≤6	_		
Available wave energy flux (*Ef*, kW/m)	_	≥15	_		
Peak wave period (*Tp*, s)	_	5≤ *Tp* ≤14	_		
Electrical network					
Distance from substations (km)	≤100	≤100	_	4COffshore (2021); Wind Europe (2021)	Parameterization
Structural survivability					
50-year return period for wind speed (*Ws50*, m/s)	≤40	_	_	4COffshore (2021); Chu et al. (2020); DNV (2010); Standard Norge (2009); TELWIND PROJECT (2018); Wind Europe (2021)	Parameterization
50-year return period for significant wave height (*Hs50*, m)	≤15	≤15	≤5		
50-year return period for current velocity (*C50*, m/s)	≤2	≤2	≤1,5		
Bathymetry (m)	≤500	≤500	≤500		
Slope (%)	≤25	≤25	≤25		Boolean
Offshore logistics					
Wind Speed (*Ws*, m/s)	≤10	≤10	≤10	4COffshore (2021); Astariz et al. (2015a); Astariz et al. (2015b); Chu et al. (2020); Guanche et al. (2015); Martini et al. (2015); Standard Norge (2009); Wind Europe (2021)	% of time
Significant wave height (*Hs*, m)	≤2	≤2	≤2		
Distance from ports (km)	≤200	≤200	≤200		Parameterization
Species requirements					
Temperature (*sst*, °C)					
Salinity (*sal*, PSU)					
Gilthead seabream *Sparus aurata*	_	_	18≤ *sst* ≤26 30≤ *sal* ≤40	FAO (2005b); Katavić et al. (2005); Seginera and Ben-Asher (2011)	% of time
Atlantic Bluefin tuna *Thunnus thynnus*	_	_	18≤ *sst* ≤26 30≤ *sal* ≤40	FAO (2015); Katavić et al. (2005); Ticina et al. (2007); Tucker (1998); Wright (2008)	
Meagre *Argyrosomus regius*	_	_	18≤ *sst* ≤26 30≤ *sal* ≤40	Duncan et al. (2013); FAO (2005c); Martínez-Llorens et al. (2011); Monfort (2010); Schuchardt et al. (2007)	
European seabass *Dicentrarchus labrax*	_	_	18≤ *sst* ≤27 30≤ *sal* ≤40	FAO (2005a); Hossu et al. (2005); Katavić et al. (2005); Kavadias et al. (2003); Person-Le Ruyet et al. (2004)	
Greater amberjack *Seriola dumerili*	_	_	20≤ *sst* ≤26 30≤ *sal* ≤36	Chambers and Ostrowski (1999); FAO (2016b); Jovera et al. (1999); Tucker (1998)	
Cobia *Rachycentron canadum*	_	_	22≤ *sst* ≤31 30≤ *sal* ≤37	Benetti et al. (2008); Benetti et al. (2010); FAO (2007); Faulk and Holt (2005); Resley et al. (2006)	

3.3.6. *Suitability for individual opportunities*

The SI of each aspect was integrated to identify zones with opportunity for exploitation of each activity. The integrations were performed according to Eqs. (8)–(10) for wind energy, wave energy, and aquaculture, respectively. The SI for the three activities (SI_{Wind},SI_{Wave},SI_{Aqua}) was expressed in a normalized probability interval of the maximum value (*max*) found in the study area. For aquaculture, the maximum value of all species evaluated was considered.

$$SI_{Wind} = \frac{min\left(SI_{WindR}, SI_{WindS}, SI_{Log}, SI_{sub}\right)}{max} \tag{8}$$

$$SI_{Wave} = \frac{min\left(SI_{WaveR}, SI_{WaveS}, SI_{Log}, SI_{sub}\right)}{max} \tag{9}$$

$$SI_{Aqua} = \frac{min\left(SI_{sp}, SI_{AquaS}, SI_{Log}\right)}{\text{max } of\ all\ species} \tag{10}$$

The SI_{Wind} was overlaid with the locations of offshore wind farms in licensing process in the study area.

3.3.7. Suitability for multi-use possibilities

The SI for multi-use possibilities was carried out through different combinations of the $SI_{Wind}, SI_{Wave}, SI_{Aqua}$, considering the minimum value found at each point on the analysis grid. For example, the multi-use possibilities for the three activities were obtained from Eq. (11). The discussion of the results of the multi-use possibilities was based on the zones with SI above 0.5.

$$SI_{MU} = min\left(SI_{Wind}, SI_{Wave}, SI_{Aqua}\right) \tag{11}$$

3.4. Spatial evaluation of conservation areas

Zones with multi-use possibilities, SI above 0.5, were overlapped with the protected areas of the National System of Conservation Units and the priority areas for biodiversity conservation, established by the Brazilian Ministry of Environment and Climate Change. The priority areas for conservation include initiatives such as the creation of protected areas, licensing of potentially polluting activities, monitoring, promotion of sustainable use and environmental regularization. In this sense, only priority areas related to the expansion and creation of protected areas and ecological corridors were considered. Percentage overlaps were calculated and discussed.

4. Results and discussion

This section is divided into five parts, sections *4.1* to *4.3* address the results of the individual opportunities for these maritime sectors. In the first section, the results for the wind sector are discussed and compared with offshore wind projects in the licensing process in the study area. Second and third sections address the possible development scenario of wave energy and aquaculture industries. Section *4.4*, presents the multi-use possibilities, addressing recent studies and the advantages of combined exploitation. Finally, section *4.5* analyzes possible spatial conflicts with protected and priority conservation areas.

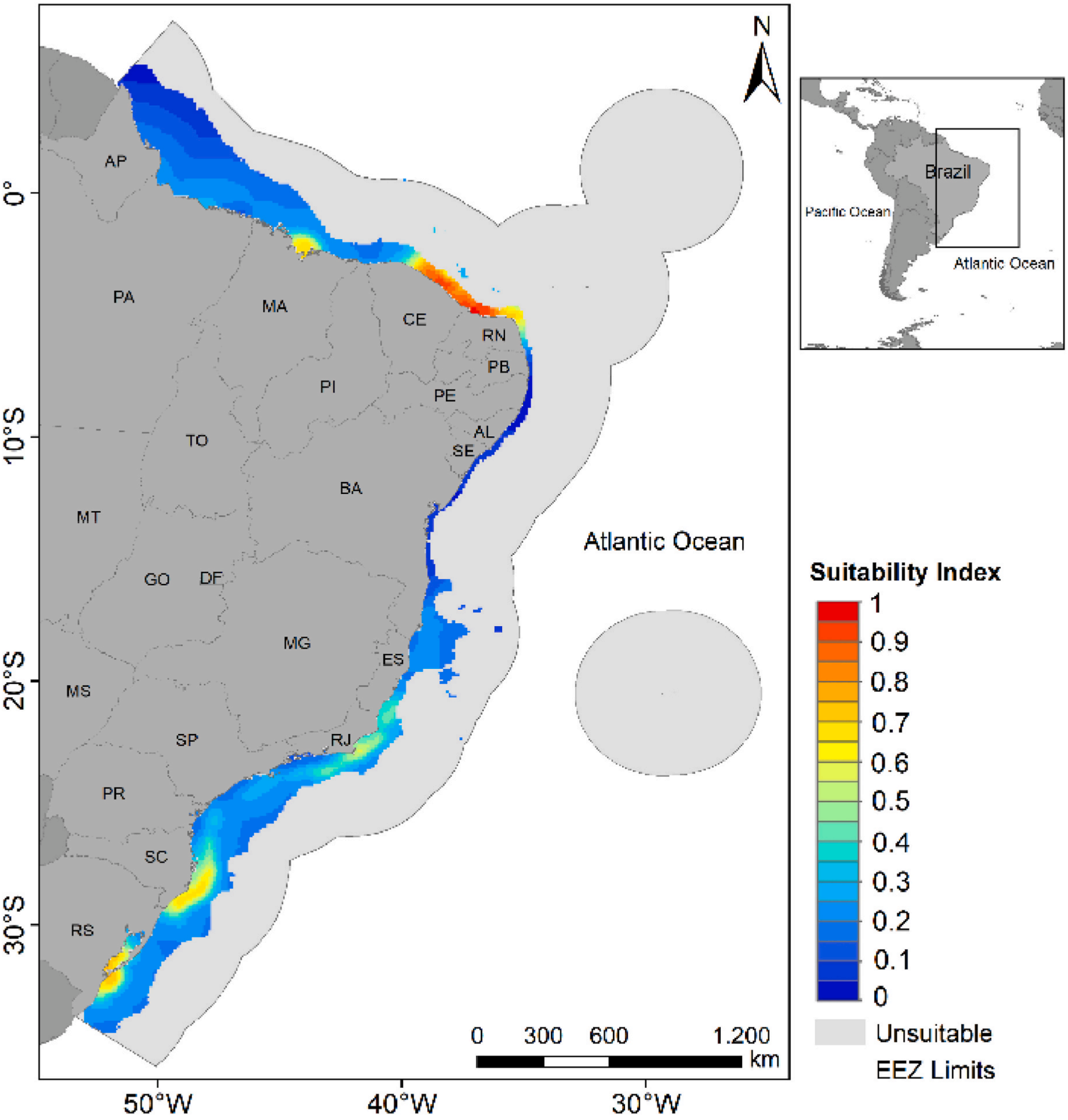

Fig. 2. Suitability index of offshore wind energy exploitation opportunities (SI_{Wind}) in the Brazilian EEZ.

The results for each calculated SI and the conservation areas can be found in the Supplementary Data. The results of the individual opportunities for each sector, as well as for the multi-use possibilities, can be accessed interactively on the platform https://mubrsea.glitch.me/.

