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Assessment of Atlantic Ocean ecosystems health: an updated calculation of the OHI goals for the Atlantic

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1. Introduction

This report provides the analysis of Atlantic Ocean Health using the Ocean Health Index Framework.

The oceans play a fundamental role in sustaining planetary life, regulating climate, and providing essential ecosystem services to human societies. Yet, concerns surrounding marine degradation have grown substantially in recent decades due to climate change, biodiversity loss, overfishing, and increasing anthropogenic pressures on coastal and offshore environments. The Atlantic Ocean, in particular, represents a diverse and economically critical basin shared by multiple nations with varying governance systems, environmental policies, and societal dependencies on marine resources. Assessing the health of such a vast and interconnected system presents a complex challenge, requiring a framework capable of integrating ecological, social, and economic dimensions.

Given the environmental and geopolitical diversity across the Atlantic Ocean, applying a unifying framework at a basin scale offers critical insights into spatial disparities, management successes, and persistent vulnerabilities. The Atlantic is home to productive fisheries, biologically rich coastlines, major shipping routes, and rapidly developing coastal economies. However, it is equally impacted by widespread stressors such as ocean warming, acidification, pollution from land-based activities, and habitat degradation. Comprehensive health assessments that address these challenges holistically are vital for ensuring long-term ocean sustainability in alignment with international goals such as the United Nations Sustainable Development Goals (SDGs) and global marine conservation strategies.

The Ocean Health Index (OHI) has emerged as one of the leading global methodologies for evaluating ocean well-being through a multidisciplinary and goal-based approach. The OHI framework quantifies ocean health based on the sustainable delivery of benefits that humans derive from marine ecosystems. It incorporates ten major goals, including clean waters, carbon storage, biodiversity, food provision. These are evaluated in this report for the Atlantic ocean using a combination of current status, trends and cumulative pressures. The index is particularly valuable because it not only identifies current performance, but also highlights potential trajectories for future ocean conditions. By translating complex environmental data into a standardized scoring system, the OHI enables comparisons across regions and supports informed decision-making in marine governance.

Beyond the broad-scale evaluation, this report include two contrasting case regions where the full OHI framework consisting in the ten goals has been applied: Galicia, located in the northeastern Atlantic along the coast of Spain, and the Southern Benguela region off the coast of South Africa.

These areas were selected because they represent distinct ecological characteristics, management systems, and socio-economic dependencies on marine resources.

Galicia is known for its rich coastal biodiversity, strong maritime cultural heritage, and highly valuable fisheries and aquaculture sectors. The region faces pressures such as coastal pollution, overexploitation of shellfish resources, and climate-induced ecological shifts, making its marine health a matter of high regional and national importance. The Southern Benguela upwelling system, by contrast, is one of the most productive marine ecosystems globally, supporting intensive commercial fisheries and contributing significantly to regional food security. However, its productivity depends heavily on climate-driven oceanographic processes.

By applying OHI to these two case studies and contrasting/integrating them within the broader Atlantic context, the report provides basis to uncover how localized environmental and socio-economic differences influence ocean health outcomes. The analysis highlight not only the variability of ocean conditions across the Atlantic, but also the needs for adaptability in management strategies under diverse governance regimes (coastal vs open sea; exclusive economic zone vs high sea). Furthermore, examining systems with high human dependency on marine resources emphasizes the importance of balancing ecological preservation with economic sustainability. The analysis will allow to identify key pressures, resilience measures, and will help to identify potential management gaps affecting ocean health at multiple scales.

The primary contents of this report are:

- the application of the Ocean Health Index framework to assess the overall condition of the Atlantic Ocean for the goals clean waters, carbon storage, biodiversity and food provision;
- the application of all OHI goals to determine status and trend for Southern Benguela region;
- the application of all OHI goals to determine status and trend for Galicia region;

Ultimately, this study by integrating very different sources of information contributes to highlight the importance of ongoing global efforts to monitor and protect the world's oceans. Some slight innovation on the index application are basis for illustrating the strengths and limitations of the OHI as a decision-support tool. It underscores the necessity of integrating ecological science with socio-economic considerations to ensure the ocean's ability to continue supporting human well-being. Through the Atlantic-wide assessment and detailed case analyses, this research emphasizes that achieving a healthy ocean is not solely an environmental goal, but a critical component of sustainable development and community livelihoods.

2. OHI assessment of the Atlantic Ocean

2.1. Introduction

The Atlantic Ocean is a single interconnected system that represents the second largest ocean on Earth. However, the governance of this large ecosystem often lacks coherence and coordination (Bennett et al., 2019), which is supported by limited knowledge and awareness of the ecosystem's functions. The physical and biogeochemical processes of the Atlantic Ocean support highly valuable ecosystem services and benefits and play a fundamental role in human well-being. Atlantic Ocean circulation regulates the global climate system (Marshall and Speer, 2012). The distribution of primary nutrients and biotic resources varies significantly with latitude (Moore et al., 2013; Reid et al., 2003), which affects the food web and the thriving of fish stocks (Pershing and Stamieszkin, 2020). The ocean's biological pump is responsible for more than 30 % of carbon sequestration from the atmosphere, buffers anthropogenic emissions (Barange et al., 2017) and helps regulate the global climate.

Despite our dependence on ecosystem services, anthropogenic pressures and global change are the main causes of disturbance in marine ecosystems around the globe, which hinders the provision of ecosystem services. Although the impacts of increasing human use on the Atlantic marine ecosystem and the resulting degradation of its services are poorly quantified, the ocean-based economy is expected to double in the next 20 years (OECD, 2016).
Therefore, there is an urgent need to improve knowledge of the Atlantic marine ecosystem, its functioning and its role in regulating and supporting ecosystem services in order to improve the international marine governance framework and lay the foundation for sustainable blue growth (EU Commission, 2020).

A promising framework to improve our understanding of eco-social interactions across the Atlantic is the Ocean Health Index (OHI) developed by Halpern et al. (2012). The OHI is an indicator that assesses the health of a marine ecosystem against 10 goals, which represent the ecosystem services and benefits that people can expect from a healthy ocean. The goals are 1) food provision through wild-caught and aquaculture harvests, 2) artisanal fishing opportunities, 3) natural products, 4) carbon storage, 5) coastal protection, 6) tourism and recreation, 7) coastal livelihoods and economies, 8) sense of place offered by special places and iconic species, 9) clean waters, 10) habitats and biodiversity. The strength of the OHI framework lies in the simultaneous integration of the ecological dimension with the economic and social dimensions, which is a key tool for producing the integrated assessments required for ecosystem-based management (Longo et al., 2017). Each goal is assessed through explicitly defined relationships weighting status, trend, pressure, and resilience and designed to measure progress to achieve maximum sustainable flows of benefits (Halpern et al., 2017).

OHI assessments have been established for many of the world's oceans and are regularly updated for countries EEZ and some specific areas (Burgass et al., 2019; Elfes et al., 2014; Longo et al., 2017). However, for the high seas of the Atlantic Ocean many functions and benefits of this basin remain poorly understood, due to paucity of data, limiting our ability to assess ocean health and guide decision-making processes. In this work, we integrate from coastal to open sea analysis of key goals for which we were able to gather data: i) biodiversity, ii) food provision, iii) carbon storage and iv) clean water goals. All of these targets are calculated at a spatial resolution of 1 degree and are not aggregated to the country level to provide an assessment that might be useful for national and international waters.

The main objectives of this work are: 1) to provide a deeper understanding of OHI methods, data, resolutions, and general information needed; 2) to identify additional source data for OHI calculations in the Atlantic Ocean; 3) to update OHI calculations for the Atlantic Ocean, considering opportunities to expand spatial coverage and/or increase data resolution.

2.2. Methodology

The Ocean Health Index

The total index score for each cell (Icell) is calculated as the weighted average of all scores (G) for each goal (g) (Eq. 2.2.1), so that:

$$I_{cell} = \frac{\sum_{g=1}^{N} w_g G_g}{\sum_{g=1}^{N} w_g}, \qquad \text{(Eq.2.2.1)}$$

where w_g is the weighting for each goal (which is assumed to be equal, since a pre-selection of meaningful goal for the study area has already been made). In our study, a region is a cell from a 1 x 1-degree grid (approximately 100 km by side at the equator) over the Atlantic basin. The total number of cells composing the Atlantic ocean is ~13108.

The global total index value (I_{Atl}) is calculated as an area-weighted average of the index values (I_{Atl}) for each cell (i) (Eq. 2.2.2):

$$I_{Atl} = \frac{\sum_{i=1}^{N} a_i I_{cell,i}}{\sum_{i=1}^{N} a_i}, \qquad \text{(Eq.2.2.2)}$$

where ai is the area of each cell (in OHI global this value is based on the EEZ area).

Table 2.2.1. Dimension used to calculate the OHI goal score. The goal scores are the average of the current and likely future status. Likely future status adjusts the current status values based on the pressures and resilience variables acting on the target and recent status trends. In this paper, only pressure (as MHW) and trend are calculated for the Likely future status.

Dimension	Subdimension	Description
Current status	-	**Current state of the goal relative to the desired "reference point". Values range from 0-100.**
Predicted future status	Resilience	Variables such as good governance and ecological factors that provide resilience to pressures, and thus, are likely to improve future status. Values range from 0-100
	Pressure	**Pressures stress the system and threaten future delivery of benefits, and thus, are likely to reduce future status. Values range from 0-100**
	Trend	**Average yearly change in status (typically estimated using most recent 5 years of data) multiplied by 5 to estimate five years into the future. Units are proportional change (absolute change/year is divided by the value of the earliest year) and range from -1 to 1**

Goal Model

Each goal score, G, is the average of its present status, x, and its likely near-term future status, $\hat{x}_F$ (Eq. 2.2.3):

$$G = \frac{x + \hat{x}_F}{2}, \qquad \text{(Eq.2.2.3)}$$

The present status of goal, x, is its present state, X, relative to a reference point, X_R, uniquely chosen for each goal (Eq. 2.2.4):

$$x_i = \frac{X}{X_R}, \qquad \text{(Eq.2.2.4)}$$

The reference point XR can be determined mechanistically using a production function (e.g. maximum sustainable yield (MSY) for fisheries) or temporally using a past benchmark (e.g. historical habitat extent) or in some cases using known (e.g. no pollution, no plastic) or fixed (e.g. 30% of waters in MPAs) targets. Previous reference points can be either a fixed point in time or a moving target (e.g. five years before the most recent data). The type of reference point can have important implications for the interpretation of target achievement.
For each cell, the estimate of the likely short-term future state of a goal is a function of 4 dimensions. The current state of the goal (x), modified by the recent trends (in the last 5 years) (T) in the state, the current cumulative pressures (p) acting on the goal; and the social and ecological resilience (r) to negative pressures (measured as a function of the governmental and social institutions established to protect or regulate the system and the ecological state of the system) (Eq. 2.2.5):

$$\hat{x}_F = [1 + \beta T + (1 - \beta)(r - p)]\ x \qquad \text{(Eq.2.2.5)}$$

where β represents the relative importance of the trend versus the resilience and pressure terms in determining the likely trajectory of the goal status into the future.

This report is primarily concerned with the status and trend. Only the stresses caused by marine heat waves (MHW) are considered and no resilience variables are included so far. The weights of the trend and the pressure are considered equivalent, so β is discarded, and therefore the updated equation is as follows (Eq. 2.2.6):

$$\hat{x}_F = [1 + T - p]\ x, \qquad \text{(Eq.2.2.6)}$$

Trend

The trend is the proportional change in status predicted for the next 5 years based on the most recent status data. In most cases, this is calculated by estimating the annual change in status using a linear regression model (i.e., slope estimation) of the last five years of status data and multiplying this value by 5 to estimate the change five years into the future. To determine the proportional change, we divide the slope estimate by the state value of the earliest year of data used for the trend calculation.
Basically, if the β, pressure (p), and resilience (r) components of the likely future status model are ignored (this assumes the pressure and resilience components fully cancel each other out), the equation becomes:

$$X_F = x(1+\text{trend})$$

where, x is the current status. Given this, if x=50, and we expect the trend to increase by 10% over 5 years, then likely future status would be: 50(1+0.10)= 55.

Trends indicate a proportional change in state and therefore usually range from -100% to +100% (or -1.0 to +1.0), which is why we have limited the values to this range.
For all goals, the trend estimate was included even if the linear model was not statistically significant (i.e. $P<0.05$). We chose to include these values for two important reasons: 1) we were not trying to predict the future, but only to indicate the probable state, 2) in almost all cases we did not have enough data to perform more accurate trend analyses.

Pressures

The pressure score, pp, describes the cumulative pressures acting on a goal which suppresses the goal score. Pressure scores range from 0 to 1 and, in this work, refer only to ecological (pE), such that (Eq. 2.2.7):

$$pi = \frac{\sum_{i=1}^{N} w_i s_i}{3}, \qquad \text{(Eq.2.2.7)}$$

Where w_i is the sensitivity ranks (Table 2.3.2: Pressure matrix) describing the relative sensitivity of each goal to each stressor, and s_i is intensity of the stressor in each region on a scale of 0-1. We divided by the maximum weighted intensity that could be achieved by the worst stressor (max = 3.0). If $p_i > 1.0$, the value is set equal to 1.0. This formulation assumes that any cumulative pressure load greater than the maximum intensity of the worst stressor is equivalent to maximum stressor intensity (Halpern et al., 2012).

In this work, we have considered pressure in the context of climate change, in particular the effects of marine heatwaves, MHW. Each target was ranked in terms of its sensitivity to MHW stressors on a scale of 1 to 3
We categorized ecological pressures as "high" (score = 3), "medium" (score = 2), "low" (score = 1) or "no" (score = NA) impact.

The methodology used to assess each of the four selected OHI-Atlantic goals are reported below.

2.3. Results

The list of data layers used for each goal is reported in Table 2.3.1. A description of each single goal calculation and the results are reported in the following paragraphs.

Table 2.3.1. Data used for the calculation of each goal.