4.1. *Wind energy*

Fig. 2 shows the zones with opportunities for wind exploitation through SI_{Wind}. The results found in this work confirm the offshore potential of the northeast, southeast, and south regions of Brazil (Hernandez et al., 2021), with the northeast region standing out (SI between 0.7 and 1). The southern and southeastern regions present favorable conditions for wind exploitation, however the SI in these regions is lower (between 0.5 and 0.85) due to other aspects considered in this study. Besides the greatest energy potential being in offshore and deeper areas in the southern and southeastern regions (Tavares et al., 2020), extreme sea conditions can compromise the survivability and strength of the structures installed. Aspects such as W_s50, H_s50 and $C50$ evaluated in SI_{WindS} limit the SI values in these zones. Logistical factors (SI_{Log}), such as *Hs* and especially the distance from ports and onshore electrical network also corroborated for lower SI in these regions. On the other hand, the northeast region presents better opportunities, due to less severe marine conditions and the presence of a larger number of public ports and electrical substations (*i.e.,* SI_{WindS} and SI_{Log} with higher values than in the other two regions). Rodrigues et al. (2015) and Pimenta et al. (2019) also noted the large continental shelf between the states of Ceara (CE) and Rio Grande do Norte (RN), verified in this study with the bathymetry in SI_{WindS}, providing better conditions for fixed turbines operating up to 60m.

Confirming the enormous potential of Brazil's three marine regions for the offshore wind sector, 66 environmental licensing processes have been opened by August 2022, with 170 GW of cumulative power (IBAMA, 2022a). As of September 2022, none of the projects had obtained the previous license (first license from the environmental agency, IBAMA, 2022b). 31 projects are in the northeast of the country, and 35% of these are in zones with SI below 0.5 (Fig. 3a). In the southern region (Figs. 3b), 55% of wind farms are in zones with SI below 0.5. 45% of the projected farms in the southeast region are in zones below 0.5 SI (Fig. 3c). The low SI_{Wind} values in the mentioned wind projects are mainly due to the distances from the onshore electrical network in the

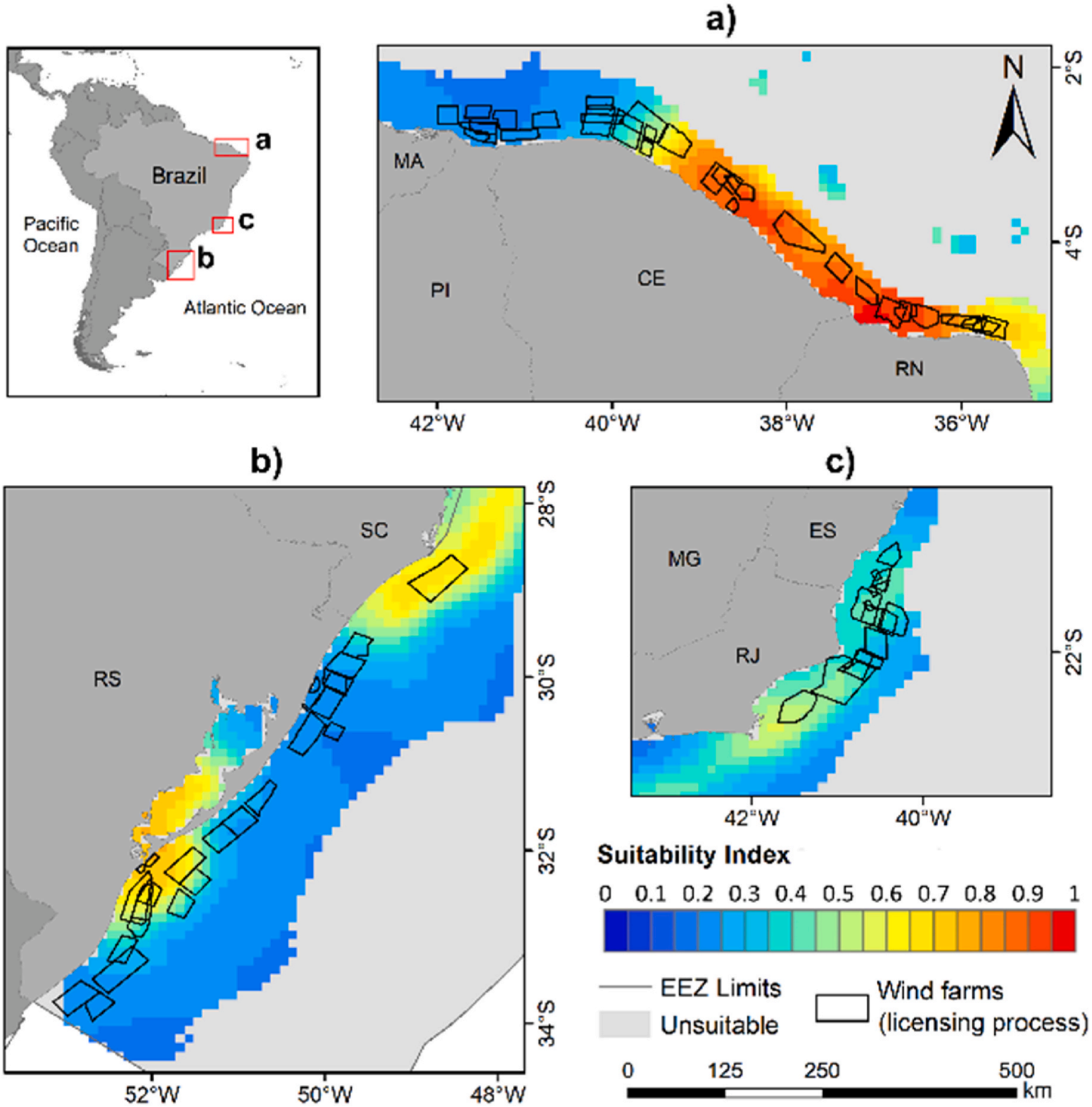

Fig. 3. Polygons of the 66 projects in the licensing stage on SI_{Wind} in the 3 Brazilian EEZ potential regions: **a)** Northeast, **b)** South and **c)** Southeast.

Brazilian Interconnected System and the public ports considered in this study. These aspects (*i.e.,* distance from electrical network and ports) do not make the implementation and operation of wind farms unfeasible, but they tend to increase the CAPEX (capital expenditures) and OPEX (operational expenditures) of the project.

In the case of the southeast region (Fig. 3c), some wind projects, closer to the coast, are in zones with SI_{WindR} below 0.5. These values are due to the potential energy not remaining above the 400 W/m^2 threshold (Table 2) more than 50% of the time analyzed (37 years of hourly data). The projects being licensed in this region are fixed-bottom foundations, however, the greatest potential is in zones with depths greater than 50m, as also found by Tavares et al. (2020), and floating structures are required in this case.

4.2. Wave energy

The zones with the greatest opportunities for wave energy are mainly located to the south and southeast of Brazil (SI_{Wave}, Fig. 4), coinciding with the findings of Weiss et al. (2018b) and de Oliveira et al. (2021). In these regions, the zones with the highest SI coincide with the most energetic spots, pointed out by Oleinik et al. (2017) and Lisboa et al. (2017) (*i.e.,* the coastal regions of Rio Grande (Rio Grande do Sul - RS), Laguna (Santa Catarina - SC), Ilhabela (São Paulo - SP) and Farol Island (Rio de Janeiro - RJ)). Zones in SC and RJ states present greater opportunities for wave exploitation (*i.e.,* SI values > 0.9) because they present higher SI_{WaveR} and because nearby services (ports and electrical network facilities) and of favorable conditions for offshore logistic activities. The RS coast also has high wave energy flux, however the resource is further from the coast, which decreases the SI for logistical (SI_{Log}) and structural (SI_{WaveS}) factors, as well as the distance from the electrical network (SI_{ENet}).

4.3. Aquaculture

Among the studied species, Greater amberjack, Cobia and Atlantic Bluefin tuna are within the native range on the Brazilian coast (Kaschner et al., 2022a, 2022b, 2022c), with the first two being mentioned as of great interest for marine aquaculture in the country (Cavalli et al., 2011; Valenti et al., 2021). On the other hand, Gilthead seabream, Meagre and European seabass are mainly distributed in the European regional seas and West African coast (Kaschner et al., 2022d, e, f).

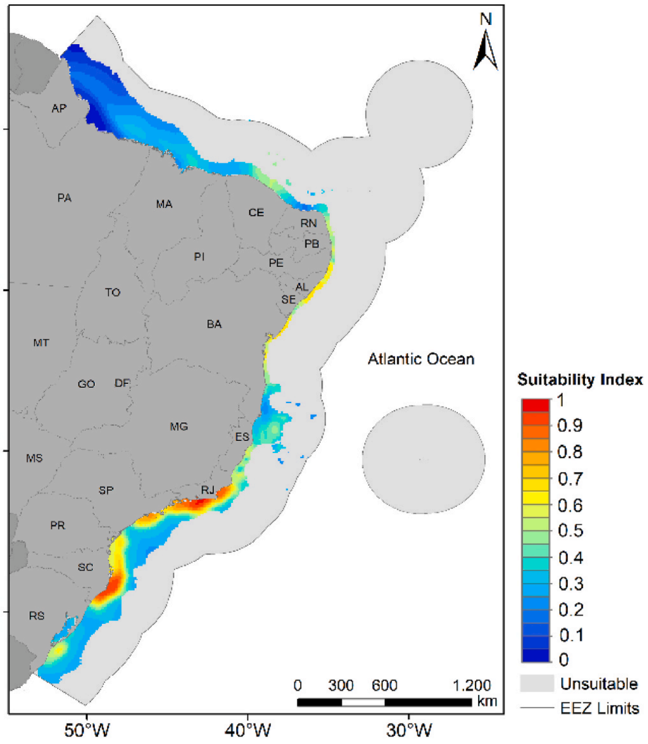

Fig. 4. Suitability index of wave energy exploitation opportunities (SI_{Wave}) in the Brazilian EEZ.

European seabass is one of the species that presents the best farming opportunities in the Brazilian sea (Fig. 5a). The marine regions of Paraná (PR) and Bahia (BA) stand out with SI > 0.8. Other regions, such as in the states of SC and SP (SI greater than 0.7), on the coast of Espírito Santo (ES) (SI between 0.6 and 0.8) and in the northeast of Brazil (SI between 0.6 and 0.7) also have favorable conditions for aquaculture. The south of BA state presents conditions that meet the species requirement (SI_{sp}), but the SI is low due to the distance to the ports of Ilhéus (BA) and Barra do Riacho (ES). This species is the most important commercial fish farmed in the Mediterranean Sea, mainly by Turkey, with production of 148,907 tonnes (live weight) in the year 2020 (FAO, 2022). The high commercial potential of this species and the favorable conditions in Brazilian waters represent an opportunity for the aquaculture industry, which can follow the example of the development of the salmonid industry in Chile (*i.e.,* species with native range in the northern seas and successfully farmed in southern America). Nevertheless, the introduction of exotic species should be studied in greater detail to avoid possible negative impacts.