Goal	Indicators	Data	Units	Spatial res.	Temporal Res	Reference value	Bibliography
CW		Microplastic modelled distribution -Microplastic mass and weight	items.km-2	1 dg Surface data		Reference 99th percentile	Poli et al., 2023
CW		Vessel density- Global Maritime Traffic Density Service	Hours per km2	1 km2 Surface data	2019-2023	Reference 99th percentile	https://globalmaritimetraffic.org/index.html
CS	POC flux at 1000m	CMIP6	TgC y-1	1 dg Surface data			Eyring et al., 2016
CS	CAR x area	Carbon accumulation rate (gC m^{-2} yr^{-1}) UNEP area distribution				1984 are distribution Literature data	UNEP
FIS	PPR/NPP	Saup PPR: Primary production requested	Catches per cell TL (Trophic level)	0.5° Specie-specific	2013-2018 /		Saup.com FishBase.com
		Net primary production - NPP – CMEMS.	Monthly	0.25°	1993- 2020		Global Ocean Biogeochemistry Hindcast https://resources.marine.copernicus.eu/product-detail/GLOBAL_MULTIYEAR_BGC_001_029/INFORMATION)
BD	α diverisity/ Species richness	Planckton richness from species distribution model	Monthly	1 dg Surface data	2012–2031	Reference 90th percentile	Benedetti et al., 2022
MHW	Intensity *	Marine Heat Waves	Daily SST	1 dg	2003-2022	1982-2011	

Pressures	Frequency /90th quantile	(Froelich Atlanteco) MHW					

The ranking of pressures is based on the scientific evidence resulting from a literature review aimed at identifying the sensitivity of each goal or goal component to each pressure and it is described in Table 2.3.2.

Table 2.3.2: Pressure matrix for ranking the sensitivity of the individual goal to the individual stressors.

Pressure / Goal	Microplastic	**Marine Heat Waves**	Overfishing
Clean water	/	2	2
Carbon storage	1	3	3
Food provisioning	3	3	3
Biodiversity	3	3	3

2.3.1. Clean water goal

Scope and introduction

The goal of "clean water" has changed from the original approach in several respects, as it is the only goal assessed in this work that is linked to a cultural perspective of people and is not strictly ecological. For this reason, the reference to this goal refers to the fact that people value marine waters that are free of pollution and debris for aesthetic and health reasons. However, as most people place a cultural value on something they normally experience, we have focused on two of the main pressures that are known to the public and which are also the main pressures on offshore areas.

The status of chemical pollution was measured using two datasets: Marine pollution from commercial shipping and pollution from microplastics.

Methods

The CW goal score is calculated as the geometric mean of its two components: **Shipping traffic**, used here as a proxy for chemical pollution, and **marine litter**. They are not intended to be a comprehensive list of pollution categories but are the ones for which we obtained data sets.

The reference point is when the pollution level is zero for all components.

The current status of this goal, x_{cw}, was calculated as the geometric mean of the two components (Eq. 2.3.1.1, so that:

$$x_{cw} = \sqrt[2]{l * d}, \quad \text{(Eq.2.3.1.1)}$$

where l = 1 – (chemical input derived from shipping traffic), rescaled at the raster level by the 99.99th quantile value; and d = 1 – (marine litter), rescaled at the grid level by the 99.99th quantile value.

The state of marine pollution (due to shipping) and microplastics at the level of the entire Atlantic is calculated with a geometric mean if both l and d are positive (l>0 and d>0), or if l or d are zero, the original value is taken.

Marine Traffic

Chemical pollution was measured as marine pollution from commercial shipping and ports. The data originates from the Global Maritime Traffic Density Service (IMF's World Seaborne Trade Monitoring System - Cerdeiro, Komaromi, Liu and Saeed, 2020).

The shipping data were converted to a resolution of 1 km^2 and, due to the extreme skewness of the data, converted to ln(x+1) using the 99.99^{th} quantile over all years/cells as the scaling value (Avg 19-23: 99.99% = 6.31). The trend is calculated on the basis of the 2014 value, which describes the annual proportional change in shipping traffic compared to 2014.

The Figure 2.3.1.1 highlights the main shipping routes, especially in the North Atlantic, and shows the main economically important routes between North America, Europe, and parts of Africa and South America (especially Brazil), while traffic in the Southern Ocean is lower. Overall, the trend is increasing compared to 2014 for the entire basin (+16%), showing a net increase in vessel density. The share of this component in the overall target is 45 %.

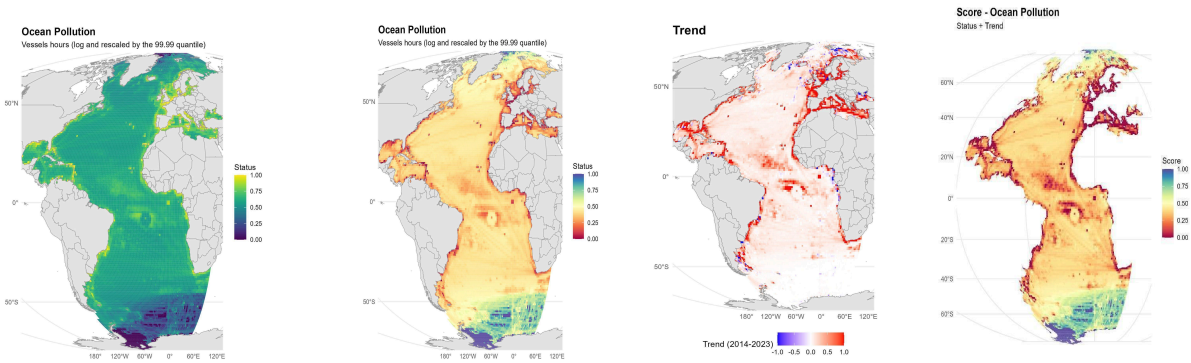


Figure 2.3.1.1: A) Data of vessels hours percentile; B) Data transformed per log(x+1) and rescaled based on the 99.99th ;C) Trend calculated on the data of 2014; D) Results of the score for ocean pollution (status + trend)

Marine debris

The status of litter pollution is estimated based on the modeled microplastic concentrations. The microplastic layer is calculated from the global predictions of monthly surface microplastic concentrations (Poli et al., 2023) (in #items.km-2, log10-transformed) modeled with five distribution models (GLM, GAM, ANN, RF, GBM), taking into account environmental and anthropogenic predictive factors. The models were trained using an observational dataset combining measurements from several microplastic sampling campaigns. The plastic particles range from 32 µm to 20 cm; concentration measurements were collected by van Sebille et al. (2015) using different sampling methods (~83 % were from plankton nets) and complemented by Schmiz (2021). To compensate for some of the stochasticity of the density data and in particular the fluctuation due to COVID-19, five years of data are used to create the grid for each year (e.g. for the 2023 grid, the average values for shipping from 2018 to 2023 are calculated). The reference is the absence of pollution.

The data on microplastics are represented by the modeled distribution of particles per km^2. These data were converted to 1 degree spatial resolution, log(x+1) transformed and rescaled by the 99.99th quantile to reduce the influence of extreme values. The results show that the largest proportion of microplastic mass is located at the sea surface, particularly in the North and Southern Oceans at around +-40° latitude and in the Mediterranean Sea.

No time-series data were available to assess trends. The average pressure score for the entire Atlantic basin, based on microplastic pollution is 43%.

Results

The geometric mean of the two components of the goal results is 35% of the entire Atlantic. The coastal areas have the lowest score, mainly due to the high traffic pressure, but the high seas also have a low average score due to the widespread distribution of microplastics.

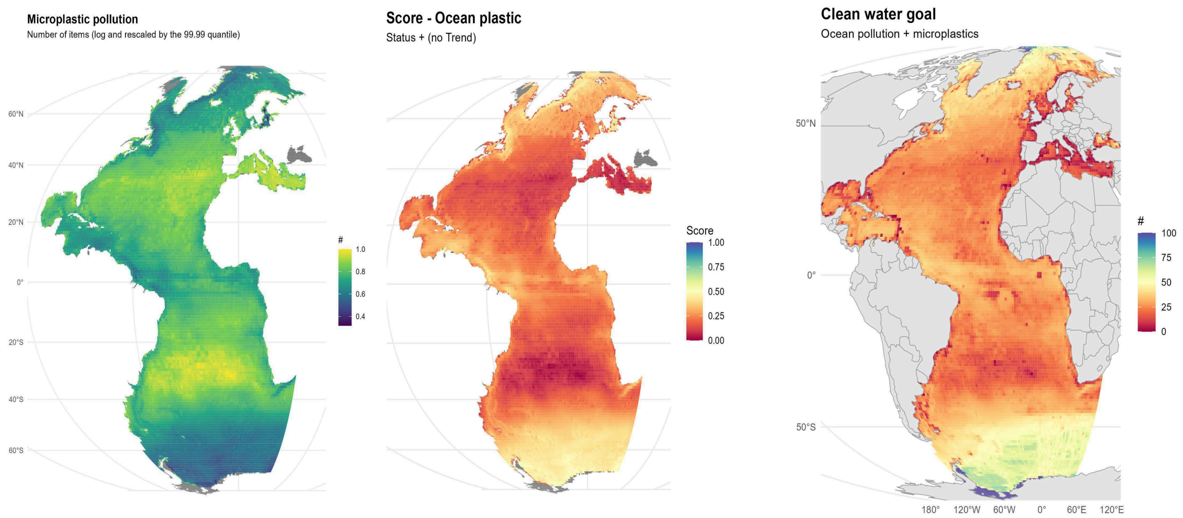


Figure 2.3.1.2. A) Microplastic distribution based on the number of items log+1 and rescaled by the 99.99th quantile. B) Score calculated only for the ocean debris. C) Final score of the Clean water goal assessed using the Marine traffic and marine debris layers

Table 2.3.1.1. Results of the Clean Waters goal for the Atlantic.

	Status	Trend	Likelifuture status (Status + Trend)	Score
CW – Marine trash	0.53	0.16	0.43	(status + Lkl)/2
CW - Ocean pollution	0.47	0.16 [0.43]	0.45	
SCORE				34.66

2.3.2. Carbon storage

Scope and introduction

Carbon sequestration is an important ecosystem service for climate regulation. The ocean plays a crucial role in mitigating climate change through carbon flux and sequestration processes involving both coastal and deep-sea ecosystems. The process of carbon flux refers to the transfer of carbon mass per unit area and time. In the open ocean, this vertical flux includes downward export by gravity, ocean mixing and migration, known as the Biological Carbon Pump (BCP). In coastal ecosystems, the Blue Carbon Ecosystems (BCE), it is linked to the Carbon Accumulation Rate (CAR), which reflects the rate of carbon stored in long-turnover pools, typically in the first meter of sediment where remineralization is minimal.

Coastal areas, with their sedimentary deposits and vegetation, have disproportionately high carbon sequestration rates per unit area compared to the open ocean. However, the current status is assessed using reference values based on estimates from the 1980s. The total contribution of oceanic compartments exceeds that of coastal ecosystems by two orders of magnitude due to their enormous spatial extent. The novelty of this work is the introduction of carbon sequestration at the open ocean scale, including the activity of the biological carbon pump. The results of both methods are reported in the analysis, and when both ecosystems are present, the contributions of both are summed at 1-degree resolution.

Methods

The BCE carbon sequestration service is based on the accumulation rate, which is specific to each coastal habitat and area extent. To assess the carbon accumulation rate at the Atlantic scale, we converted the areal extent of each BCE using the median carbon accumulation rate (CAR) (gC m-2 yr-1) for each habitat (Chen & Lee 2022b), according to Equation 2.3.2.1..

$$C_{CAR} = A_i * CAR_i \quad \text{(Eq.2.3.2.1)}$$

where: A is the extent of habitat i in km^2, and w is the carbon accumulation rate (CAR) per habitat i in ($gC\ m^{-2}\ yr^{-1}$) as in Table 1. Considering the high variability of the CAR depending on the study site, we have used the median value as assessed by Mackanzie et al., 2019.

The area is calculated from the spatial extent of mangroves, salt marshes, tidal flats (2014-2016), and seagrass meadows habitat derived from the Ocean Data Viewer of the United Nations Environment Program - World Conservation Monitoring Center UNEP-WCMC (https://data.unep-wcmc.org) on the most recent data available. Furthermore, data on extension of mangroves (last assessment 2020) were downloaded from the website Global Mangrove Watch (https://www.globalmangrovewatch.org), which provides remote sensing data and tools for monitoring mangroves.

At the oceanic level, the carbon flux is calculated as the POC flux at 1000 m being a good proxy for Csoft at or near equilibrium, i.e. for an ocean with minimal disturbance, which is a reliable prediction of the impact of POC on carbon sequestration. The input data are the mean of the monthly average from the historical simulations (1995-2014) of 3 Earth System Models (ESM), which are part of the Coupled Model Intercomparison Project Phase 6 (CMIP6; Eyring et al., 2016): GFDL-ESM4 (Dunne et al., 2020), IPSL-CM6A-LR (Boucher et al., 2020), MPI-ESM1-2-HR (Mauritsen et al., 2019).

The reference values for the two cases are the 1984 value for the BCE, as given in the literature as a reference value (Jennerjahn et al., 2020), and the 1850-1979 value for the BCP (CMIP6 model output). For the BCE, the reference values were calculated as follows based on the annual loss rates of 1984 (Equation 2.3.2.2):

$$Flux_{past} = \frac{Flux_{pres}}{(1-r)^{t}}, \qquad \text{(Eq.2.3.2.2)}$$

Where, $Flux_{past}$ is the value of the flux in the 1984, $Flux_{pres}$ is the flux value in the present, r is the fractional rate of loss (e.g., 0.07 for 7% loss per year) and t is the number of years between the past and present measurements. The final score is calculated as the sum for each cell of the contributor in flux of both BCE and BCP, as follows (Equation 2.3.2.3):

$$x_{CS} = \sum_{i=1}^{N} \left(\frac{FluxBCE_{pres}}{FluxBCE_{past}} + \frac{FluxBCP_{pres}}{FluxBCP_{past}}\right), \qquad \text{(Eq.2.3.2.3)}$$

Results

The carbon flux (TgC y^{-1}) for both the BCE and the oceanic BCP is assessed at 1 degree for all the Atlantic Ocean.

The Carbon Storage score for the Atlantic basin is 91 (on a scale from 0 to 100), reflecting a high level of performance. This value is primarily driven by the open-ocean component (BCP), which shows a current status of 0.936, while the coastal component (BCE) has a lower status of 0.405 due to historical habitat loss. No trend or resilience data were included, so the score reflects current conditions only.

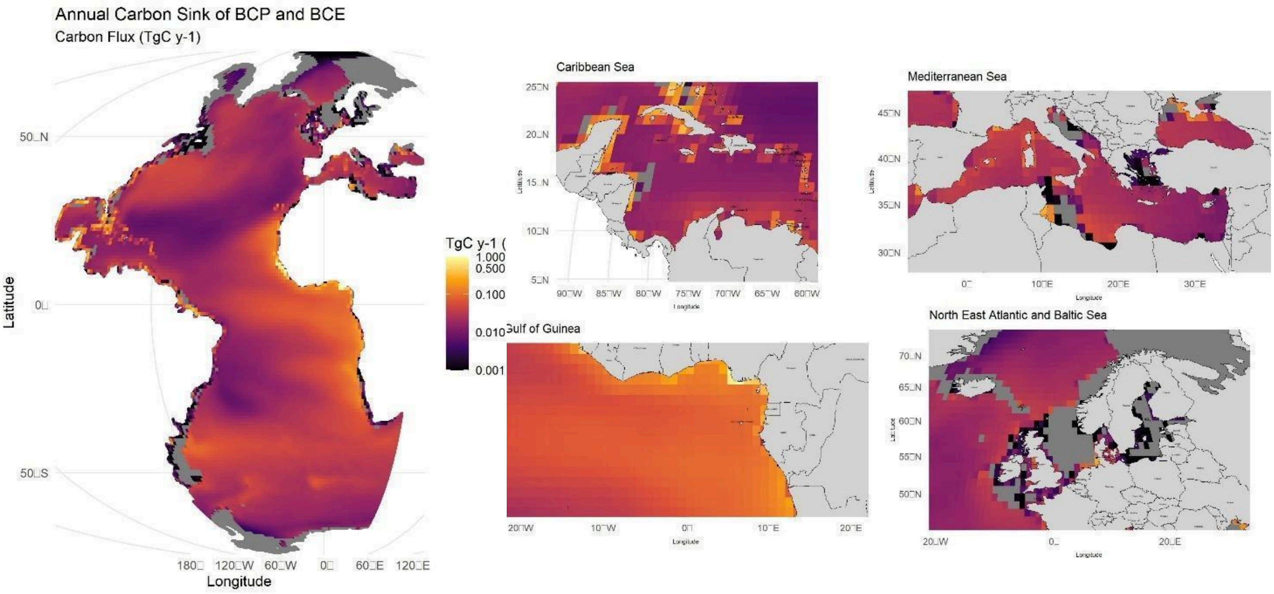


Figure 2.3.2.1. POCFLUX1000m: Poc flux at 1000m (TgCy-1) as the *sum of both the BCE and BCP components of the carbon flux. For BCE the carbon flux is calculated as the CAR *area; In the BCP the spatial distribution is the transfer efficiency of POC at 1000m. Detailed pictures of the Carbon flux rate (TgC y-1) including BCE and BCP : A)Caribbean sea, B) Mediterranean Sea, C)Gulf of Guinea, D) North Sea.*

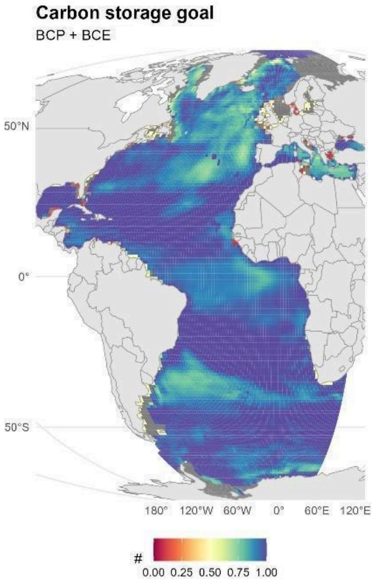


Figure 2.3.2.2. SCORECS: Status score for CS goal

Table 2.3.2.1. Results of the calculation of the Carbon Storage goal for the Atlantic.

	Status	Trend	Likelifuture status (Status + Trend)	Score (status + Lkl)/2
CS BCP	0.936	-	-	
CS BCE	0.405	-	-	
SCORE	0.91	-	-	91

Discussion

The results illustrate how the difference between coastal and marine ecosystems in their function as carbon reservoirs has changed in recent decades. In particular, the result for coastal ecosystems is strongly affected by the high rate of habitat loss affecting these habitats globally (CIT).

On the other hand, oceanic ecosystems have improved their POC flux, mainly due to increased atmospheric CO_2 concentrations over the last century. However, this is not necessarily a positive ecological feedback, mainly due to the potential disadvantages that this achievement could bring to ecosystems, especially in the deep sea (e.g. ocean acidification).

Consequently, when assessing this objective, especially for the oceanic components, it is urgent to include the components of the pressure layers in the final assessment.

2.3.3. Food provisioning – Wild fisheries

Scope and Introduction

Current status: Fishing leads to high mortality of marine resources with impacts on the structure and functioning of marine ecosystems beyond individual species' depletion. Formal stock assessments provide information on the status of individual species, but they are limited and never cover all species exploited in mixed fisheries. Therefore, an assessment of the status of the exploited ecosystem as a whole can be made by combining the complex catches for an area under comparison with the potential fisheries yield that can be sustained by primary production.

In this work, we calculate the footprint of global multitarget fisheries for the Atlantic Ocean and compare it to net primary production to quantify an index of fisheries ecosystem sustainability at a spatial resolution of 1 degree. The analysis uses fishery yields by country and species for the last six years obtained from the Sea Around Us database (2013-2018) at ½ degree spatial resolution (Zeller et al., 2018), as well as monthly estimates of net primary production (NPP) provided by the Copernicus Marine Service at 1/4 degree resolution (Table 2.3.3.1)..

The yield data can be used to estimate the footprint of global fisheries for each grid cell of the Atlantic Ocean (Pauly and Christensen, 1995), which are spatially averaged based on the movement potential of the species. The calculated indicator is the primary production requirement (PPR) of each species group, taking into account their trophic level and transfer efficiency. This fishery footprint (PPR) is compared to the potential energy to support the fishery yield, represented by the NPP, to determine the sustainability level of exploitation at a spatial resolution of 1 degree for the Atlantic Ocean. This hypothesis is based on the concept that in a healthy marine ecosystem, PPR should be in balance with NPP.

The ecosystem overfishing index makes it possible to identify hotspots of unsustainable fishing pressure and areas where yield potential is not fully exploited. Application to the Atlantic allows confirmation of the results with the cumulative stock status derived from the assessments in the RamLegacy database (Hilborn et al., 2020). The approach is used as a preliminary step for the determination of the health status of the Atlantic Ocean (Halpern et al., 2012).

Table 2.3.3.1. Data used to calculate the Wild fisheries subgoal of the Atlantic.

Product name & type	Documentation

GLOBAL_MULTIYEAR_BGC_001_029 *Reanalysis*	PUM: https://catalogue.marine.copernicus.eu/documents/PUM/CMEMS-GLO-PUM-001-029.pdf QUID: http://marine.copernicus.eu/documents/PUM/CMEMS-GLO-QUID001-029.pdf
SEA AROUND US DATA (dataset on catches reconstructed by country, species and by fishing area for artisanal and industrial fisheries worldwide)	Pauly D., Zeller D., Palomares M.L.D. (Editors), 2020. Sea Around Us Concepts, Design and Data (https://seaaroundus.org).
RAM Legacy Stock Assessment Database (dataset on results of stock assessments conducted all over the world; results are reported in terms of time series of indicators of exploitation)	RAM Legacy Stock Assessment Database. (2021). Extended RAM Legacy Stock Assessment Database version 4.495 (v4.495) [Data set]. Zenodo. https://doi.org/10.5281/zenodo.5709081

Methods

The concept of Primary Production Required (PPR) is based on the fact that an exploited species requires a minimum amount of organic energy to sustain its population. At each trophic level, only a portion of the energy consumed (after accounting for metabolic costs) is converted to the growth of the individual or population. The proportion of energy used for growth is called transfer efficiency. This efficiency is influenced by various factors, such as the energy spent on hunting, metabolic costs and the organism's ability to assimilate organic carbon from food. Thus, the PPR is the amount of primary production required to produce 1 unit of production at each TL (Pauly & Christensen, 1995). Therefore, the calculation of PPR requires an understanding of the trophic level of the species and assumptions about the efficiency of energy transfer at different trophic levels. To account for these factors, Pauly and Christensen (1995) estimate the PPR required to support a given wet weight catch (WWC) for a species at a given trophic level using the following formula (Equation 2.3.3.1):

$$PPR = \frac{WWC}{WTD} \cdot \left(\frac{1}{TE}\right)^{TL-1}, \qquad \text{(Eq.2.3.3.1)}$$

which was based on a conservative wet weight catch to dry weight carbon conversion (WTC) of 1:9 (Strathmann, 1967), a mean trophic efficiency (TE) and estimates of trophic levels (TL) based on diet composition. The transfer efficiency (TE) is the fraction of energy transferred from one trophic level to the next, typically ranges between **0.1** and 0.2 in aquatic ecosystems (Pauly & Christensen 1995) depending on ecosystem type and trophic structure. Coastal systems may have higher TE than oceanic systems. The depth layer is from CMEMS, specifically from the same product used to calculate the NPP (global model output- GLOBAL_MULTIYEAR_BGC_001_029). Therefore, if the depth is between 0 and 250 mt, is used the TE of 0.14; if the depth is larger than 250 mt 0.1 TE value is used.

The trophic level of a species (TLs) represents the position of the species in the food web, which results from the composition of the diet and ranges from about 2 (herbivores) to 4.5–5 (apex predators). The trophic level is taken from the FishBase repository (Froese and Pauly, 2008) and if a general aggregation of catches is reported, a value of 3 is used.

Wet weight is derived from catch data from the SAUP database (Pauly et al., 2020), which contains catches of artisanal and industrial fisheries reconstructed by country, species, and fishing area for the years 2013-2018 and covers the Atlantic Ocean at ½ degree resolution.

Net primary productivity represents the total primary production available in the ecosystem after accounting for autotrophic respiration. The data are taken from the CMEMS database and are given as an annual average integrated over the entire water column (mgC m^{-3} day^{-1}). The CMEMS product GLOBAL_MULTIYEAR_BGC_001_029 is used to calculate the integrated net primary production.

We resample the two layers of PPR and NPP in order to match the same spatial resolution of 1 degree.

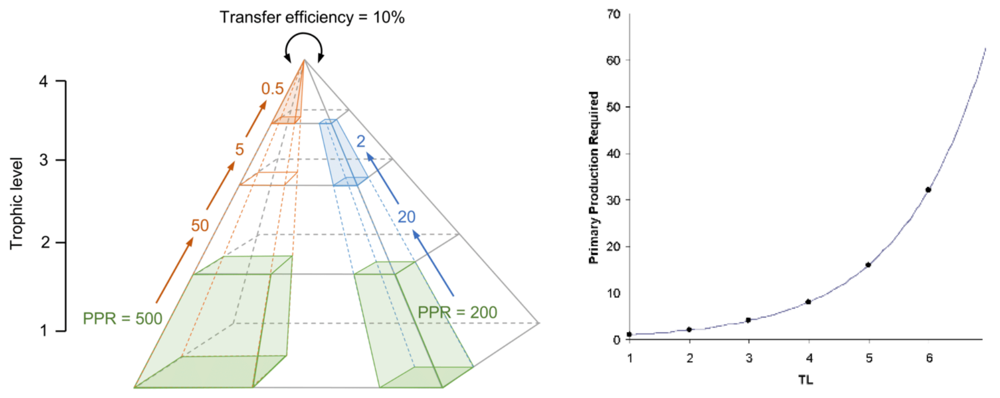


Figure 2.3.3.1. GRAPH: Representation of the transfer efficiency across

The measures of PPR/NPP show how much primary production is needed to support the fish yield (SAUP catch data) for each specific cell, (x,y), species (s), and time (t) (Equation 2.3.3.2):

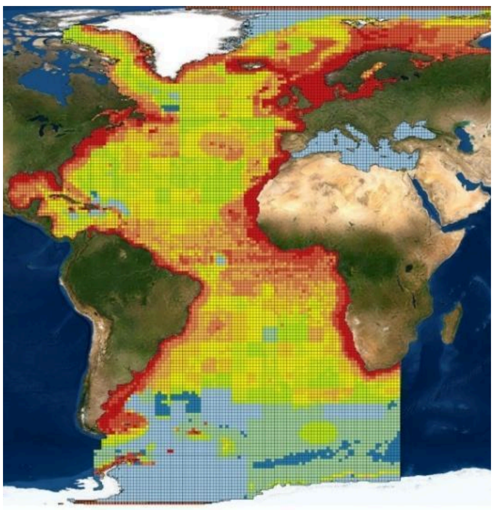
$$PPR_{(x,y,s,t)} = Yield_{(x,y,s,t)} \cdot \left(\frac{1}{TE}\right)^{TL-1},$$

(Eq.2.3.3.2)

The status for the wild-fish production is calculated, at 1 degree resolution over the Atlantic Ocean as Equation 2.3.3.3:

$$xfis = 1 - PPR_{(x,y,t)}/NPP_{(x,y,t)}, \qquad \text{(Eq.2.3.3.3)}$$

When xfis is low (closer to or 0), the index shows bad status of the wild-fisheries catches, while on the other ends, high value shows a system in good status.



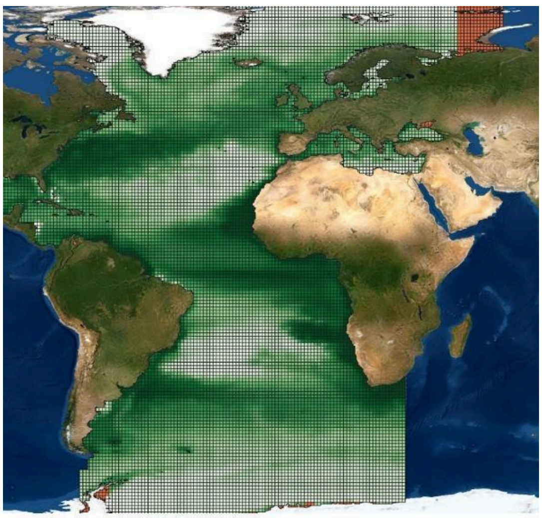


Figure 2.3.3.2. A: SeaAroundUs (SAUP) dataset of catch reconstructed data by country, by taxa (ton/year) at high resolution (0.5x0.5 degree) (ton $cell^{-1}$ $year^{-1}$). Net Primary Production from CMEMS products (various including model simulated, reanalysis with data assimilation of Chla, satellite derived NPP) 0.25x0.25 degree. Originally: mgC m^{-3} day^{-1}

The indicator used to assess the fisheries goal is calculated as the ratio between the PPR x,y and the NPP x,y in each cell of the domain and transformed by log(x+1).