Given the similarity in the biological requirement of the species (Table 2), the spatial distribution pattern of farming opportunities for Gilthead seabream, Atlantic Bluefin tuna and Meagre follows the same trend as European seabass in the south and southeast of the country (Fig. 5b). The marine region in BA also shows favorable conditions for this species, with SI > 0.6, with SI_{Log} being a limiting factor in the south of the state, due to the same situation mentioned for European seabass. These three species are also mainly produced in the Mediterranean Sea, with a notable production of 109,749 tonnes of Gilthead seabream in 2020 in Turkey (FAO, 2022). Among these three species, the Atlantic Bluefin tuna farming could culminate in a faster process in Brazil, given the environmental licensing processes and authorizations in the case of exotic species farming (IBAMA, 1998).

Zones with favorable conditions for the farming of Greater amberjack are concentrated in the southern region, mainly on the northern coast of SC, PR, and southern SP, but with lower SI compared to the species mentioned above (SI between 0.7 and 0.8, Fig. 5c). This region coincides with the largest number of records of this species at the country sea, 38 in total (SIBBR, 2022). The temperature is considered suitable from the northeast to the south of the country; however, salinity remains within favorable conditions only in the south. SI_{AquaS} is also low in the state of RS, where SI_{sp} is high. Currently, only Spain and Greece have marine production data for this species (FAO, 2022).

Zones with opportunities for Cobia farming are distributed in the south, southeast, and northeast of the Brazilian coast (Fig. 5d). The coast of Maranhão (MA) also presents opportunities, with SI > 0.6. As mentioned previously, offshore farming experiments have been conducted in northeastern Brazil, in the state of Pernambuco (PE), where the SI_{Aqua} for Cobia is between 0.62 and 0.67. Currently, this fish is farmed in the southeast Brazil, with annual production of 100 tonnes since 2016 (FAO, 2022), however in sheltered coastal areas with small-scale near-shore farms (Rombenso et al., 2021). In this current production region, the SI_{Aqua} ranged from 0.36 to 0.7.

Due to the spatial resolution of the analyzed data and the criteria adopted for identifying opportunities in offshore zones, results for very specific zones close to shore, as in the case of Cobia production zones, may not be identified. In addition, other factors, such as the influence of rivers and concentrated precipitation in the coastal region, can locally affect water temperature and salinity (Hopkins et al., 2013; Ogino et al., 2017). In this sense, local scale studies are necessary to verify the feasibility of farming in specific zones. Overall, SI_{AquaS} limited the favorable conditions to zones relatively closer to the coast, due to the

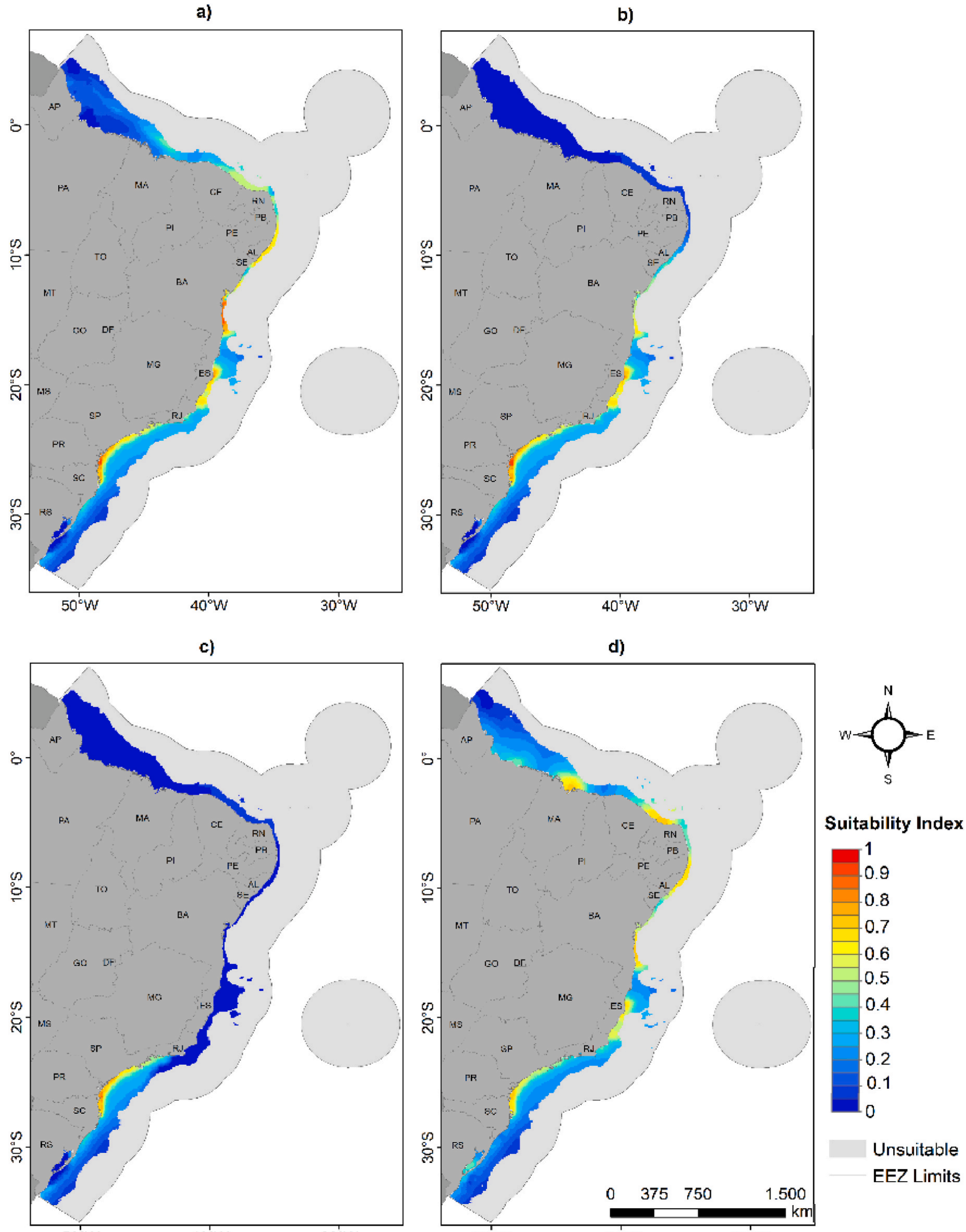

Fig. 5. Suitability index of aquaculture exploitation opportunities (SI_{Aqua}) in the Brazilian EEZ for: **a)** European seabass; **b)** Gilthead seabream, Atlantic Bluefin tuna, Meagre; **c)** Greater amberjack; **d)** Cobia.

extreme conditions analyzed (50-year return period). On the other hand, the distance of the ports and the *Hs*, especially to the south, area the factors that most limited SI_{Log}.

4.4. Multi-use possibilities

The zones with multi-use possibilities between renewable energy and aquaculture activities are distributed in Brazil's EEZ in different combinations between these sectors. The possibilities for wave energy and aquaculture multi-use in the south, southeast, and northeast of Brazil stand out (blue color, Fig. 6). Zones with possibility for the combined exploitation of wind energy and aquaculture are in the northeast (green color, Fig. 6). On the other hand, multi-use possibilities between wind and wave energy are located to the south, with small areas in the

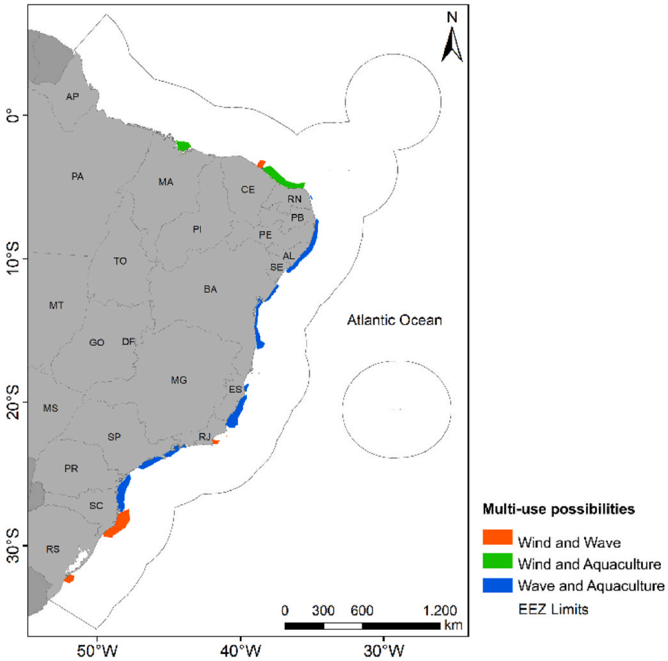

Fig. 6. Multi-se possibilities for wind energy, wave energy and aquaculture activities.

southeast and northeast (red color, Fig. 6).

The possibilities of combined exploitation of wave energy with aquaculture are in the south and southeast, in the states of SC, PR, SP, and RJ, with Greater amberjack farming. Multi-use between these sectors is possible for Gilthead seabream, Atlantic Bluefin tuna, and Meagre from SC to BA states, and for Cobia and European seabass from SC to RN (Fig. 6). Despite the high potential for multi-use among these sectors in the study area, both activities are in the development and planning phase for expansion towards the offshore environment (IEA-OES, 2022; Valenti et al., 2021). In this sense, the consolidation of WECs devices can boost open ocean aquaculture and vice versa (Garavelli et al., 2022; LiVecchi et al., 2019).

Currently, the multi-use in operation between aquaculture and wave energy works with WECs powering the offshore operations of the aquaculture farm (Clemente et al., 2023; Garavelli et al., 2022). For example, the offshore finfish aquaculture located in China, which is powered by wave and solar energy (OES, 2021). Projects have evaluated the combination of wave energy with offshore finfish aquaculture in Scotland (Campbell, 2017) and the Mediterranean Sea (MARIBE, 2015). Although current wave energy exploitation prototypes do not provide a structure for aquaculture use, as is the case with oil and gas (Harmon, 2016) and wind energy platforms (Jansen et al., 2016), WECs can be incorporated with the aquaculture structure or anchored separately to provide power (Garavelli et al., 2022). Beyond energy supply, the shielding effect of WEC on other structures, in this case fish cages, is another multi-use advantage (Pérez-Collazo et al., 2013).