Results

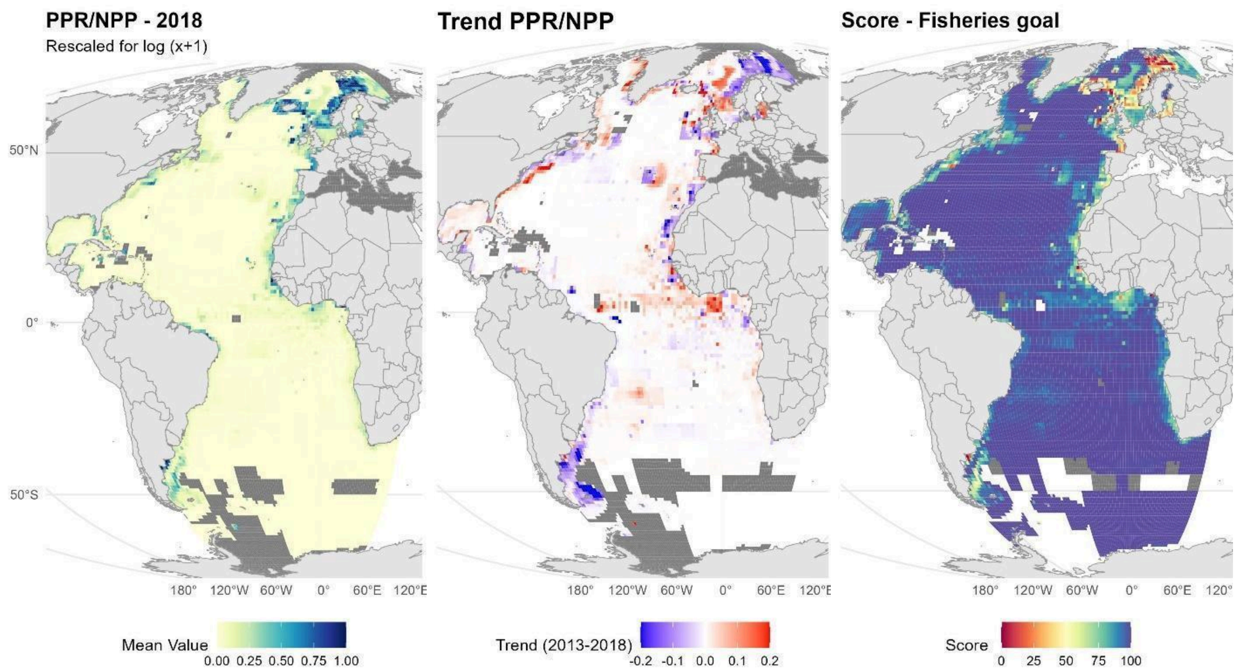


Figure 2.3.3.3: A) Assessment of the state of the fishery using the PPR/NPP index. The value is log(x+1)-transformed; B) Trend analysis to assess the likelihood future. The trend is calculated by first determining the regression coefficient of the data over the time-series available (2013-2018). This coefficient is then adjusted by normalizing it based on the value of the last year of data. The final adjusted trend value is then multiplied by 5. C) Score analysis of the fisheries goal. The status is 1-xfis. Note that the legend differs between the plots.

This hypothesis is based on the concept that in a healthy marine ecosystem the PPR should be in balance with the NPP. If the PPR exceeds the NPP, this could indicate that the ecosystem is overfished or that the energy available to the fishery is insufficient to sustain current populations. This is theoretically unsustainable as no yields would be possible if PPR >> NPP, but this is a bias in the model as stock movements in the study areas are not taken into account. If the NPP is greater than the PPR, the ecosystem may be able to support a healthy fish population, suggesting an ecosystem in good condition.

Table 2.3.3.2. Results of the calculation of the Fisheries sub-goal for the Atlantic.

	Status	Trend	Likelifuture status (Status + Trend)	Score(status + Lkl)/2
FIS	0.93	0.01	0.94	93.76

2.3.4. Biodiversity

Scope and introduction

Biodiversity at the Atlantic scale is assessed on the basis of plankton diversity, measured as species richness. Plankton biodiversity is a key component of marine pelagic ecosystems. They form the basis of the food web, control the productivity of marine ecosystems and provide numerous ecological provisioning and regulating services. The data, derived from the work of Benedetti et al. (2021, 2023), were derived from an ensemble of species distribution models comprising 860 plankton species (336 phytoplankton, 524 zooplankton) from 13 phyla, 71 orders and 324 genera. These models determine the current habitat range of each species, from which the alpha diversity or species richness (SR) is calculated.

Methods

The data is a monthly resolved 1° x 1° grid that excludes observations from regions where the seafloor is shallower than 200 m and covers the period 2012–2031.

The model for the status of the biodiversity goal, x_{BD}, is described in Equation 2.3.4.1:

$$x_{BD} = \frac{BD}{BD_{90th}} \quad \text{(Eq.2.3.4.1)}$$

where, BD_{90th} is the BD value of the study site value that corresponds to the 90th quantile, due to the absence of data relative to pristine conditions, (e.g. before the industrial period).

The trend assessment takes into account the changes in the future projection for the period 2081–2100, in which phytoplankton species richness will increase by more than 16 % in most regions except the Arctic Ocean, while zooplankton richness will decrease slightly in the tropics but increase strongly in temperate to subpolar latitudes. At these latitudes, almost 40 % of the phytoplankton and zooplankton communities will be replaced by species moving towards the poles.

Results

The study predicts a strong latitudinal gradient in plankton species richness (SR), with a decrease in SR from the equator to the poles (Figure 2.3.4.1). This pattern results from the combined contributions of phytoplankton and zooplankton.

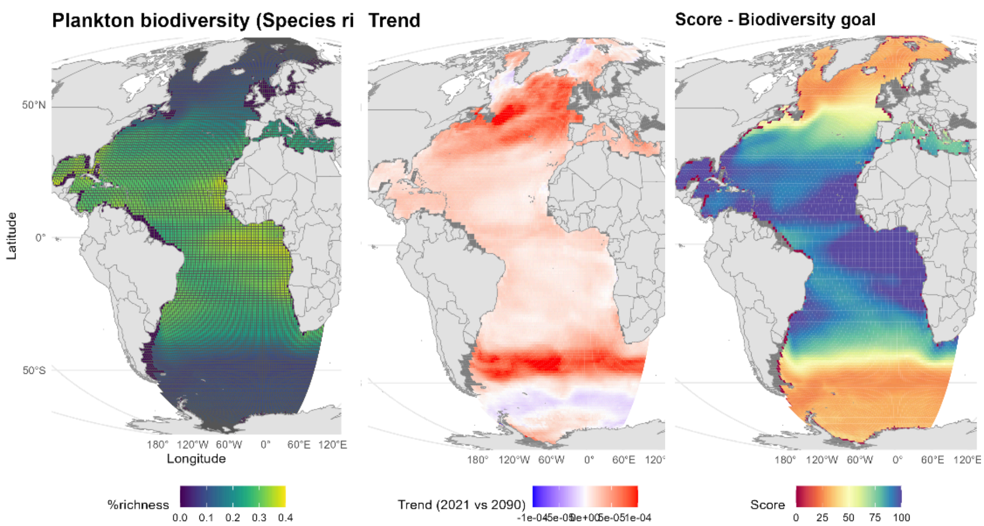


Figure 2.3.4.1: The annual mean species richness for all 860 phyto- and zooplankton species modeled at 1 degree resolution. B) Trend calculated as linear regression based on future projections for the period 2080-2100), and C) Final score for the Biodiversity goal (as average between Status and Likelifuture status).

Table 2.3.4.1. Results of the calculation of the goal Biodiversity for the Atlantic.

	Status	Trend	Likelifuture status (Status + Trend)	Score(status + Lkl)/2
BD	0.57	4.716e-07	57.07	57.07

Discussion

The results confirm a strong latitudinal gradient with a higher species richness in equatorial and tropical regions and a decline towards the poles. This pattern is consistent with previous findings that temperature is a major factor in plankton biodiversity, as it influences metabolic rates, growth and dispersal (Benedetti et al., 2021). The trend, which was calculated using linear regression based on future projections, illustrates possible changes in plankton diversity over time. Although the analysis is not statistically significant, it suggests a decline in species richness in certain regions due to warming-induced habitat shifts, while other areas may see a localized increase. The final biodiversity score integrates both the current biodiversity status and the projected trend and provides a comprehensive assessment of the biodiversity target. This score is the average between the normalized current species richness (status) and the likelihood of future status.

2.3.5. Pressures

Marine heat waves

Scope and introduction

Extreme events such as marine heatwaves (Hobday et al., 2016) are associated with a range of negative impacts on marine organisms and ecosystems (Cavole et al., 2016; Smale et al., 2019; Smith et al., 2023; Wernberg et al., 2013, 2016), including the collapse of entire ecosystems (e.g. Wernberg, 2021).

Quantifying the intensity and frequency of MHWs is crucial for assessing their cumulative hazard over time. In this study, an integrated index combining MHW intensity and frequency is introduced and rescaled to a standardized range using the 99.99th quantile.

MHWs have various impacts on many goals, from biodiversity to provisioning services (Smale et al., 2019, Cheung and Froelicher, 2020), and indirect impacts on the carbon storage goal due to the degradation of BCE such as seagrass beds (Marba and Duarte, 2010; Thomson et al., 2015).

The goal of CW is influenced by MHW, as MHW can cause surface water warming and increased stratification, which can lead to a concentration of microplastics in certain areas (Haque and Fan, 2023). Warmer temperatures during marine heat waves can accelerate the decomposition of larger plastic debris into smaller microplastics (Lincoln et al., 2022), a process known as photodegradation, which increases the concentration in the water column.

Methods

MHWs are determined based on the approach proposed by Hobday et al. (2016), which defines MHWs as events in which the SST exceeds the 90th percentile of the historical climatology for at least five consecutive days.

The occurrence of marine heat waves (MHWs) is calculated based on the climatological baseline (1982-2011), from which we derived the frequency and intensity of MHWs following the approach of Hodaby (et al., 2016).

The MHW intensity indicates how much the SST exceeds the 90th quantile threshold at a given location (defined as SST exceedance above the 90th quantile threshold) and the MHW frequency (between 0 and 1, where 1 means that all days in the period are an MHW day). To capture both the severity and persistence of MHWs, we define an integrated index as the product of MHW intensity and MHW frequency. We then rescale the data to values between 0 and 1 by dividing each cell value by the 99.99th quantile of all products, so that 1 represents the most extreme MHW conditions (Equation 2.3.5.1:

$$\text{IndexMHW}_{x,y} = \frac{Intensity_{x,y} * Frequency_{x,y}}{99.99^{th}\ quantile}, \qquad \text{(Eq.2.3.5.1)}$$

The data originate from the CMEMS satellite observation (https://data.marine.copernicus.eu/product/SST_GLO_SST_L4_REP_OBSERVATIONS_010_024/description)

for the years 2003-2022, taking into account the climatological mean from 1982-2011. In addition, the data from the CMIP6 models (GFDL-ESM4, IPSL-CM6A-LR, MPI-ESM1-2-HR) are taken into account to assess the current status and future changes.

Results

All four panels (Figure 2.3.5.1: MHW) show higher MHW index values in the northern hemisphere, especially in the North Atlantic and on the east coast of North America.

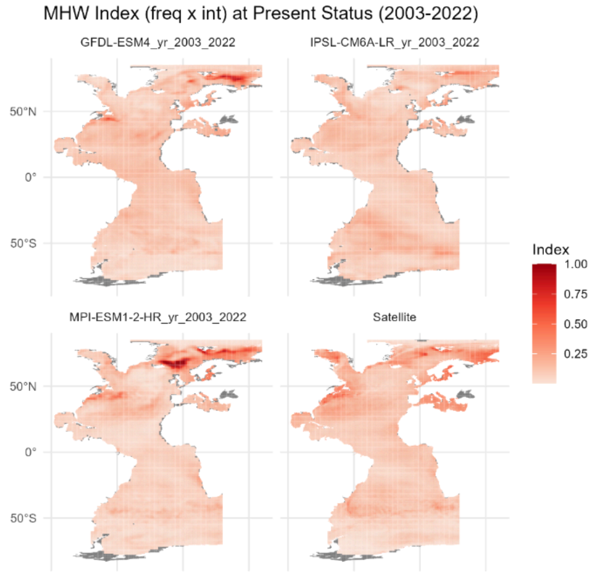


*Figure 2.3.5.1. MHW: **Marine Heatwave (MHW) Index** (computed as **frequency × intensity and normalized by the 90th quantile**) for different climate models and satellite observations over the period **2003–2022**.*

3. Integrated calculation of OHI at the regional level: Southern Benguela

3.1. Background

The Ocean Health Index (OHI) is an assessment used to evaluate ocean health by measuring the sustainable delivery of benefits and services that people rely on from healthy oceans, including food provision, cultural and social significance, and economic opportunities (https://oceanhealthindex.org). The OHI was originally developed by Halpern et al. (2012), to assess global ocean health, and since then, the global OHI assessment has been repeated every year. The OHI is composed of four dimensions (status, trend, pressures and resilience) which are derived from a wide range of data. The combination of these dimensions indicates the current status and likely future condition for each of ten goals. The OHI framework can be tailored to different spatial scales and can accommodate a range of contexts and values. This is possible because the core framework of how goals are scored does not change while the goal models can be adapted to accommodate the data available for the local assessment. In this section, we are focusing on the tailored assessment of the OHI+ to the southern Benguela South Africa study site (SA-BEN).

The southern Benguela, together with the northern Benguela, form the Benguela Current Large Marine Ecosystem (BCLME), one of the four major upwelling systems on the eastern border. The selection of study areas also includes the Agulhas Bank on the southern coast of South Africa, which is closely linked to the southern Benguela upwelling system by robust oceanographic and ecological processes (Bornmann et al., 2024) (Figure 3.1.1). The area, a highly productive marine ecosystem, encompasses the west and south coasts of South Africa, where the cold, nutrient-rich, upwelled waters support most of South Africa's major commercial fisheries, including large-scale pelagic and demersal offshore fisheries, as well as commercially valuable inshore, spiny lobster and abalone fisheries (Blamely et al., 2015).

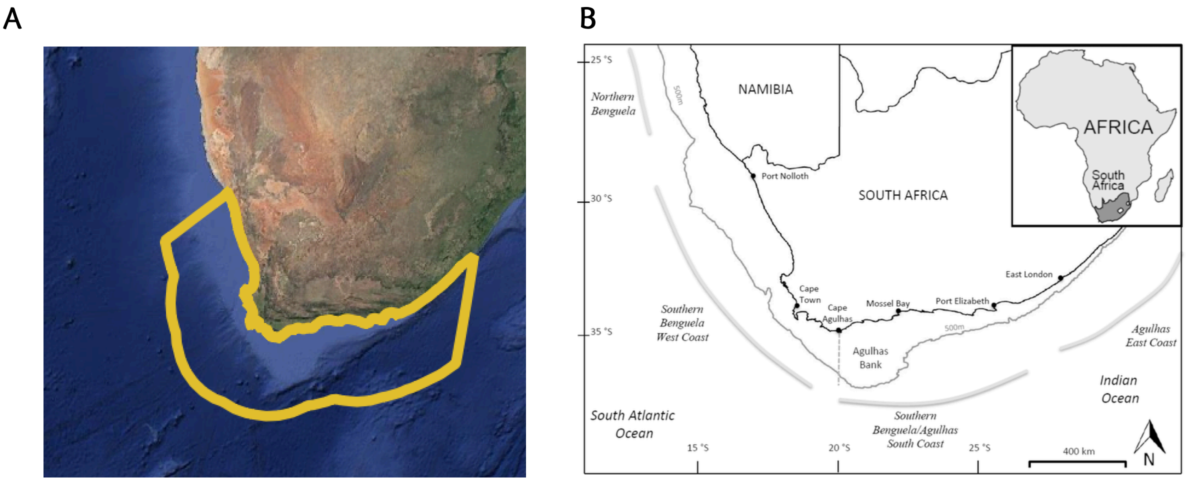


Figure 3.1.1: A) Study area of Southern Benguela and Agulhas Bank. B) The southern Benguela with west and south coasts divided at Cape Agulhas (Watermeyer et al., 2016).

The aim of the work is to provide a tool to synthesize many different layers of information in order to get synthetic indicators useful to assess the status of the marine ecosystem of SA-BEN and the provisioning of ecosystem services.

3.2. Methods and Results

For the calculation of the OHI+ – Southern Benguela, the methodology described by Halpern et al, (2012) was followed and applied on the most updated data accessible. The reference OHI toolbox can be found in GitHub OHI-Science global preparation (https://github.com/OHI-Science). However, some equations were modified according to the data available. The approach used and eventual modifications of the equations introduced for the OHI+ - Southern Benguela (SA-BEN) are described in each goal. The data used for this assessment were obtained from national reports and a literature review and are summarized in Table 3.2.1. The analyses were carried out using R software.

Table 3.2.1. Synthesis table with all the data used in the calculation of the OHI – Benguela.

Goal	Subgoal	Reference	Data	Units	Spatial resolution	Temporal Resolution	Reference
SSFO (Small-scale fishing opportunities)		Understanding Drivers of Fishing Pressure in South Africa's Western Cape: Development of a First Set of	Social vulnerability indicators	Population Composition, Poverty, Personal Disruption, Labour			Gammage, LC., Jarre, A., Jarre, IC., & Ward, C. 2023. Understanding Drivers of

		Social Vulnerability Indicators for Comparability Around the Atlantic Ocean		Market Status, Housing, Retiree Migration			Fishing Pressure in South Africa's Western Cape.
BD (Biodiversity)	SPP (Species)	National Biodiversity Assessment 2018 – SANBI IUCN red list of Threatened Species	Extent of habitats Risk status (IUCN classification)	Km^2 CR EN VU NT LC	Vector data at high resolution Global assessment	2018	https://bgis.sanbi.org https://www.iucnredlist.org
	HAB (Habitat)	National Biodiversity Assessment 2018 – SANBI	Extent	Km^2	1:3000 to 1:50 000	1896-2018	https://bgis.sanbi.org
CS (Carbon Storage)		Ocean Data Viewer – UNEP-WCMC Literature review	Habitat extent Carbon accumulation rate CAR	Km^2	tidal marsh: 30 m seagrass: 1:1,000,000 saltmarsh: Between 1:10,000 to 1:4,000,000 (largely 1:10,000 - 1:100,000)	tidal flat: 1984 – 2016 seagrass: 1934 – 2020 salt marshes: 1973 - 2015	https://data.unep-wcmc.org Adams (2016) Chen and Lee (2022)
CW (Clean waters)		National Guidance For Plastic Pollution Hotspotting and Shaping Action Final Report for South Africa	Plastic pollution leakage in marine waters	Tonnes		2020	IUCN-EA-QUANTIS (2020). National Guidance for Plastic Pollution Hotspotting and Shaping Action: Country Report South Africa (updated, April 2021)
CP (Coastal protection)		Ocean Data Viewer – UNEP-WCMC	Habitat extent	Km^2	tidal marsh: 30 m	tidal flat: 1984 – 2016	https://data.unep-wcmc.org Adams (2016)

		Literature review	Carbon accumulation rate CAR		seagrass: 1:1,000,000 saltmarsh: Between 1:10,000 to 1:4,000,000 (largely 1:10,000 - 1:100,000)	seagrass: 1934 – 2020 salt marshes: 1973 - 2015	Chen and Lee (2022)
SP (Sense of place)	ICO (Iconic species)	IUCN red list of Threatened Species	Risk status (IUCN classification)	CR EN VU NT LC			https://www.iucnredlist.org
	LSP (Lasting special places)	The World Database on Protected Areas (WDPA) Marine protected areas South Africa	Extent of MPA Year of establishment	Km^2 Year		1964 - 2019	https://www.marineprotectedareas.org.za/ https://data-gis.unep-wcmc.org/portal/home/item.html?id=1919c32890074ce5a589a1a99b48994b
TR (Tourism and recreation)		Experimental Biodiversity-Based Tourism Estimates - StatsSA	Proportion of employees directly involved in Biodiversity Based Tourism			2013 - 2019	https://www.statssa.gov.za
NP (Natural products)		FAO software FishStatJ, global aquatic trade - South Africa - Quantities and Values - 2019-2022 Sea Around Us SAU Status of the South African marine fishery resources 2023.	Quantity and value Quantity, B/bmsy	Tonnes USD Tonnes		2019-2022 2015-2019	https://www.fao.org/fishery/en/collection/global_commodity_prod https://www.seaaroundus.org/ https://www.dffe.gov.za/sites/default/files/reports/research/fisheries/statusofsouthafrican_marinefi

							sheryresources2023.pdf
FP (Food production)	FIS (Fisheries)	Sea Around Us SAU Department of Forestry, Fisheries and the Environment (DFFE) of South Africa. Fisheries data were provided by the South African Department of Forestry and Fisheries (DFFE) through PAIA request No. PAIA23868 RAM Legacy Stock Assessment Database 2021 Status of the South African marine fishery resources 2023.	Quantity, B/bmsy BMSY BMSY	Tonnes		2015-2019	https://www.seaaroundus.org/ https://www.dffe.gov.za https://www.re3data.org/repository/r3d100012095 https://www.dffe.gov.za/sites/default/files/reports/research/fisheries/statusofsouthafrican_marinefisheryresources2023.pdf
	MAR (Mariculture)	FAO software FishStatJ, production source, aquaculture production SASSI Sustainability index	Quantity	Tonnes		2018-2022	https://www.fao.org/fishery/en/collection/global_production https://wwfsassi.co.za/sassi-list/
LE (Livelihoods and economies)	LIV (Livelihoods)	Project Phakisa	Number of jobs in BE sectors GDP contribution	Jobs, 000 GDP South African Rand (R) Billion (B)		2013-2018	https://www.operationphakisa.gov.za/Pages/Home.aspx

	ECO (Economies)	Project Phakisa	GDP contribution	GDP South African Rand (R) Billion (B)		2013-2018	https://www.operationphakisa.gov.za/Pages/Home.aspx

3.2.1. Artisanal Fishing Opportunities/ Small Scale Fishing Opportunities (SSFO)

Scope and introduction

Although in the original assessment the goal is called Artisanal Fishing Opportunities (AO), in this study the goal is called Small Scale Fishing Opportunities (SSFO). The objective of the SSFO goal is to assess the opportunity to conduct sustainable artisanal-scale fishing when the need is present, rather than the actual amount of catch or household revenue that is generated.

Methods

For the calculation of the SSFO goal, the approach developed by Gammage et al. (2023) derived from the TRIATLAS project (https://triatlas.w.uib.no) was applied. The goal focuses on 63 areas representing a subset of southern Benguela (SB) that were considered as a good proxy for the status of the region. In this analysis, the communities that have scored a medium to high reliance for fishing regarding economic and/or social-cultural importance in the social vulnerability component (Gammage et al., 2023) were taken into account (table 3.2.1.1), the data resolution is maintained and the scale/aggregation was not changed. As the final result is a single score, each community was rescaled based on the goal calculation. Therefore, a high level of detail is retained in the data that makes up the final score.

Table 3.2.1.1. List of communities assessed in the SSFO goal.

Local Municipality	Community
Swartland	Yzerfontein
Saldanha Bay	Stofbergsfontein (Small Area 0159)
Saldanha Bay	Langebaan
Saldanha Bay	Blue Water Bay
Saldanha Bay	Parker's Town
Saldanha Bay	Saldanha SP
Saldanha Bay	White City
Saldanha Bay	Diazville
Saldanha Bay	Jacob's Bay
Saldanha Bay	Paternoster
Saldanha Bay	Britannia Bay
Saldanha Bay	Shelly Point
Saldanha Bay	Stompneusbaai
Saldanha Bay	Columbine
Saldanha Bay	Sandy Point
Saldanha Bay	Steenbergs Cove
Saldanha Bay	West Point
Saldanha Bay	Laingville
Bergrivier	Laaiplek
Bergrivier	Noordhoek (Velddrif)
Cederberg	Elands Bay
Cederberg	Lamberts Bay (incl Malkopbaai)
Matzikama	Doring Baai
Matzikama	Strandfontein (Matzikama)
Matzikama	Papendorp (Small Area 008)
Cape Aghulhas	Arniston

Cape Aghulhas	Struisbaai
Cape Aghulhas	Agulhas
Overstrand	Pearly Beach (Small Area 0044)
Overstrand	Eluxolweni (Small Area 0075)
Overstrand	Franskraalstrand
Overstrand	Van Dyksbaai
Overstrand	GansBaai (incl Blompark & Masakhane)
Overstrand	De Kelders
Overstrand	Hermanus (incl Westdene)
Overstrand	Fernkloof
Overstrand	Mount Pleasant
Overstrand	Hawston
Overstrand	Fisherhaven
Overstrand	Kleinmond
Overstrand	Betty's Bay
Overstrand	Pringle Bay
Bitou	Nature's Valley
Bitou	Plettenberg Bay (excl Pine Tree)
Bitou	Pine Tree
Bitou	Knysna (excl Hornless & Xolweni)
Bitou	Hornlee
Bitou	Xolweni
Knysna	Sedgefield
George	Kleinkrantz
George	Wilderness Heights
George	Touwsranten
George	Wilderness SP

Mossel bay	Groot Brak River
Mossel bay	Klein Brak River
Mossel bay	Hartenbos
Mossel bay	Mossel bay
Hessequa	Gouritsmond
Hessequa	Stilbaai
Hessequa	Melkhoutfontein
Hessequa	Groot Jongensfontein
Hessequa	Vermaaklikheid (Small Area 175031)
Hessequa	Port Beaufort (incl Witsand)

The SSFO goal is composed of two components that were equally weighted:

- social vulnerability index
- gentrification index

Three indices were developed to assess the social vulnerability component in relation to fishing dependence: Personal Disruption, Population Composition, and Poverty. The Personal Disruption Index captures barriers to employment such as poverty, unemployment, lack of education, and disability. The Population Composition Index reflects demographic factors linked to vulnerability, including the presence of young children, female-headed households, non-English speakers, and racial inequalities. The Poverty Index quantifies reliance on social assistance and household income below the upper-bound poverty line, distinguishing between working-age and retired household heads. These indicators collectively highlight the socio-economic drivers of vulnerability in coastal communities.

Three indices were developed to assess the social vulnerability component related to gentrification and mobility in coastal communities: Labour Market Status, Housing Characteristics, and Retiree Migration. These indices capture structural pressures from demographic shifts, rising property values, and displacement linked to urbanisation and retiree influx. Gentrification threatens the sustainability of fishing communities by altering labour dynamics, housing access, and community composition. Higher index scores indicate greater vulnerability to displacement and socio-economic disruption. Data limitations constrained indicator selection, but the indices provide a critical lens for understanding how external development pressures impact traditional coastal livelihoods.

Data containing socio-economic indicators at the community level derived from Gammage et al. (2023) are presented in Appendix 1. To ensure comparability across indicators measured on different scales, each value was normalized to a unit interval [0, 1]. Min-max normalization was applied to each value x, transforming it as Equation 3.2.1.1:

$$x' = \frac{x - min(x)}{max\,(x) - min\,(x)} \qquad \text{(Eq. 3.2.1.1)}$$

This normalization method preserves the distribution of each variable while rescaling values so that 0 corresponds to the minimum observed value and 1 to the maximum.

For each community, an index was calculated by averaging the normalized scores across the six indicators according to Equation 3.2.1.2:

$$I_i = \frac{1}{n} \sum_{j=1}^{n} x'_{ij} \qquad \text{(Eq. 3.2.1.2)}$$

where:

- x'_{ij} is the normalized value of indicator *j* for community *i*
- *n* = 6 is the number of indicators (Population Composition, Poverty, Personal Disruption, Labour Market Status, Housing, Retiree Migration)

The current status of the SSFO across all communities was calculated as the mean of the individual indices according to Equation 3.2.1.3:

$$x_{SSFO} = \frac{1}{m} \sum_{i=1}^{m} I_i \qquad \text{(Eq. 3.2.1.3)}$$

where:

- *m* is the number of communities.