On the other hand, multi-use possibilities between wind energy and aquaculture are located in the CE and RN states for European seabass and Cobia farming, and in MA for Cobia (Fig. 6). Although the SI does not identify opportunities for wind farms to the southeast, in the ES state (cf., section 4.1), this region has projects in the licensing process and SI > 0.65 for Gilthead seabream, Atlantic Bluefin tuna, Meagre and European seabass farming. The current development scenario of offshore wind energy projects in Brazil's EEZ (IBAMA, 2022a) represents a great opportunity for the aquaculture sector. Given the high potential for both activities in northeastern Brazil, aquaculture can benefit from the wind farm structures that will be installed. The advantages of moving aquaculture towards offshore, where the wind farms will be installed, include better water quality, social license to operate, better waste management, and reduced risk of diseases associated with farming (Aryai et al., 2021). Still, the technological advancement of the offshore wind sector and the logistical and operational synergies may represent a useful stepping-stone for the aquaculture sector.

Different multi-use concepts have been evaluated. For example, dynamical behaviors of a semi-submersible floating wind turbine with aquaculture cage were assessed by Cao et al. (2022). Li et al. (2023) assessed the dynamics responses of a new concept integrating a jacket offshore wind turbine with a steel cage. The economic feasibility of combining aquaculture cages and offshore wind farms was demonstrated in a case study in Taiwan (Huang et al., 2022).

Sharing infrastructure, such as foundation and mooring system, can provide economic and environmental advantages by reducing costs and minimizing impact (Connolly y Hall, 2019; Clark et al., 2019). Multi-use can also provide synergies in O&M activities (Dalton et al., 2019) and cost savings in decommissioning (Calado et al., 2019). In addition, other benefits of the combination may be the buffering effect for wind devices and the possibility of energy autonomy for the aquaculture plant (Aryai et al., 2021; Dalton et al., 2019). However, synergies will depend on the type of MU, the technology used, and the level of integration between activities (Schupp et al., 2019).

Zones with multi-use possibilities for wind and wave energy exploitation are found in the south (RS and SC states), southeast in RJ, and in the northeast (CE, Fig. 6). All identified multi-use zones present wind energy projects in the licensing process (IBAMA, 2022a). In this sense, the establishment of the wind sector, considering the short-medium term development scenario in Brazil, can contribute to the development of the wave energy sector.

Currently, experimental work has been conducted to validate hybrid systems with floating technology combining wind harvesting and WECs (*e.g.*, Hu et al., 2020; Zhang et al., 2023). Ulazia et al. (2023), considered an integrated system with a floating wind turbine co-located aside a WEC-type oscillating buoy to estimate energy production in Canary Islands. The possibility of increasing production, studied by Gonzalez et al. (2023), shows that wave energy can be used to increase the power reserve of the wind farm. Considering a hybrid system of Oscillating Water Columns-type WEC and floating offshore wind turbines, Fenu et al. (2023) also found an increase in productivity without significantly affecting platform motion. The hydrogen generation capacity of wave energy converters can maximize the production of wind and wave far offshore farms (Saenz-Aguirre et al., 2022). However, increased production and the possibility of reduced CAPEX and OPEX (Astariz et al., 2015b) are directly related to the multi-use combination type and the logistics employed.

No multi-use zones are identified among these three activities with SI greater than 0.5 in Brazil's EEZ. Zones with higher SI values (0.45) for the combined exploitation of wind and wave energy and aquaculture are situated on the coast of RJ and ES states for Gilthead seabream, Atlantic Bluefin tuna, Meagre farming and in the state of CE for European seabass. The combined exploitation of these three activities has been studied as multipurpose platforms. For instance, the integration of a deepwater industrial aquaculture production system with wind and wave energy harvesting technologies was analyzed in the scope of the Blue Growth Farm project (Li et al., 2020; Ruzzo et al., 2022). Despite advances in physical models and experiments, there is still a long way to go to improve the proposed multipurpose platform concepts. In this sense, extensive experimental fields should be conducted to enable industrial-scale exploitation (Ruzzo et al., 2021). The ideal combination of devices must be analyzed for each possible situation (Dallavalle et al., 2023). In addition, a guide to assessing the potential for multi-use application should be considered, as proposed in the MULTI-FRAME project on the Multi-use Assessment Approach (MUAA, McCann et al., 2023).

4.5. Environmental background

Although the balance between conservation and development is fundamental to MSP, these have progressed in parallel in recent years (Santos et al., 2021; Vaughan and Agardy, 2020). In this sense, sustainable development strategies, as is the case of MU, and the establishment of a conservation ready MSP (Reimer et al., 2023), tend to enable Blue Growth and confirm its sustainability prerogatives. Therefore, environmental assessment is a critical part of MSP for the development of these industries.

As environmental licensing is regulated in Brazil, protected areas are strategic and restrictive factors in the analysis of zones for the development of offshore activities. The country has Law 9.985/2000 that establishes the National System of Conservation Units, which is divided into two main groups: the fully protected areas, and the sustainable use areas (Fig. A7, Supplementary Data). Both have the main objective, with their particularities, of preserving the heritage and biodiversity. Furthermore, the Brazilian Ministry of Environment and Climate Change has established a mapping with priority areas for biodiversity conservation (Fig. A8, Supplementary Data). It includes initiatives such as the expansion and creation of protected areas and ecological corridors.

Zones with multi-use possibilities have been identified within the protection and conservation priority areas (Fig. 7). 5.8% of the multi-use zones for renewable energies is in protected areas of sustainable use. For wave energy and aquaculture, sustainable use protected areas cover a large part of the multi-use zones (32% for Greater amberjack; 21% for Atlantic Bluefin tuna; 18% for European seabass; and 30% for Cobia). Priority areas for creation of protected area overlap 10% with multi-use zones for wave energy with Cobia and European seabass. Ecological corridors, specifically the one between SC and SP, overlap with the multi-use zones, covering 29% for wave energy and Greater amberjack combination. Multi-use possibilities zones for wind and Cobia overlapped with protected and priority areas, 26% for sustainable use protected areas and 8% for creation of protected areas. Zones for wind exploitation and European seabass farming overlap about 4% with integral protection areas, the highest level of conservation defined in the Brazilian system.

The need for an official framework for national MSP is evidenced by the development trend towards offshore and the potential pressure on conservation areas. Multisectoral approaches at the local scale should analyze possible compatibilities and conflicts in and around protected and priority areas. In this sense, it is important to review the priority areas and legitimize their protection role in the Brazilian system of protected areas. Ecosystem-based approach should be considered for the management and planning of marine activities and biodiversity conservation (Domínguez-Tejo et al., 2016).

5. Concluding remarks

The possibilities of expanding resource exploitation towards offshore must be guided by sustainable development strategies, seeking alternatives to optimize the integrated use of the marine space. This pilot case study builds on the benefits of multi-use for Blue Growth, addressing a holistic view on the development trend of emerging industries. This preliminary assessment integrates and complements global studies (*i.e.,* Weiss et al., 2018b, c), using specific criteria of the study area support the national MSP. Potential zones for individual exploitation and with possibilities multi-use between wind energy, wave energy and fish farming are identified in Brazil's EEZ, as well as possible conflicts with protected areas. Although this analysis is based on the specific situation of Brazil, aiming to fill gaps to start the MSP process, the findings, as well as the methodology employed, can be transferred to countries, especially those without MSP or in an initial phase.

The fast and unprecedented global Blue Growth (Jouffray et al., 2020) highlights the importance of studies that can support planning in regions that lack organized and accessible data. The use of a long-term global database with fine temporal and spatial resolution, available from international programs, has made it possible to study a region that generally lacks measurements and models of physical variables used as predictors. It therefore highlights the importance of a reliable and accessible database for the sustainable development of marine economies, which is generally not available empirically in developing countries, as is the case of Brazil (Gandra et al., 2018).

The need for MSP to promote synergies between uses, as well as with environmental components, is eminent (Schupp et al., 2019; Reimer et al., 2023). In this sense, the definition and analysis of current and future conditions are essential in the MSP process (steps 5 and 6, Ehler and Douvere, 2009), as they allow the identification of synergies between uses and possible environmental conflicts. In the study area, zones with multi-use possibilities between the wave and aquaculture sectors stood out in the south, southeast, and northeast of Brazil. Zones with the possibility of combined use of wind energy and aquaculture are in the northeast. Multi-use possibilities between wind and wave energy are concentrated to the south, with small areas in the southeast and northeast. No zones with high SI for multi-use are identified among the three marine economies. The short-medium term development scenario for the wind sector in the country can contribute to multi-use, both because other activities can benefit from the structures installed, and because of the operational and logistical synergies between these industries. Special attention should be given to environmental protection areas where there may be interest in the exploitation of these activities. For example, about 63% of the multi-use zones for wave energy and Greater amberjack farming are in protected and priority conservation areas.

Multi-use is essential to ensure sustainable development in the

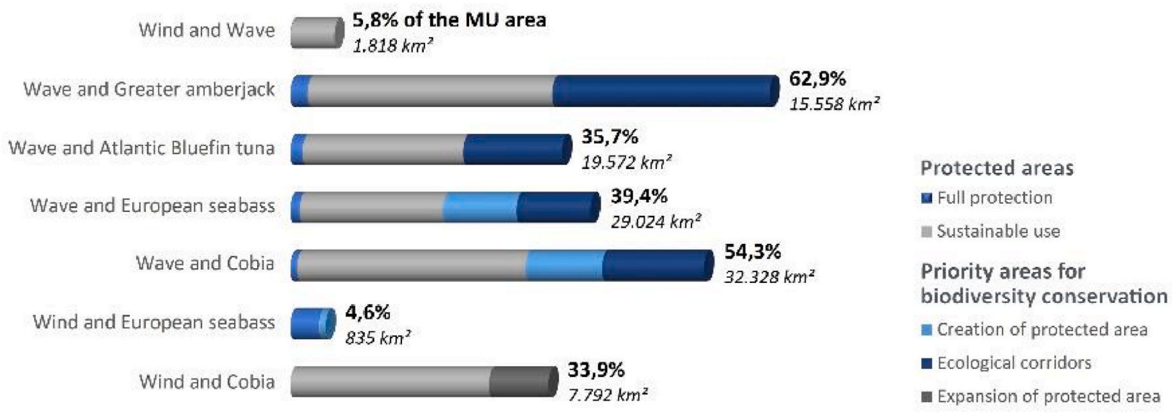

Fig. 7. Percentage of protected and priority areas that overlap with multi-use zones. Maps of protected and priority areas available in the Supplementary Material (Fig. A7 and A8, respectively).

marine environment, thus optimizing the use of space and reducing the negative impacts. MSP is key to balancing the interests of sectors and achieving Blue Growth by addressing tradeoffs of individual and multi-use of the marine environment. In this sense, this case study is a guide for future local studies in Brazil's EEZ, mainly in the selection of sites for analysis. Given the spatial synergies identified in the study area, the present contribution represents a starting point for the discussion of multi-use in the country. Fragmented views of research and experiments carried out in the country for these sectors are discussed and integrated in a multi-use perspective. Given the scale of the spatial analysis and the limitations of the data and methods employed, a comprehensive analysis is needed to verify the feasibility of implementing these activities at a local scale. Furthermore, other activities with multi-use potential must be considered, as well as social, economic (*e.g.,* market demand) and legal aspects. It is expected that the results of this study will stimulate a multisectoral and participatory MSP that considers the development trend of these marine economies, as well as the possible associated impacts.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Carlos V. C. Weiss reports financial support was provided by National Council for Scientific and Technological Development. Carlos V. C. Weiss reports financial support was provided by University of Cantabria.