As the fishing cooperatives were only recently established (2022), and they are the primary source of data, it is not possible to assess the trend for the SSFO goal due to the absence of time-series data. Therefore, the score of the SSFO goal is equal to the current status.

Results

The normalized indicators from the 63 communities representing SA-BEN and the calculated individual indices are presented in table 3.2.1.2.

Table 3.2.1.2. Normalized indicators per community and individual index.

Municipality	Community	Population Composition	Poverty	Personal Disruption	Labour Market Status	Housing	Retiree Migration	Index
Swartland	Yzerfontein	0.260309278	0.251322751	0.37963	0.135065	0.087931	0.535980149	0.27504
Saldanha Bay	Stofbergsfontein (Small Area 0159)	0.448453608	0.542328042	0.52037	0.332468	0.368966	0.158808933	0.395232
Saldanha Bay	Langebaan	0.510309278	0.296296296	0.418519	0.303896	0.077586	0.270471464	0.312846
Saldanha Bay	Blue Water Bay	0.337628866	0.19047619	0.342593	0.161039	0.048276	0.138957816	0.203162
Saldanha Bay	Parker's Town	0.18556701	0.216931217	0.35	0.158442	0	0.203473945	0.185736
Saldanha Bay	Saldanha SP	0.430412371	0.243386243	0.372222	0.184416	0.062069	0.143920596	0.239404
Saldanha Bay	White City	0.845360825	0.507936508	0.540741	0.594805	0.160345	0.106699752	0.459315
Saldanha Bay	Diazville	0.904639175	0.724867725	0.67037	0.81039	0.403448	0.044665012	0.593063
Saldanha Bay	Jacob's Bay	0.265463918	0.17989418	0.196296	0.109091	0.041379	0.253101737	0.174204
Saldanha Bay	Paternoster	0.778350515	0.645502646	0.52963	0.522078	0.17069	0.114143921	0.460066
Saldanha Bay	Britannia Bay	0.347938144	0.224867725	0.272222	0.293506	0.084483	0.58560794	0.301438
Saldanha Bay	Shelly Point	0.265463918	0.074074074	0.296296	0.184416	0.075862	0.600496278	0.249435
Saldanha Bay	Stompneusbaai	0.721649485	0.489417989	0.472222	0.345455	0.082759	0.081885856	0.365565
Saldanha Bay	Columbine	0.574742268	0.285714286	0.307407	0.174026	0.151724	0.196029777	0.281607
Saldanha Bay	Sandy Point	0.394329897	0.394179894	0.564815	0.368831	0.317241	0.188585608	0.37133

Saldanha Bay	Steenbergs Cove	0.806701031	0.404761905	0.546296	0.524675	0.206897	0.114143921	0.433913
Saldanha Bay	West Point	0.427835052	0.095238095	0.414815	0.044156	0.186207	0.248138958	0.236065
Saldanha Bay	Laingville	0.922680412	0.761904762	0.753704	0.857143	0.177586	0.049627792	0.587108
Bergrivier	Laaiplek	0.365979381	0.166666667	0.388889	0.083117	0.101724	0.35483871	0.243536
Bergrivier	Noordhoek (Velddrif)	0.894329897	0.666666667	0.694444	0.675325	0.253448	0.086848635	0.545177
Cederberg	Elands Bay	0.806701031	0.703703704	0.85	0.737662	0.256897	0.138957816	0.58232
Cederberg	Lamberts Bay (incl Malkopbaai)	0.783505155	0.478835979	0.537037	0.511688	0.196552	0.210918114	0.453089
Matzikama	Doring Baai	0.845360825	0.457671958	0.625926	0.685714	0.275862	0.17369727	0.510705
Matzikama	Strandfontein (Matzikama)	0.582474227	0.507936508	0.438889	0.394805	0.315517	0.196029777	0.405942
Matzikama	Papendorp (Small Area 008)	0.860824742	0.711640212	0.740741	0.828571	0.263793	0.188585608	0.599026
Cape Aghulhas	Arniston	0.672680412	0.624338624	0.675926	0.67013	0.186207	0.203473945	0.505459
Cape Aghulhas	Struisbaai	0.520618557	0.439153439	0.527778	0.45974	0.222414	0.35235732	0.420344
Cape Aghulhas	Agulhas	0.291237113	0	0.231481	0	0.131034	0.687344913	0.223516
Overstrand	Pearly Beach (Small Area 0044)	0.25	0.076719577	0.292593	0.25974	0.112069	0.771712159	0.293806
Overstrand	Eluxolweni (Small Area 0075)	0.621134021	0.978835979	0.97037	1	1	0	0.761723
Overstrand	Franskraalstrand	0.25257732	0.031746032	0.331481	0.12987	0.101724	0.687344913	0.255791
Overstrand	Van Dyksbaai	0.409793814	0.142857143	0.337037	0.290909	0.148276	0.665012407	0.332314

Overstrand	GansBaai (incl Blompark & Masakhane)	0.654639175	0.764550265	0.701852	0.753247	0.484483	0.084367246	0.573856
Overstrand	De Kelders	0.291237113	0.079365079	0.248148	0.202597	0.098276	0.637717122	0.259557
Overstrand	Hermanus (incl Westdene)	0.304123711	0.103174603	0.292593	0.179221	0.101724	0.744416873	0.287542
Overstrand	Fernkloof	0	0.19047619	0.292593	0.119481	0.056897	0.620347395	0.213299
Overstrand	Mount Pleasant	0.737113402	0.645502646	0.568519	0.605195	0.174138	0.089330025	0.469966
Overstrand	Hawston	0.726804124	0.563492063	0.596296	0.690909	0.193103	0.114143921	0.480791
Overstrand	Fisherhaven	0.195876289	0.132275132	0.351852	0.218182	0.053448	0.573200993	0.254139
Overstrand	Kleinmond	0.569587629	0.560846561	0.598148	0.732468	0.453448	0.379652605	0.549025
Overstrand	Betty's Bay	0.229381443	0.145502646	0.385185	0.314286	0.091379	0.58808933	0.292304
Overstrand	Pringle Bay	0.146907216	0.195767196	0.35	0.293506	0.089655	0.58808933	0.277321
Bitou	Nature's Valley	0.492268041	0.182539683	0.344444	0.12987	0.118966	0.563275434	0.305227
Bitou	Plettenberg Bay (excl Pine Tree)	0.175257732	0.246031746	0.381481	0.244156	0.141379	0.330024814	0.253055
Bitou	Pine Tree	0.190721649	0.211640212	0.340741	0.18961	0.106897	0.538461538	0.263012
Bitou	Knysna (excl Hornless & Xolweni)	0.863402062	0.492063492	0.557407	0.498701	0.153448	0.099255583	0.444046
Bitou	Hornlee	0.706185567	0.534391534	0.637037	0.522078	0.415517	0.183622829	0.499805
Bitou	Xolweni	0.87371134	1	1	0.838961	0.77069	0.009925558	0.748881
Knysna	Sedgefield	0.56185567	0.351851852	0.492593	0.332468	0.331034	0.342431762	0.402039
George	Kleinkrantz	0.56443299	0.436507937	0.55	0.412987	0.387931	0.215880893	0.427957

George	Wilderness Heights	0.082474227	0.412698413	0.357407	0.236364	0.310345	0.709677419	0.351494
George	Touwsranten	1	0.46031746	0.716667	0.716883	0.553448	0.076923077	0.587373
George	Wilderness SP	0.182989691	0.158730159	0.342593	0.145455	0.118966	0.496277916	0.240835
Mossel bay	Groot Brak River	0.742268041	0.425925926	0.474074	0.379221	0.225862	0.330024814	0.429563
Mossel bay	Klein Brak River	0.484536082	0.222222222	0.368519	0.220779	0.286207	0.518610422	0.350146
Mossel bay	Hartenbos	0.507731959	0.208994709	0.414815	0.197403	0.118966	0.459057072	0.317828
Mossel bay	Mossel bay	0.641752577	0.322751323	0.481481	0.288312	0.144828	0.297766749	0.362815
Hessequa	Gouritsmond	0.541237113	0.452380952	0.598148	0.47013	0.110345	0.367245658	0.423248
Hessequa	Stilbaai	0.324742268	0.063492063	0.225926	0.114286	0.122414	0.848635236	0.283249
Hessequa	Melkhoutfontein	0.68556701	0.505291005	0.538889	0.363636	0.327586	0.086848635	0.41797
Hessequa	Groot Jongensfontein	0.291237113	0.058201058	0	0.075325	0.127586	1	0.258725
Hessequa	Vermaaklikheid (Small Area 175031)	0.512886598	0.558201058	0.633333	0.342857	0.57069	0.23573201	0.475617
Hessequa	Port Beaufort (incl Witsand)	0.213917526	0.076719577	0.231481	0.023377	0.12069	0.615384615	0.213595

Results of the calculation of the SSFO goal are presented in table 3.2.1.3.

Table 3.2.1.3. Results of the calculation of the goal SSFO.

Status	Trend	Score
0.4	/	0.4

Discussion

The status of the SSFO goal is 0.4 indicating moderate to low level of opportunity for sustainable small-scale fishing across the assessed communities. These results suggest that the opportunity for engaging in small-scale fishing is present but constrained by social, economic, or structural barriers such as poverty, unemployment, or demographic vulnerabilities that can impede fishing opportunities. Additionally, rising property values, demographic shifts (e.g., influx of retirees), and related structural changes may be displacing traditional fishers or limiting community stability and access to resources.

3.2.2. Biodiversity – Habitats (BD-HAB)

The goal biodiversity (BD) assesses the conservation status of species through two sub-goals: species (SPP) and habitats (HAB).

Scope and introduction

The objective of the BD-HAB subgoal is to measure the average condition of marine ecosystems that provide habitat for a broad range of species. Data on the extent and status of marine and estuarine habitats from SANBI's 2018 National Biodiversity Assessment were used to calculate the BD-HAB subgoal (https://bgis.sanbi.org). Data from the 2011 National Biodiversity Assessment was used as the past situation to calculate the trend. The reference point for the BD-HAB subgoal is the risk status "Least Concern" (LC = 1.0) for all habitats.

Methods

According to the classification in the NBA 2018 report, a total of 150 marine ecosystem types (in this study called habitats) are grouped into 14 broad ecosystem groups (Figure 3.2.2.1). As the ecosystems classification of the NBA 2018 differs considerably from the ecosystems classification from the NBA 2011 (used to calculate the trend), a synthetic new classification map was created to make both datasets comparable. This new classification contains the so-called macro-categories (Figure 3.2.2.2 and Table 3.2.2.1) and it was done based on similarities between the marine ecosystem types (habitats) of the NBA 2018 and NBA 2011 datasets. .

To calculate the BD-HAB subgoal, the weighted status of each macro-category is first calculated as the product of the status of each habitat within a macro-category, multiplied by its area within the macro-category, divided by the total area of the macro-category (Eq. 3.2.2.1)

$$Ws = \frac{\sum x \cdot a}{A} , \qquad \text{(Eq. 3.2.2.1)}$$

where:

- *x* is the status of each habitat within each macro-category
- *a* is the area of the habitat within each macro-category

- A is the total area of each macro category

Then, the BD-HAB subgoal is calculated as follows (Eq. 3.2.2.2) :

$$X\,hab = \frac{\sum \frac{Ws}{Cr}}{N} \quad , \qquad \text{(Eq. 3.2.2.2)}$$

where:

- W_s is the weighted status of each macro category
- C_r is the reference status = 1
- N is the total number of macro categories

Results

The habitats selected for the calculation of this subgoal are based on SANBI's 2018 NBA classification (Figure 3.2.2.1) and have been designated as macro-categories (Table 3.2.2.1 and Figure 3.2.2.2). The macro-categories were selected based on similarities between the areas and their ecosystems. The aim of this classification was to compare with the NBA 2011 SANBI classification map.

A total of seven macro-categories with a total area of 982,076.7 km^2 were analysed (Table 3.2.2.1). The SANBI dataset contains the status of each habitat. The results of the calculation of the subgoal are described in the table 3.2.2.2. The weights range from 1 (abyss and seamounts) to 0.4 (islands) and reflect the weighted status of each macro-category. This weighting ensures that all macro-categories are given equal importance, despite variations in their sizes, preventing larger areas from disproportionately influencing the results.

The status is calculated as the average of the statuses of the individual macro-categories classified in this study.

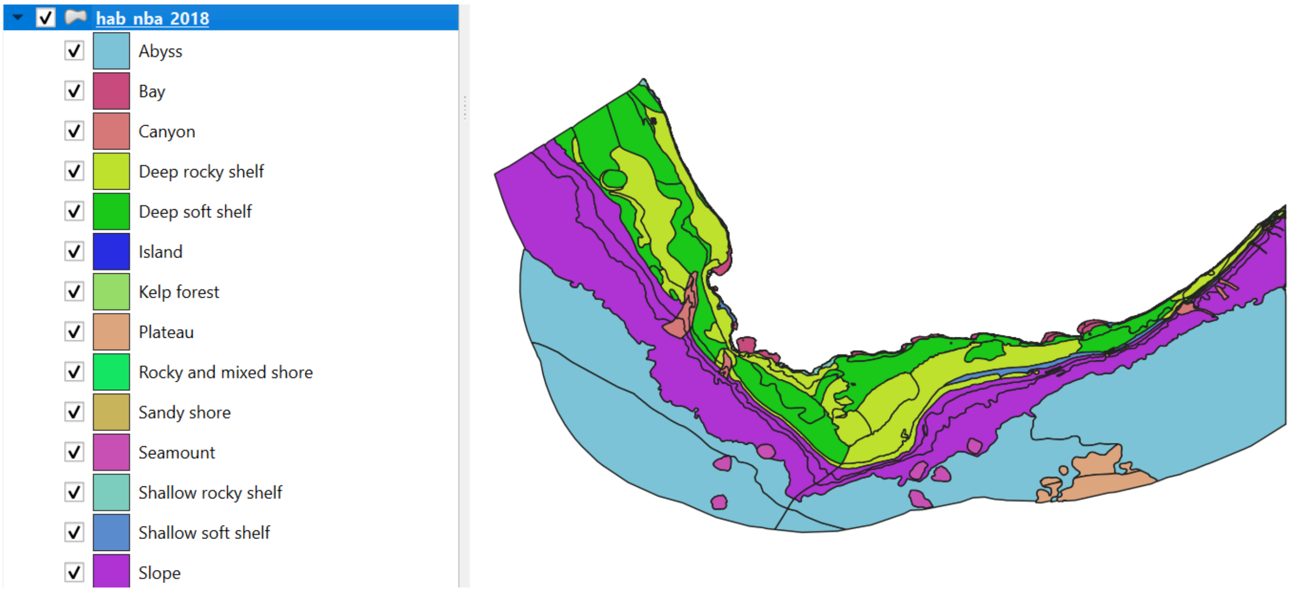


Figure 3.2.2.1. Division of habitats in SA-BEN region by Broad Ecosystem according to NBA 2018 SANBI classification.

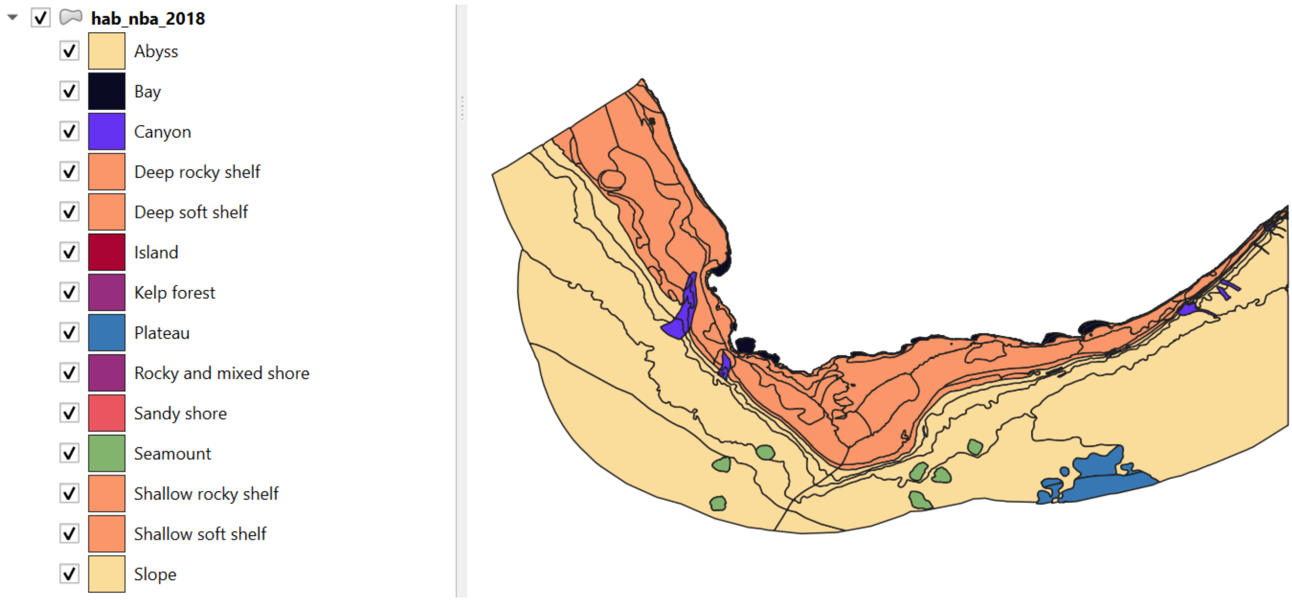


Figure 3.2.2.2. Division of macro-categories in SA-BEN region classified in this study. Broad ecosystems with the same color (left side) indicate that they are aggregated in the same macro-category.

Table 3.2.2.1. Classification of the macro-categories used in this study and their status according to the SANBI assessment.

Macro-categories (this study)	Habitats (SANBI, 2018)	Extent (km^2) (SANBI 2018)	Weighted status 2018 (this study)	Status 2018 (this study)	Habitats (SANBI, 2011)	Extent (km^2) (SANBI, 2011)	Weighted status 2011 (this study)	Status 2011 (this study)
Rocky and mixed shore	Kelp forest, rocky and mixed shore	443.14	0.6	Vulnerable	Mixed coast, rocky coast	712.2	0.6	Vulnerable
Island	Island	9.25	0.5	Vulnerable	Island	2,143.3	0.4	Endangered
Abyss	Abyss, plateau, slope	758,133.2	1.0	Least concerned	Unconsolidated deepsea	520,952.8	0.8	Near threatened
Seamount	Seamount	6,150.9	1.0	Least concerned	Seamount	5,290.7	0.8	Near threatened
Sandy shore	Sandy shore	225.8	0.9	Least concerned	Harbour, sandy coast	458.73	0.8	Near threatened
Canyon	Canyon	7,734.8	0.8	Near treated	Rocky shelf edge	2,004.7	0.2	Critical risk
Shelf	Deep rocky shelf, deep soft shelf, shallow rocky shelf, shallow soft shelf	209,379.6	0.9	Least concerned	Inshore reefs, rocky shelf, rocky shelf edge, unconsolidated inshore, unconsolidated shelf, unconsolidated shelf edge	215,685.3	0.7	Near threatened
Total		**982,076.7**				**747,247.7**		

The trend is assessed by calculating the status of the year 2011 (using the data of the NBA 2011 report) following the same methodology to keep consistency, then a linear regression is done between the status of 2011 and 2018, then the slope is multiplied by 5 to predict the future likelihood in the next 5 years.

Table 3.2.2.2. Results of the calculation of the subgoal BD-HAB.

Status	Trend	Score
0.8	0.1	0.7

Discussion

The status of the subgoal BD-HAB is 0.8 indicating a good level of status of the marine ecosystems in SA-BEN. This contrasts with the results provided by NBA 2018 SANBI which reports that 50% of the marine ecosystem types are threatened (Sink et al., 2019). However, the NBA 2018 SANBI reports the whole marine area of SA, and this study only takes into account the Southern Benguela region. The trend for the subgoal BD-HAB based on 2011 and 2018 status is -0.65, indicating a slight decline in the level of status of the marine ecosystems: this trend is considered a projected situation for the next five years. The trend results.depend mainly on the improvement of the macro-categories Canyon, whose status changes from 0.2 (critical risk) to 0.8 (near-threatened), Shelf, whose status changes from 0.7 (near-threatened) to 0.9 (least concern), Sandy Shore, whose status changes from 0.8 (Near Threatened) to 0.9 (Least Concern), Seamount, whose status changes from 0.8 (Near Threatened) to 1.0 (Least Concern), and Abyss, whose status changes from 0.8 (Near Threatened) to 1.0 (Least Concern). Only the macro-category Rocks and Mixed Shores remained at Vulnerable status.

3.2.3. Biodiversity – Species (BD-SPP)

Scope and introduction

The objective of the BD-SPP subgoal is to assess the average condition of the marine and estuarine species based on IUCN status.

Methods

The data used to calculate this subgoal was the area occupied by each species within a 0.5 degree cell bounded within the study area (Appendix 2) and the risk status of marine and estuarine species from the IUCN red list database (https://www.iucnredlist.org). The spatial distribution data are taken from SANBI 2018. The reference point is the risk status "Least Concern" (LC = 1.0). To calculate the trend, a linear regression was performed taking into account the two years of assessment, then multiplying the slope by 5 to estimate the future likelihood in the next five years.

The BD-SPP subgoal is calculated as follows (Eq. 3.2.3.1):

$$\bar{R}_{spp} = \frac{\sum_{c=1}^{M}\left(\sum_{i=1}^{N_c} w_i\right) \times A_c}{\sum_{c=1}^{M} A_c \times N_c} , \qquad \text{(Eq. 3.2.3.1.)}$$

Where:

- W_i is the risk status of the cell i
- A_c is the area of cell in a 0.5 grid
- N_c is the total number of species in a cell
-

In this study, w is considered as the risk status of the cell, which is assessed by multiplying the status of each species within a cell by the area that the species occupies within the cell divided by the total area of the cell (Eq. 3.2.3.2.):

$$w = \sum\left(\frac{s\ x\ a}{A}\right), \qquad \text{(Eq. 3.2.3.2)}$$

where:

- s is the status of each species within a cell
- a is the area that each species occupies within a cell
- A is the total area of the cell

In this way, the status risk for species takes into account the spatial distribution of species more accurately and is less influenced by the cell resolution used.

Due to the fact that not all the species assessed in this study had a historical record of risk status in the IUCN Red list, only those species who had historical records were taken into account for the calculation of the trend (Appendix 3).

Following the original approach of Halpern et al. (2012), to convert R_{spp} into a score, we set a floor at 25% (representing a catastrophic loss of biodiversity) and then rescaled to produce a x_{spp} value between zero and one (Eq. 3.2.3.3).

$$x_{spp} = max\left(\frac{\bar{R}_{SPP} - .25}{.75}, 0\right) , \qquad \text{(Eq. 3.2.3.3)}$$

To incorporate phytoplankton into the assessment, the final score of the BD-SPP subgoal was averaged with the phytoplankton score derived for the Atlantic case study (score = 0.9). The SA-BEN phytoplankton score was extracted from the OHI Atlantic assessment (section 2.3.4) (Figure 3.2.3.1).

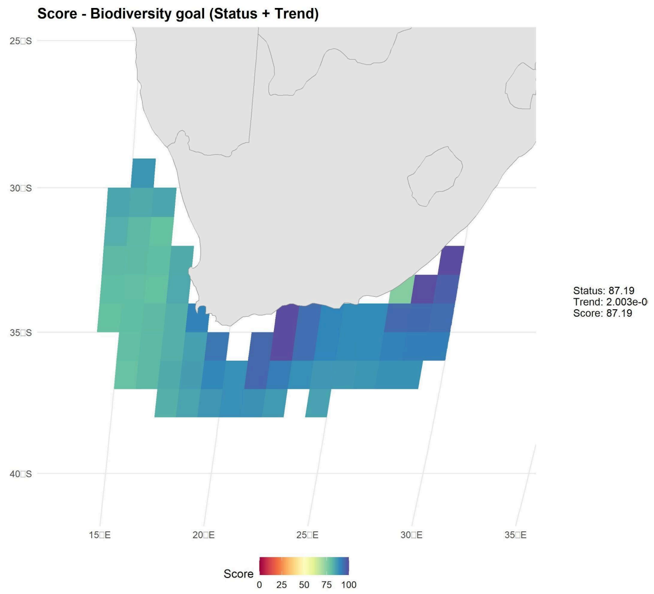


Figure 3.2.3.1: Score of the phytoplankton for SA-BEN, extracted from the OHI Atlantic assessment.

Results

The total number of species analyzed in this study was 357 (Appendix 3) encompassing marine and estuary species (including sea birds), and the total number of cells in the grid was 354. The number of grid-cells is important for the calculation of the subgoal, as it is necessary to know the number of species and their area by cell. Results of the calculation of the subgoal BD-SPP are described in Table 3.2.3.1.

Table 3.2.3.1. Results of the calculation of the subgoal BD-SPP.

Status	Trend	Score
0.9	0.2	1.0

Discussion

The status of the subgoal BD-SPP is 0.9 indicating a good level of status of the marine species in SA-BEN. This result is aligned with the data gathered, as from the 367 species assessed, 264 are Least concerned, and 27 are Near threatened, which constitutes 80% of the total of species assessed in this study. The trend is 0.2 which indicates a slight increase in the good level of risk status for marine species foreseen for the next five years. This slight increase was expected as from the 99 species assessed in the trend, 11 increased the risk category to LC in the recent assessment. All the rest remained in the status of LC. It is important to note that in this study, the coefficient w was calculated differently from the original assessment, which could result in a different outcome if the original methodology had been used, since in the original assessment the coefficient w is based on the IUCN risk categories.

3.2.4. Carbon Storage (CS)

Scope and introduction

The CS goal refers to the sequestration of carbon in coastal habitats, the so-called blue carbon ecosystems (BCE). The objective of this goal is to measure the ability of coastal habitats to sequester carbon from the atmosphere, helping mitigate the impact of climate change. To assess the goal we refer to the carbon flux meaning the transfer of carbon mass per unit area and time. There are three habitats in the SA-BEN study site that are considered main contributors to blue carbon sequestration: salt marshes, tidal flats, and seagrasses (Figure 3.2.4.1).

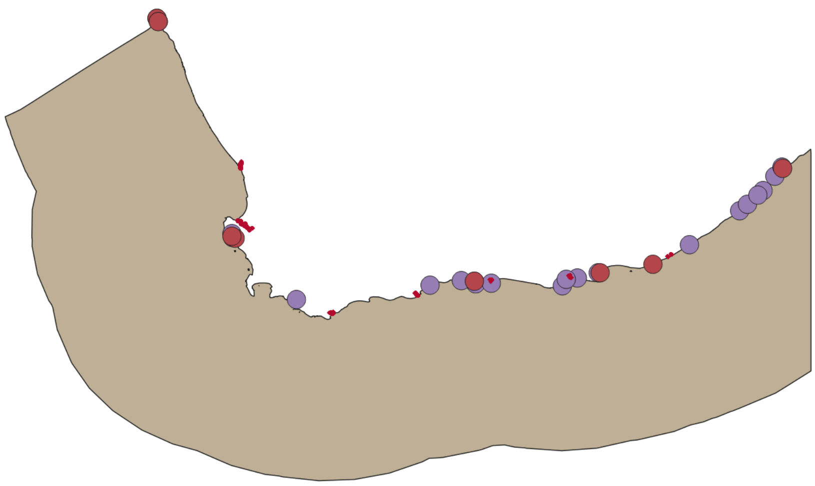


Figure 3.2.4.1 Distribution map of the three habitats assessed in the CS goal. Red points and polygons represent salt marshes, purple points represent seagrasses. Tidal flats are too small that cannot be appreciated in the map.