Data availability

Data will be made available on request.

Acknowledgements

C.V.C. Weiss is grateful to the Brazilian National Council for Scientific and Technological Development (CNPq) for the PDJ (Pós-doutorado Junior) fellowship granted (151228/2020–5), and the financial support from the Universidad de Cantabria (UC) through the Agusto González de Linares and Margarita Salas Grants (POS-UC-2019-06 and RMS-04, respectively). J. Bonetti is a Research Fellow of CNPq (Grant 306633/2019–1). Raúl Guanche acknowledges the Grant RYC-2017-23260 funded by MCIN/AEI/10.13039/501100011033 and "ESF Investing in your future". This work is framed in the project "ACUFLOT", supported by the Biodiversity Foundation of the Ecological Transition and Demographic Challenge Ministry of Spain and the IHCantabria - Instituto de Hidráulica Ambiental de la Universidad de Cantabria.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ocecoaman.2023.106764.

References

4 COffshore, 2021. Maps: Global Offshore Map (4C Offshore Windfarm Map). Available from: http://www.4coffshore.com/offshorewind/. (Accessed 14 June 2021).

Amante, C., Eakins, B.W., 2009. ETOPO1 1 arc-minute global relief model: procedures, data sources and analysis. In: NOAA Technical Memorandum NESDIS NGDC-24. National Geophysical Data Center, NOAA. https://doi.org/10.7289/V5C8276M.

ANTAQ, 2022. Agência nacional de Transportes aquaviários (ANTAQ), instalações portuárias outorgadas. Available from: https://www.gov.br/antaq/pt-br/central-de-conteudos/informacoes-geograficas. (Accessed 25 August 2022).

Aryai, V., Abbassi, R., Abdussamie, N., Salehi, F., Garaniya, V., et al., 2021. Reliability of Multi-Purpose Offshore-Facilities: Present Status and Future Direction in Australia, vol. 148. Process Safety and Environmental Protection, pp. 437–461. https://doi.org/10.1016/j.psep.2020.10.016.

Astariz, S., Abanades, J., Perez-Collazo, C., Iglesias, G., 2015a. Improving wind farm accessibility for operation & maintenance through a co-located wave farm: influence of layout and wave climate. Energy Convers. Manag. 95, 229–241. https://doi.org/10.1016/j.enconman.2015.02.040.

Astariz, S., Perez-Collazo, C., Abanades, J., Iglesias, G., 2015b. Co-located wind-wave farm synergies (Operation & Maintenance): a case study. Energy Convers. Manag. 91, 63–75. https://doi.org/10.1016/j.enconman.2014.11.060.

FAO, 2007. Cultured aquatic species information programme. Rachycentron canadum. Cultured aquatic species information programme. Text by kaiser, J.B., holt, J.G. In: FAO Fisheries and aquaculture department [Cited 26 September 2020]. http://www.fao.org/fishery/culturedspecies/Rachycentron_canadum/en. (Accessed 23 May 2007).

Aymamí, J., García, A., Lacave, O., Lledó, L., Mayo, M., Parés, S., 2011. Análisis del recurso. Atlas eólico de España. Estudio Técnico PER 2011-2020. IDEA – Instituto para la Diversificación y Ahorro de la Energía. Available from: https://www.idae.es/uploads/documentos/documentos_11227_e4_atlas_eolico_A_9b90ff10.pdf. (Accessed 14 May 2021).

Babarit, J.A., Hals, J., Muliawan, M.J., Kurniawan, A., Moan, T., Krokstad, J., 2012. Numerical benchmarking study of a selection of wave energy converters. Renew. Energy 41, 44–63. https://doi.org/10.1016/j.renene.2011.10.002.

Bak, C., Zahle, F., Bitsche, R., Kim, T., Yde, A., Henriksen, L.C., Natarajan, A., Hansen, M. H., 2013. Description of the DTU 10 MW Reference Wind Turbine. DTU Wind Energy Report-I-0092. DTU Wind Energy, p. 138.

Benetti, D.D., Sardenberg, B., Welch, A., Hoenig, R., Refik-Orhun, M., Zink, I., 2008. Intensive larval husbandry and fingerling production of cobia Rachycentron canadum. Aquaculture 281, 22–27. https://doi.org/10.1016/j.aquaculture.2008.03.030.

Benetti, D.D., O'Hanlon, B., Rivera, J.A., Welch, A.W., Maxey, C., Orhun, M.R., 2010. Growth rates of cobia (Rachycentron canadum) cultured in open ocean submerged cages in the Caribbean. Aquaculture 302, 195–201. https://doi.org/10.1016/j.aquaculture.201.02.021.

Bocci, M., Sangiuliano, S.J., Sarretta, A., Ansong, J.O., Buchanan, B., 2019. Multi-use of the sea: a wide array of opportunities from site-specific cases across Europe. PLoS One. https://doi.org/10.1371/journal.pone.0215010.

Calado, H., Papaioannou, E.A., Caña-Varona, M., Onyango, V., Zaucha, J., 2019. Multi-uses in the eastern atlantic: building bridges in maritime space. Ocean Coast Manag. 174, 131–143. https://doi.org/10.1016/j.ocecoaman.2019.03.004.

Campbell, D., 2017. Albatern WaveNet device isle of much deployment. Available from: http://grebeproject.eu/wp-content/uploads/2017/09/Wave-Energy-Albatern-Wave Net-Scotland.pdf. (Accessed 11 October 2022).

Cao, S., Cheng, Y., Duan, J., Fan, X., 2022. Experimental Investigation on the Dynamic Response of an Innovative Semi-submersible Floating Wind Turbine with Aquaculture Cages, vol. 200. Renewable Energy, pp. 1393–1415. https://doi.org/10.1016/j.renene.2022.10.072.

Cavalli, R.O., 2022. Aquicultura Do Beijupirá (*Rachycentron canadum*) No Brasil. Editora da FURG, Rio Grande, Brazil, p. 1. ISBN 978-65-5754-120-3.

Cavalli, R.O., Domingues, E.C., Hamilton, S., 2011. Development of open ocean marine fish farming in Brazil: possibilities and constraints. Rev. Bras. Zootec. V. 40, 155–164. ISSN 1806-9290.

Chambers, M.D., Ostrowski, A.C., 1999. Development of bluefin trevally (Caranx melampygus) and greater amberjack (Seriola dumerili) for offshore aquaculture. In: Stickney, R.R. (Ed.), Joining Forces with Industry: Proceedings of the Third International Conference on Open Ocean Aquaculture, Corpus Christi, Texas (USA). Sea Grant College Program Publication, Texas A&M University, pp. 132–141.

Chu, Y.I., Wang, C.M., Park, J.C., Lader, P.F., 2020. Review of cage and containment tank designs for offshore fish farming. Aquaculture 519, 734928. https://doi.org/10.1016/j.aquaculture.2020.734928.

Clark, C.E., Miller, A., DuPont, B., 2019. An analytical cost model for co-located floating wind-wave energy arrays. Renew. Energy 132, 885–897. https://doi.org/10.1016/j.renene.2018.08.043.

Clemente, D., Rosa-Santos, P., Ferradosa, T., Taveira-Pinto, F., 2023. Wave energy conversion energizing offshore aquaculture: prospects along the Portuguese coastline. Renew. Energy 204, 347–358. https://doi.org/10.1016/j.renene.2023.01.009.

Connolly, P., Hall, M., 2019. Comparison of pilot-scale floating offshore wind farms with shared moorings. Ocean. Eng. 171, 172–180.

Copernicus: Marine Service Information (European Union), 2016. Global observed ocean physics temperature salinity heights and currents reprocessing (1993-2014): marine environment monitoring service. Available from: http://marine.copernicus.eu/services-portfolio/access-to-products/?option=com_csw&view=details&product_id=GLOBAL_REP_PHYS_001_013.

Costello, C., Cao, L., Gelcich, S., et al., 2020. The future of food from the sea. Nature 588, 95–100. https://doi.org/10.1038/s41586-020-2616-y.

Dallavalle, E., Zanuttigh, B., Contestabile, P., Giuggioli, A., Speranza, D., 2023. Improved methodology for the optimal mixing of renewable energy sources and application to a multi-use offshore platform. Renew. Energy 210, 575–590. https://doi.org/10.1016/j.renene.2023.03.099.

Dalton, G., Bardócz, T., Blanc, M., Campbell, B., Johnson, K., 2019. Feasibility of investment in Blue Growth multiple-use of space and multi-use platform projects; results of a novel assessment approach and case studies. Renew. Sustain. Energy Rev. 107, 338–359. https://doi.org/10.1016/j.rser.2019.01.060.

de Andres, A., Guanche, R., Weber, J., Costello, R., 2015a. Finding gaps on power production assessment on WECs: wave definition analysis. Renew. Energy 83, 171–187. https://doi.org/10.1016/j.renene.2015.04.026.

de Andres, A., Guanche, R., Vidal, C., Losada, I.J., 2015b. Adaptability of a generic wave energy converter to different climate conditions. Renew. Energy 78, 322–333. https://doi.org/10.1016/j.renene.2015.01.020.

de Oliveira, L., dos Santos, I.F.S., Schmidt, N.L., Filho, G.L.T., Camacho, R.G.R., Barros, R.M., 2021. Economic feasibility study of ocean wave electricity generation in Brazil. Renew. Energy 178, 1279–1290. https://doi.org/10.1016/j.renene.2021.07.009.

DNV (Det Norske Veritas), 2010. Offshore standard - DNV-OS-e301 (position mooring). Available from: http://www.dnv.com/. (Accessed 28 June 2021).

Domínguez-Tejo, E., Metternicht, G., Johnston, E., Hedge, L., 2016. Marine Spatial Planning advancing the Ecosystem-Based Approach to coastal zone management: a review. Mar. Pol. 72, 115–130. https://doi.org/10.1016/j.marpol.2016.06.023.

Donlon, C.J., Martin, M., Stark, J.D., Roberts-Jones, J., Fiedler, E., Wimmer, W., 2012. The operational sea surface temperature and sea ice analysis (OSTIA). Rem. Sens. Environ. 116, 140–158. https://doi.org/10.1016/j.rse.2010.10.017.

Duncan, N.J., Estevez, A., Fernández-Palacios, H., Vallés, L.R., 2013. Aquaculture production of meagre (Argyrosomus regius): hatchery techniques, ongrowing and market. In: Geoff, Allan, Gavin, Burnell (Eds.), Advances in Aquaculture Hatchery Technology. Publisher: Woodhead Publishing, pp. 519–541. https://doi.org/10.1533/9780857097460.3.519. Chapter: 17.

Ehler, C., Douvere, F., 2009. Marine Spatial Planning: a step-by-step approach toward ecosystem-based management. In: Intergovernmental Oceanographic Commission and Man and the Biosphere Programme. IOC Manual and Guides No. 53, ICAM Dossier No. 6. UNESCO, Paris.

FAO, 2005a. Cultured aquatic species information programme. Dicentrarchus labrax. Cultured aquatic species information programme. Text by bagni, M. In: FAO Fisheries and aquaculture department [Cited 26 September 2020]. http://www.fao.org/fishery/culturedspecies/Dicentrarchus_labrax/en. (Accessed 18 February 2005).

FAO, 2005b. Cultured aquatic species information programme. Sparus aurata. Cultured aquatic species information programme. Text by colloca, F., cerasi, S. In: FAO Fisheries and aquaculture department [Cited 26 September 2020]. http://www.fao.org/fishery/culturedspecies/Sparus_aurata/en. (Accessed 8 February 2005).

FAO, 2005c. Cultured aquatic species information programme. Argyrosomus regius. Cultured aquatic species information programme. Text by stipa, P., angelini, M. In: FAO Fisheries and aquaculture department [Cited 26 September 2020]. http://www.fao.org/fishery/culturedspecies/Argyrosomus_regius/en. (Accessed 10 February 2005).

FAO, 2015. Cultured aquatic species information programme. Thunnus thynnus. Cultured aquatic species information programme. Text by de la Gándara, F. In: FAO Fisheries division [Cited 29 September 2020]. http://www.fao.org/fishery/culturedspecies/Thunnus_thynnus/en. (Accessed 2 October 2015).

FAO, 2016b. Cultured aquatic species information programme. Seriola dumerili. Cultured aquatic species information programme. Text by herrera, J., agius, R.V. In: FAO Fisheries and aquaculture department [Cited 26 September 2020]. http://www.fao.org/fishery/culturedspecies/Seriola_dumerili/en. (Accessed 1 January 2016).

FAO, 2022. Global aquaculture production quantity (1950 - 2020). Food and agriculture organization of the united nations (FAO). Available from: https://www.fao.org/fishery/statistics-query/en/aquaculture/aquaculture_quantity. (Accessed 15 August 2022).

Faulk, C.K., Holt, G.J., 2005. Advances in rearing cobia Rachycentron canadum larvae in recirculating aquaculture systems: live prey enrichment and greenwater culture. Aquaculture 249, 231–243. https://doi.org/10.1016/j.aquaculture.2005.03.033.

Fenu, B., Bonfanti, M., Bardazzi, A., Pilloton, C., Lucarelli, A., Mattiazzo, G., 2023. Experimental investigation of a Multi-OWC wind turbine floating platform. Ocean Eng. 281 (1), 114619 https://doi.org/10.1016/j.oceaneng.2023.114619.

Gandra, T.B.R., Bonetti, J., Scherer, M., 2018. Onde estão os dados para o Planejamento Espacial Marinho (PEM)? Análise de repositórios de dados marinhos e das lacunas de dados geoespaciais para a geração de descritores para o PEM no Sul do Brasil. Desenvolv. Meio Ambiente 44, 405–421. https://doi.org/10.5380/dma.v44i0.54987.

Garavelli, L., Freeman, M.C., Tugade, L.G., Greene, D., McNally, J., 2022. A feasibility assessment for co-locating and powering offshore aquaculture with wave energy in the United States. Ocean Coast Manag. 255, 106242 https://doi.org/10.1016/j.ocecoaman.2022.106242.

Ghiasi, Y., Nafisi, V., 2015. Strain estimation using ordinary Kriging interpolation. Surv. Rev. 48, 361–366. https://doi.org/10.1080/00396265.2015.1116155.

Gonzalez, H.P., Bianchi, F.D., Dominguez-Garcia, J.L., Gomis-Bellmunt, O., 2023. Co-located wind-wave farms: optimal control and grid integration. Energy 272 (1), 127176. https://doi.org/10.1016/j.energy.2023.127176.

Guanche, R., de Andrés, A., Losada, I.J., Vidal, C., 2015. A global analysis of the operation and maintenance role on the placing of wave energy farms. Energy Convers. Manag. 106, 440–456. https://doi.org/10.1016/j.enconman.2015.09.022.

Harmon, C.M., 2016. Considerations for Co-location of Aquaculture and Ocean Energy Facilities. Sea Grant Law Fellow Publications, p. 77.

Hernandez, O.M., Shadman, M., Amiri, M.M., Silva, C., Estefen, S.F., La Roverea, E., 2021. Environmental impacts of offshore wind installation, operation and maintenance, and decommissioning activities: a case study of Brazil. Renew. Sustain. Energy Rev. 144, 110994 https://doi.org/10.1016/j.rser.2021.110994.

Hopkins, J., Lucas, M., Dufau, C., Sutton, M., Stum, J., Lauret, O., Channelliere, C., 2013. Detection and variability of the Congo River plume from satellite derived sea surface temperature, salinity, ocean colour and sea level. Remote Sens. Environ. 139, 365–385. https://doi.org/10.1016/j.rse.2013.08.015.

Hossu, B., Korkut, A.Y., Salnur, S., 2005. Investigation on feeding tables for sea bass (Dicentrarchus labrax L., 1758) in net-cage (Pinar Marine Company) culture. In: Montero, D., Basurco, B., Nengas, I., Alexis, M., Izquierdo, M. (Eds.), Mediterranean Fish Nutrition. CIHEAM, Zaragoza, pp. 35–43 (Cahiers Options Méditerranéennes; n. 63).

Hu, J., Zhou, B., Vogel, C., Liu, P., Willden, R., Sun, K., Zang, J., Geng, J., Jin, C., Jiang, B., Collu, M., 2020. Optimal design and performance analysis of a hybrid system combing a floating wind platform and wave energy converters. Appl. Energy 269, 114998. https://doi.org/10.1016/j.apenergy.2020.114998.

Huang, C.-T., Afero, F., Hung, C.-W., Chen, B.-Y., Nan, F.-H., Chiang, W.-S., Tang, H.-J., Kang, C.-K., 2022. Economic feasibility assessment of cage aquaculture in offshore wind power generation areas in Changhua County, Taiwan. Aquaculture 548 (1), 737611. https://doi.org/10.1016/j.aquaculture.2021.737611.

IBAMA, 1998. PORTARIA IBAMA N° 145-N, DE 29 DE OUTUBRO DE 1998.

IBAMA, 2022a. Mapas de projetos em licenciamento - complexos Eólicos Offshore. Available from: https://www.ibama.gov.br/laf/consultas/mapas-de-projetos-em-licenciamento-complexos-eolicos-offshore. (Accessed 17 August 2022).

IBAMA, 2022b. Processos de licenciamento ambiental. Available from: https://servicos.ibama.gov.br/licenciamento/consulta_empreendimentos.php. (Accessed 8 September 2022).

IEA-OES, 2022. Annual Report: an Overview of Ocean Energy Activities in 2021.

Jansen, H.M., Van Den burg, S., Bolman, B., Jak, R.G., Kamermans, P., Poelman, M., Stuiver, M., 2016. The feasibility of offshore aquaculture and its potential for multi-use in the North Sea. Aquacult. Int. 24, 735–756. https://doi.org/10.1007/s10499-016-9987-y.

Jonkman, J., Butterfield, S., Musial, W., Scott, G., 2009. Definition of a 5-MW Reference Wind Turbine for Offshore System Development. NREL/TP-500-38060 (Technical Report). Availablre from: https://www.nrel.gov/docs/fy09osti/38060.pdf. (Accessed 3 June 2021).

Jonkman, J., Robertson, A., Popko, W., Vorpahl, F., Zuga, A., Kohlmeier, M., et al., 2012. Offshroe code comparison collaboration continuation (OC4), phase I – results of coupled simulations of an offshore wind turbine with jacket support structure. In: Conference Paper NREL/CP-5000-54124. Engineers Conference, Rhodes, Greece.

Jouffray, J.-B., Blasiak, R., Norström, A.V., Österblom, H., Nyström, M., 2020. The blue acceleration: the trajectory of human expansion into the ocean. One Earth V2 (1), 43–54. https://doi.org/10.1016/j.oneear.2019.12.016.

Jovera, M., García-Gómez, A., Tomás, A., De la Gándara, F., Pérez, L., 1999. Growth of Mediterranean yellowtail (Seriola dumerilii) fed extruded diets containing different levels of protein and lipid. Aquaculture 179, 25–33. https://doi.org/10.1016/S0044-8486(99)00149-0.

Kaschner, K., Kesner-Reyes, K., Garilao, C., Segschneider, J., Rius-Barile, J., Rees, T., Froese, R., 2022a. Computer generated distribution maps for *Seriola dumerili* (Greater amberjack), with modelled year 2050 native range map based on IPCC RCP8.5 emissions scenario. AquaMaps -Version of Oct. 2019. www.aquamaps.org. (Accessed 19 August 2022).

Kaschner, K., Kesner-Reyes, K., Garilao, C., Segschneider, J., Rius-Barile, J., Rees, T., Froese, R., 2022b. Computer generated distribution maps for *Rachycentron canadum* (Cobia), with modelled year 2050 native range map based on IPCC RCP8.5 emissions scenario. AquaMaps -Version of Oct. 2019. www.aquamaps.org. (Accessed 19 August 2022).

Kaschner, K., Kesner-Reyes, K., Garilao, C., Segschneider, J., Rius-Barile, J., Rees, T., Froese, R., 2022c. Computer generated distribution maps for *Thunnus thynnus* (Atlantic Bluefin tuna), with modelled year 2050 native range map based on IPCC RCP8.5 emissions scenario. AquaMaps -Version of Oct. 2019. www.aquamaps.org. (Accessed 19 August 2022).

Kaschner, K., Kesner-Reyes, K., Garilao, C., Segschneider, J., Rius-Barile, J., Rees, T., Froese, R., 2022d. Computer generated distribution maps for *Sparus aurata* (Gilthead seabream), with modelled year 2050 native range map based on IPCC RCP8.5 emissions scenario. AquaMaps -Version of Oct. 2019. www.aquamaps.org. (Accessed 19 August 2022).

Kaschner, K., Kesner-Reyes, K., Garilao, C., Segschneider, J., Rius-Barile, J., Rees, T., Froese, R., 2022e. Computer generated distribution maps for *Argyrosomus regius* (Meagre), with modelled year 2050 native range map based on IPCC RCP8.5 emissions scenario. AquaMaps -Version of Oct. 2019. www.aquamaps.org. (Accessed 19 August 2022).

Kaschner, K., Kesner-Reyes, K., Garilao, C., Segschneider, J., Rius-Barile, J., Rees, T., Froese, R., 2022f. Computer generated distribution maps for Dicentrarchus labrax (European seabass), with modelled year 2050 native range map based on IPCC RCP8.5 emissions scenario. AquaMaps -Version of Oct. 2019. www.aquamaps.org. (Accessed 19 August 2022).

Katavić, I., Herstad, T.-J., Kryvi, H., White, P., Franičević, V., Skakelja, N., 2005. Guidelines to Marine Aquaculture Planning, Integration and Monitoring in Croatia. Project "Coastal zone management plan for Croatia", Zagreb, p. 78p.

Kavadias, S., Castritsi-Catharios, J., Dessypris, A., 2003. Annual cycles of growth rate, feeding rate, food conversion, plasma glucose and plasma lipids in a population of European sea bass (Dicentrarchus labrax) farmed in floating marine cages. J. Appl. Ichthyol. 19, 29–34. https://doi.org/10.1046/j.1439-0426.2003.00346.x.

Kyriazi, Z., 2018. From identification of compatibilities and conflicts to reaching marine spatial allocation agreements. Review of actions required and relevant tools and processes. Ocean Coast Manag. 166, 103–112. https://doi.org/10.1016/j.ocecoaman.2018.03.018.

Li, L., Ruzzo, C., Collu, M., Gao, Y., Failla, G., Arena, F., 2020. Analysis of the coupled dynamic response of an offshore floating multi-purpose platform for the Blue Economy. Ocean Eng. 217, 107943 https://doi.org/10.1016/j.oceaneng.2020.107943.

Li, N., Shi, W., Han, X., Li, X., Verma, A.S., Liu, C., 2023. Dynamic analysis of an integrated offshore structure comprising a jacket-supported offshore wind turbine and aquaculture steel cage. Ocean Eng. 274, 114059 https://doi.org/10.1016/j.oceaneng.2023.114059.

Lisboa, R.C., Teixeira, P.R.F., Fortes, C.J., 2017. Numerical evaluation of wave energy potential in the south of Brazil. Energy 121 (15), 176–184. https://doi.org/10.1016/j.energy.2017.01.001.

LiVecchi, A., Copping, A., Jenne, D., Gorton, A., Preus, R., Gill, G., Robichaud, R., Green, R., Geerlofs, S., Gore, S., Hume, D., McShane, W., Schmaus, C., Spence, H., 2019. Powering the Blue Economy; Exploring Opportunities for Marine Renewable

Energy in Maritime Markets. Available from:. U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Washington, DC, USA https://www.energy.gov/sites/prod/files/2019/03/f61/73355.pdf. (Accessed 11 October 2022).

MARIBE, 2015. Marine investment for the blue Economy (project). Blue growth combination for blue Economy. Financed by the European union's horizon 2020 research and innovation programme under grant agreement no 652629. Available form: http://maribe.eu/.

Martínez-Llorens, S., Espert, J., Moya, J., Cerdá, M.J., Vidal, A.T., 2011. Growth and nutrient efficiency of meagre (Argyrosomus regius, Asso1801) fed extruded diets with different protein and lipid levels. Int. J. Fish. Aquacult. 3, 195–203.

Martini, M., Guanche, R., Losada, I.J., Vidal, C., 2015. Accessibility assessment for operation and maintenance of offshore wind farms in the North Sea. Wind Energy 20, 637–656. https://doi.org/10.1002/we.2028.

McCann, J., Hodson, C., Walsh, J.P., Freeman, P., Lukic, I., Tephany, J.G., Trouillet, B., Thomas, J.-B., Juell-Skielse, E., Gröndahl, F., Rebours, C., Diederichsen, S., Scherer, M., Weiss, C.V.C., Lima, F.A.V., dos Santos, B.A.Q., 2023. Ocean multi-use assessment approach (MUAA). @MULTI-FRAME project. ISBN: 979-8-218-17554-2. Availabre from: https://www.submariner-network.eu/multi-frame-publication-page.

Méndez, F.J., Menéndez, M., Luceño, A., Losada, I.J., 2006. Estimation of the long term variability of extreme significant wave height using a time-dependent Peak over Threshold (POT) model. J. Geophys. Res. 111, 1–13. https://doi.org/10.1029/2005JC003344.

MMA, 2018. Ministério do Meio Ambiente e Mudança do Clima – 2a Atualização das Áreas Prioritárias para Conservação da Biodiversidade. Available from: https://www.gov.br/mma/pt-br/assuntos/ecossistemas-1/conservacao-1/areas-prioritarias/2a-atualizacao-das-areas-prioritarias-para-conservacao-da-biodiversidade-2018. (Accessed 1 May 2023).

MMA, 2023. Ministério do Meio Ambiente e Mudança do Clima – download de dados geográficos - i3Geo. Available from: http://mapas.mma.gov.br/i3geo/datadownload.htm. (Accessed 1 May 2023).

Monfort, M.C., 2010. Present market situation and prospects of meagre (Argyrosomus regius), as an emerging species in Mediterranean aquaculture. In: Food and Agriculture Organization of the United Nations. Studies and Reviews. N. 89 General Fisheries Commission for the Mediterranean. ISSN: 1020-9549.

NCAR (National Center for Atmospheric Research Staff), 2016. Available from:. In: The Climate Data Guide: Climate Forecast System Reanalysis (CFSR) https://climatedataguide.ucar.edu/climate-data/climate-forecast-system-reanalysis-cfsr. (Accessed 22 May 2021).

OES, 2021. Ocean Energy Systems (OES). Alternative Markets for Ocean Energy. IEA Technology Programme for Ocean Energy Systems. Available from: https://www.ocean-energy-systems.org/publications/oes-documents/market-policy-/document/alternative-markets-for-ocean-energy/. (Accessed 5 October 2022).

ONS, 2018. Operador nacional do sistema elétrico (ONS) Available from: http://www.ons.org.br/. (Accessed 19 July 2021).

Ogino, S.Y., Yamanaka, M.D., Mori, S., Matsumoto, J., 2017. Tropical coastal dehydrator in global atmospheric water circulation. Geophys. Res. Lett. 44, 11636–11643. https://doi.org/10.1002/2017GL075760.

Oleinik, P.H., Marques, W.C., Kirinus, E.d.P., 2017. Estimate of the wave climate on the most energetic locations of the south-southeastern Brazilian shelf. Defect Diffusion Forum 370, 130–140. https://doi.org/10.4028/www.scientific.net/DDF.370.141.

Perez, J., Menendez, M., Losada, I.J., 2017. GOW2: a global wave hindcast for coastal applications. Coast. Eng. 124, 1–11. https://doi.org/10.1016/j.coastaleng.2017.03.005.

Pérez-Collazo, C., Jakobsen, M.M., Buckland, H., Fernández-Chozas, J., 2013. Synergies for a Wave-Wind Energy Concept. European Offshore Wind Energy Conference - Frankfurt, Germany. https://doi.org/10.13140/2.1.5155.1523. Conference paper.

Person-Le Ruyet, J., Mahé, K., Le Bayon, N., Le Delliou, H., 2004. Effects of temperature on growth and metabolism in a Mediterranean population of European sea bass. Dicentrarchus labrax. Aquaculture 237, 269–280. https://doi.org/10.1016/j.aquaculture.2004.04.021.

Pimenta, F.M., Silva, A.R., Assireu, A.T., Almeida, V.d.S.e., Saavedra, O.R., 2019. Brazil offshore wind resources and atmospheric surface layer stability. Energies 12 (21), 4195. https://doi.org/10.3390/en12214195.

Reguero, B.J., Menéndez, M., Méndez, F.J., Mínguez, R., Losada, I.J., 2012. A global ocean wave (GOW) calibrated reanalysis from 1948 onwards. Coast. Eng. 65, 38–55. https://doi.org/10.1016/j.coastaleng.2012.03.003.

Reimer, J.M., Devillers, R., Trouillet, B., Ban, N.C., Agardy, T., Claudet, J., 2023. Conservation ready marine spatial planning. Mar. Pol. 153, 105655 https://doi.org/10.1016/j.marpol.2023.105655.

Resley, M., Webb, K., Holt, J., 2006. Growth and survival of juvenile cobia, Rachycentron canadum, at different salinities in a recirculating aquaculture system. Aquaculture 253, 398–407. https://doi.org/10.1016/j.aquaculture.2005.08.023.

Roberson, B., Hiles, C., Luczko, E., Bradley, B., 2016. Quantifying wave power and wave energy converter array production potential. International Journal of Marine Energy 14, 143–160. https://doi.org/10.1016/j.ijome.2015.10.001.

Rodrigues, S., Restrepo, C., Kontos, E., Pinto, R.T., Bauer, P., 2015. Trends of offshore wind projects. Renew. Sustain. Energy Rev. 49, 1114–1135. https://doi.org/10.1016/j.rser.2015.04.092.

Rombenso, A.N., Tsuzuki, M.U., Sebastiani, E.F., Kerber, C.E., 2021. Produção de beijupirá na região sudeste do Brasil. In: Cavalli, R.O. (Ed.), Aquicultura Do Beijupirá (*Rachycentron canadum*) No Brasil. Editora da FURG, Rio Grande, Brazil, pp. 71–81. ISBN 978-65-5754-120-3.

Ruzzo, C., Muggiasca, S., Malara, G., Taruffi, F., Belloli, M., Collu, M., Li, L., Brizzi, G., Arena, F., 2021. Scaling strategies for multi-purpose floating structures physical modeling: state of art and new perspectives. Appl. Ocean Res. 108, 102487 https://doi.org/10.1016/j.apor.2020.102487.

Ruzzo, C., Malara, G., Collu, M., Santoro, A., Fiamma, V., Scialò, A., Lagasco, F., Arena, F., 2022. Field experiment on a scaled prototype of a floating multi-purpose offshore platform: dynamic response determination with uncertainty quantification. Appl. Ocean Res. 129, 103402 https://doi.org/10.1016/j.apor.2022.103402.

Saenz-Aguirre, A., Saenz, J., Ulazia, A., Ibarra-Berastegui, G., 2022. Optimal strategies of deployment of far offshore co-located wind-wave energy farms. Energy Convers. Manag. 251, 114914 https://doi.org/10.1016/j.enconman.2021.114914.

Saha, S., Moorthi, S., Pan, H.-L., Wu, X., Wang, J., Nadiga, S., et al., 2010. The NCEP climate forecast system reanalysis. Bull. Am. Meteorol. Soc. 91, 1015–1057. https://doi.org/10.1175/2010BAMS3001.1.

Saha, S., Moorthi, S., Wu, X., Wang, J., Nadiga, S., Tripp, P., et al., 2014. The NCEP climate forecast system version 2. J. Clim. 27, 2185–2208. https://doi.org/10.1175/JCLI-D-12-00823.1.

Santos, C.F., Agardy, T., Andrade, F., Crowder, L.B., Ehler, C.N., OrbachM, K., 2021. Major challenges in developing marine spatial planning. Mar. Pol. 132, 103248 https://doi.org/10.1016/j.marpol.2018.08.032.

Schuchardt, D., Fernández-Palacios, H., Roo, J., Hernández-Cruz, C.M., 2007. Estabulación y mantenimiento de un stock de reproductores de corvina (*Argyrosomus regius*, Asso, 1801), en Canarias. In: Libro de Actas Toma II XI Congreso Nacional de Acuicultura, Vigo. Pontevedra. Graficas Salnes SL, pp. 727–730.

Schultz-Zehden, A., Lukic, I., Ansong, J.O., Altvater, S., Bamlett, R., Barbanti, A., Bocci, M., et al., 2018. Ocean Multi-Use Action Plan. MUSES project, Edinburgh.

Schupp, M.F.F., Bocci, M., Depellegrin, D., Kafas, A., Kyriazi, Z., Lukic, I., Schultz-Zehden, A., Krause, G., Onyango, V., Buck, B., 2019. Toward a common understanding of ocean multi-use. Front. Mar. Sci. https://doi.org/10.3389/fmars.2019.00165.

Seginera, I., Ben-Asher, J., 2011. Optimal harvest size in aquaculture, with RAS cultured sea bream (*Sparus aurata*) as an example. Aquacult. Eng. 44, 55–64. https://doi.org/10.1016/j.aquaeng.2011.03.001.

SIBBR (Sistema de informação sobre a biodiversidade brasileira), 2022. *Rachycentron canadum* (Linnaeus, 1766). Catálogo Taxonômico da Fauna do Brasil e Lista da Flora do Brasil 2020. Available from: https://sibbr.gov.br/. (Accessed 7 August 2022).

Silva, A.R., Pimenta, F.M., Assireu, A.T., Spyrides, H.C., 2016. Complementarity of Brazil's hydro and offshore wind power. Renew. Sustain. Energy Rev. 56, 413–427. https://doi.org/10.1016/j.rser.2015.11.045.

Stancheva, M., Stanchev, H., Zaucha, J., Ramieri, E., Roberts, T., 2022. Supporting multi-use of the sea with maritime spatial planning.The case of a multi-use opportunity development - Bulgaria, Black Sea. Mar. Pol. 136, 104927 https://doi.org/10.1016/j.marpol.2021.104927.

Standard Norge, 2009. Norwegian Standard NS 9415.E:2009. Marine Fish Farms: Requirements for Site Survey, Risk Analyses, Design, Dimensioning, Production, Installation and Operation.

Tavares, L.F.A., Shadman, M., Assad, L.P.F., Silva, C., Landa, L., Estefen, S.F., 2020. Assessment of the offshore wind technical potential for the Brazilian Southeast and South regions. Energy 196, 0–117097. https://doi.org/10.1016/j.energy.2020.117097.

Available form:, 2018. TELWIND PROJECT http://www.esteyco.com/projects/telwind/. (Accessed 8 July 2021).

Ticina, V., Katavic, I., Grubisic, L., 2007. Growth indicies of small northern bluefin tuna (Thunnus thynnus, L.) in growth-out rearing cages. Aquaculture 269, 538–543. https://doi.org/10.1016/j.aquaculture.2007.05.029.

Tucker, J.W., 1998. Marine Fish Culture. Kluwer Academic Publishers, Norwell Massachusetts, USA.

Ulazia, A., Sáenz, J., Saenz-Aguirre, A., Ibarra-Berastegui, G., Carreno-Madinabeitia, S., 2023. Paradigmatic case of long-term colocated wind–wave energy index trend in Canary Islands. Energy Convers. Manag. 283, 116890 https://doi.org/10.1016/j.enconman.2023.116890.

Valenti, W.C., Barros, H.P., Moraes-Valenti, P., Bueno, G.W., Cavalli, R.O., 2021. Aquaculture in Brazil: past, present and future. Aquaculture Reports 19, 100611. https://doi.org/10.1016/j.aqrep.2021.100611.

van den Burg, S.W.K., Schupp, M.F., Depellegrin, D., Barbanti, A., Kerr, S., 2020. Development of multi-use platforms at sea: barriers to realising Blue Growth. Ocean Eng. 217, 107983 https://doi.org/10.1016/j.oceaneng.2020.107983.

Vaughan, D., Agardy, T., 2020. Marine Protected Areas and Marine Spatial Planning – Allocation of Resource Use and Environmental Protection. Marine Protected Areas, Elsevier Ltd, p. 35. https://doi.org/10.1016/B978-0-08-102698-4.00002-2.

Vidal-Amaro, J.J., Østergaard, P.A., Sheinbaum-Pardo, C., 2015. Optimal energy mix for transitioning from fossil fuels to renewable energy sources – the case of the Mexican electricity system. Appl. Energy 150, 80–96. https://doi.org/10.1016/j.apenergy.2015.03.133.

Vizonha, A., Schaeffer, R., 2021. Brazil's offshore wind energy potential assessment based on a Spatial Multi-Criteria Decision Analysis. Renew. Sustain. Energy Rev. 146, 111185 https://doi.org/10.1016/j.rser.2021.111185.

Weiss, C.V.C., Ondiviela, B., Guinda, X., del Jesus, F., González, J., Guanche, R., et al., 2018a. Co-location opportunities for renewable energies and aquaculture facilities in the Canary Archipelago. Ocean Coast Manag. 166, 62–71. https://doi.org/10.1016/j.ocecoaman.2018.05.006.

Weiss, C.V.C., Guanche, R., Ondiviela, B., Castellanos, O.F., Juanes, J.A., 2018b. Marine renewable energy potential: a global perspective for offshore wind and wave exploitation. Energy Convers. Manag. 177, 43–54. https://doi.org/10.1016/j.enconman.2018.09.059.

Weiss, C.V.C., Ondiviela, B., Guanche, R., Castellanos, O.F., Juanes, J.A., 2018c. A global integrated analysis of open sea fish farming opportunities. Aquaculture 497, 234–245. https://doi.org/10.1016/j.aquaculture.2018.07.054.

Weiss, C.V.C., Menendez, M., Ondiviela, B., Guanche, R., Losada, I.J., Juanes, J.A., 2020. Climate change effects on marine renewable energy resources and environmental conditions for offshore aquaculture in Europe. ICES (Int. Counc. Explor. Sea) J. Mar. Sci. 77, 3168–3182. https://doi.org/10.1093/icesjms/fsaa226.

Wind Europe, 2021. Offshore Wind in Europe: Key Trends and Statistics 2020, pp. 1–36. Belgium. Available from: https://windeurope.org/about-wind/statistics/offshore/european-offshore-wind-industry-key-trends-statistics-2017/. (Accessed 8 May 2021).

Wright, H., 2008. Japan's Kinki first again. In: Fish Farming International (FFI) May 2008, pp. 22–23.

Xylia, M., Passos, M.V., Piseddu, T., Barquet, K., 2023. Exploring multi-use platforms: a literature review of marine, multifunctional, modular, and mobile applications (M4s). Heliyon 9 (6). https://doi.org/10.1016/j.heliyon.2023.e16372.

Zanuttigh, B., Palma, G., Brizzi, G., Bellotti, G., Romano, A., Suffredini, R., 2021. Design of a multi-use marine area off-shore the Mediterranean Sea. Ocean Eng. 221, 108515 https://doi.org/10.1016/j.oceaneng.2020.108515.

Zhang, Z., Chen, X., Wu, H., Liu, W., Cui, L., 2023. Numerical study of a novel hybrid system with the Wavestar wave energy converter array and a SPIC semi-submersible floating platform. J. Clean. Prod. 407, 137178 https://doi.org/10.1016/j.jclepro.2023.137178.