Methods

The data used to calculate the CS goal is the extent in km^2 of each habitat in km^2, from UNEP-WCMC (Murray et al., 2022; UNEP-WCMC, Short FT, 2021; Mcowen C, et al 2017), validated by literature review (Adams 2016). The earliest available data we had was for tidal flats in 1984. Therefore, we used this year as the baseline for the reference extent of other habitats as well, assuming a percentage of annual loss estimated through literature (e.g., 2% annual loss for salt marshes (Adams et al., 2021); 7% yearly loss of seagrass (Waycott et al., 2009); 0.5% yearly loss of tidal flat (Murray et al., 2019). To calculate the trend, a linear regression was calculated taking into account the most recent extent and the extent of the previous five years, then multiplying the result by 5 to estimate the future likelihood in the next five years. The data refers to the years 2015 for salt marshes, 2020 for seagrasses, and 2016 for tidal flats.

The CS goal is calculated as follows (Eq. 3.2.4.1):

$$x_{cs} = \frac{\sum_{k=1}^{N} (h_k \times w_k \times A_k)}{\sum_{k=1}^{N} (w_k \times A_k)} ,$$ (Eq. 3.2.4.1)

- W_k is the coefficient that describes the relative contribution of each habitat to total carbon sequestration (Chen and Lee 2022). The coefficient W_k refers to the carbon accumulation rate (CAR) which estimates the quantity of carbon that is transferred by unit of area (m^2) and time (year) (i.e. the CAR is therefore a flux).
- A_k is the area of the habitat in km^2

and where h is calculated as (Eq. 3.2.4.2):

$$h = \frac{C_c}{C_r} ,$$ (Eq. 3.2.4.2)

- C_c is current condition of the habitat, calculated as the current extent of the habitat in km^2
- C_r is the reference condition of the habitat, calculated as the estimate of the extent in km^2 of previous years assuming a % of yearly loss for each habitat.

Results

The three habitats analyzed in the CS goal cover a total area of 232.55 km^2 in the assessment year (2018). The habitat with the largest extent is tidal flat, and the smaller extent is the seagrass (Table 3.2.4.1.). Table 3.2.4.1 reports the data related to the *w* (sequestration flux), the habitat extent at reference (1984), the extent at 2013, necessary to assess the trend, and the extent at the year of the OHI assessment, 2018.

Results of the calculation of the goal CS are described in the table 3.2.4.2.

Table 3.2.4.1. Habitats used for the CS goal.

Habitat	**Sequestration flux CAR (w)**	**Reference year 1984 (km^2)**	**Extent year 2013 (km^2)**	**Extent year 2018 (km^2)**
Salt marshes	244.7	104.89	58.38	52.77
Tidal flat	129.8	333.50	170.05	165.84
Seagrasses	138	164.38	20.04	13.94

Table 3.2.4.2. Results of the calculation of the goal CS.

Status	**Trend**	**Score**
0.5	-0.02	0.5

Discussion

The status of the goal CS is 0.5 and the trend is -0.02. The low value of the status could depend largely on the high contribution to the goal of tidal flats, which have the highest extent but the least carbon accumulation rate (CAR = 129.8), while seagrass and specially salt marshes have the higher CAR, despite the reduced extent and the high yearly loss percentage compared with tidal flats. That means that even though tidal flats cover the most area, their low carbon storage rate reduces the overall CS value. Seagrass and salt marshes are more efficient at storing carbon but are less extensive and more vulnerable to degradation, limiting their positive impact on the overall score. The declining trend (-0.02) suggests that factors such as habitat loss or environmental changes might be negatively affecting the goal over time.

As a difference from the OHI global calculation, in SA-BEN there were no mangroves, as mangroves in South Africa are distributed in the Indian Ocean. The reference year is 1984 and the reference extent of the habitats are: 104.89 km^2 for saltmarshes, 333.50 km^2 for tidal flats, and 164.38 km^2 for seagrasses.

3.2.5. Clean Waters (CW)

Scope and introduction

The objective of this goal is to assess the contamination level of coastal waters in SA-BEN. The CW goal focuses on coastal zones due to the concentration of pollution and the proximity to human activity. These nearshore areas are where most people interact with the marine environment through recreation and subsistence, making them central to public concern and management efforts. In the global calculation, four measures of pollution in the CW goal are included: eutrophication (nutrients), chemicals, pathogens and marine debris. In this study we include only one component: marine debris represented by plastic pollution and microplastic. The CW goal scores highest when the contamination level is zero, therefore, the status of the CW components is the inverse of their intensity (i.e., high input results in low status score).

Methods

To assess the status of the CW goal, we focused on the marine debris component, due to the availability of reliable data. Specifically, we used information on plastic pollution leakage from the national plastic pollution hotspotting report (IUCN-EA-QUANTIS, 2020) :

- Total plastic waste generated annually in SA: 2,371 thousand tonnes.
- Plastic leakage to ocean and rivers: 107 thousand tonnes/year. This leakage represents approximately 5% of annual plastic waste generation in SA.

Data about microplastic pollution for SA was extracted from the microplastic estimations for the calculation of the CW goal in the Atlantic ocean (section 2.3.1). Microplastic was estimated based on the modeled microplastic concentrations. The score of microplastic pollution for SA is 0.23 (figure 3.2.5.1).

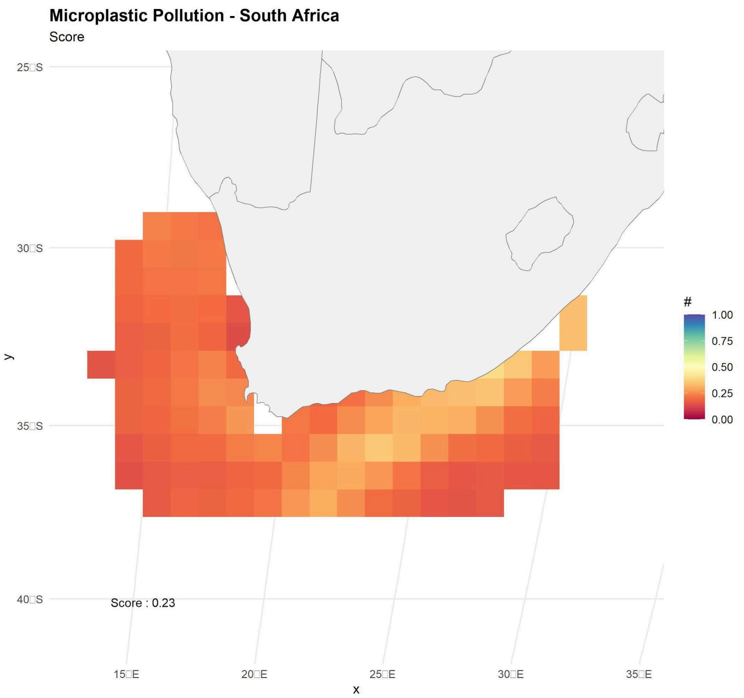


Figure 3.2.5.1. Score of microplastic pollution in SA, extracted from the microplastic estimations for the calculation of the CW goal in the Atlantic ocean

The status of the CW goal was calculated using the geometric mean of the rescaled marine debris and microplastics pollution scores (Eq. 3.2.5.1):

$$x_{cw} = \sqrt[2]{a * b} \qquad \text{(Eq. 3.2.5.1)}$$

Where:

- a is the inverse of the normalized plastic leakage, rescaled between 0 and 1

$$a = 1 - p_{norm} \qquad \text{(Eq. 3.2.5.2)}$$

To rescale the marine debris component, plastic leakage (p) was normalized using min-max normalization (Eq. 3.2.5.3), assuming p_{min} = 0 and p_{max} = 2371:

$$p_{norm} = \frac{p - p_{min}}{p_{max} - p_{min}} \qquad \text{(Eq. 3.2.5.3)}$$

- *b* is the microplastics pollution score derived from the microplastic estimations for the calculation of the CW goal in the Atlantic ocean, and has a value of 0.23.

Results

Results of the CW status score for the SA-BEN, based on available marine debris data and microplastic pollution models, is indicated in table 3.2.5.1. Due to the lack of time-series data on plastic leakage, it was not possible to calculate the trend for the CW goal. However, according to the IUCN-EA-QUANTIS, 2020, SA has consistently produced similar amounts of marine plastic litter each year. As a result, the trend is assumed to be zero (i.e., no observed improvement or decline over time). Therefore, the final CW score is equal to the status, which is 0.9.

Table 3.2.5.3.1. Results of the calculation of the goal CW.

Status	Trend	Score
0.5	/	0.5

Discussion

Based on the available data, the CW status for SA-BEN, assessed solely through the marine debris component related to plastic pollution and microplastics, was estimated at 0.5. This score reflects a moderate level of plastic leakage when normalized against the total annual plastic waste generation in SA. Although this suggests a moderate pressure from marine pollution in proportional terms, sustained monitoring and improved data collection are essential to enhance the accuracy of future assessments.

3.2.6. Coastal Protection (CP)

Scope and introduction

The goal of CP is to assess the extent of protection that marine and coastal habitats provide to inhabited and uninhabited coastal areas that are valued by people. Coastal protection is an ecosystem service provided by coastal ecosystems such as mangroves, seagrass beds, corals, tidal flats, and salt marshes. They play an important role in reducing the vulnerability of coastal communities to sea level rise and coastal hazards through wave attenuation, sediment uptake, vertical accumulation, erosion reduction and attenuation of storm surges and debris movement

(Tallis et al., 2012, Spalding et al., 2024). There are three habitats in the SA-BEN study area that provide this service: saltmarshes, tidal flats, and seagrasses (Figure 5.5.1 CS section). The data used to calculate this goal is the extent of each habitat in km^2 from UNEP-WCMC, validated by literature review (Adams 2016). To calculate the reference, we estimate the extent of past years assuming a percentage annual loss using 1984 as the baseline for the reference. To calculate the trend, a linear regression was calculated, taking into account the most recent extent and the extent of the last five years. The result was then multiplied by 5 to estimate the future likelihood over the next five years.

Methods

The CP goal is calculated as follows (Eq. 3.2.6.1):

$$x_{cp} = \frac{\sum_{k=1}^{N} (h_k \times w_k \times A_k)}{\sum_{k=1}^{N} (w_k \times A_k)} \quad , \qquad \text{(Eq. 3.2.6.1)}$$

Where:

- A_k is the area of the habitat in km^2
- W_k is the rank weight of the habitat's protective ability . This coefficient was taken from Tallis et al., 2012, and it is used in this study assuming that the habitat in this study provides the same protection level than the habitats in Tallis et al., 2012.
- h is calculated as follows (Eq. 3.2.6.2):

$$h = \frac{C_c}{C_r} \quad , \qquad \text{(Eq. 3.2.6.2)}$$

where:

- C_c is current condition of the habitat, calculated as the current extent of the habitat in km^2
- Cr is the reference condition of the habitat, calculated as the estimate of the extent in km^2 of previous years assuming a % of yearly loss for each habitat.

Results

The habitats used to the CP goal are the same analysed in the CS goal, named salt marshes, tidal flats and seagrasses, which cover a total area of 232.55 km^2. The habitat with the largest extent is tidal flat, and the smaller extent is the seagrass (Table 3.2.6.1). The reference year is 1984 and the reference extent of the habitats are:

- Seagrasses = 164.3776 km^2, assuming 7% yearly loss (Waycott et al., 2009).
- Salt marshes = 104.8907 km^2 assuming 2% yearly loss (Adams et al., 2021).
- Tidal flats = 333.5054 km^2 assuming 0.5% yearly loss (Murray et al., 2019).

Results of the calculation of the goal of CP are described in the table 3.2.6.2.

Table 3.2.6.1. Habitats used for the calculation of the CP goal.

Habitat	**Extent year 2018 (km^2)**	**Extent year 2013 (km^2)**	**Protectiveness rank (w)**
Salt marshes-Tflat	52.77	58.38	4
Tidal flat	165.84	170.05	4
Seagrasses	13.94	20.04	1

Table 3.2.6.2. Results of the calculation of the CP goal.

Status	**Trend**	**Score**
0.5	-0.02	0.5

Discussion

The status of the goal CP is 0.5 and the trend is -0.02, equal to CS goal. This is expected due to the fact that for the calculation of both goals, the same dataset was analyzed, with the difference of the variable w. For CP, w refers to the protectiveness rank.

3.2.7. Food Provision - Capture Fisheries (FP-FIS)

Scope and introduction

The aim of this goal is to analyze the status and trend of the FP-FIS subgoal in the SA-BEN case study. The approach adopted assesses the amount of wild catch that can be sustainably harvested and the reference unit is the B/BMSY.

Commercial fishing is composed of large-scale industrial fishing and small-scale artisanal fishing. In South Africa, the most important sector is the deep-sea trawl fishery and the small-scale coastal trawl fishery, both of which target hake stocks (*Merluccius paradoxus* and *M. capensis*; Burgener 2011). On the Agulhas Bank, horse mackerel (*Trachurus capensis*) are fished with a midwater trawl.

Hakes are also the subject of artisanal fishing (demersal longlines and handlines). The artisanal fishery includes a coastal fishery for west coast rock lobster (*Jasus lalandii*) on the west coast and a deep-sea fishery for *Palinurus gilchristi* on the south coast (Okes and Burgener 2011). Rock lobster accounts for less than 1 % of the total fishery by mass, but around 9-10 by value. Smaller industrial fishing sectors include fleets targeting shrimp off the coast of Kwa-Zulu Natal, a pelagic longline fishery targeting various tuna species, sharks and billfishes, a tuna bait fishery and a pole-and-line fishery. Fishing for the production of fishmeal, oil and canned fish accounts for 25% of the value of commercial fisheries in South Africa and consists mainly of sardine (*Sardinops ocellatus*), anchovy (*Engraulis capensis*) and herring (*Etrumeus whiteheadi)* (Hersoug and Holm 2000; Okes and Burgener 2011). The artisanal sector in the area also includes a small squid fishery targeting choka squid *(Loligo vulgaris reynaudi*) for export and a linefish sector targeting a wide variety of fish species, including sharks, tunas, and groupers, which is important both in terms of area fished and number of people employed.

Methods

Current status: Following the methodology developed in the toolbox (Halpern et al., 2012), the status of wild caught fisheries, $xfis$, for the region in each year was calculated as the geometric mean of the stock status scores, SS (derived from $B/BMSY$ score for each stock, described below) and weighted by the stock's relative contribution to overall catch, C, such that (Eq. 3.2.7.1):

$$xfis = \prod_{i=1}^{n} SS_i^{\left(\frac{C_i}{\sum C_i}\right)} \qquad \text{(Eq. 3.2.7.1)}$$

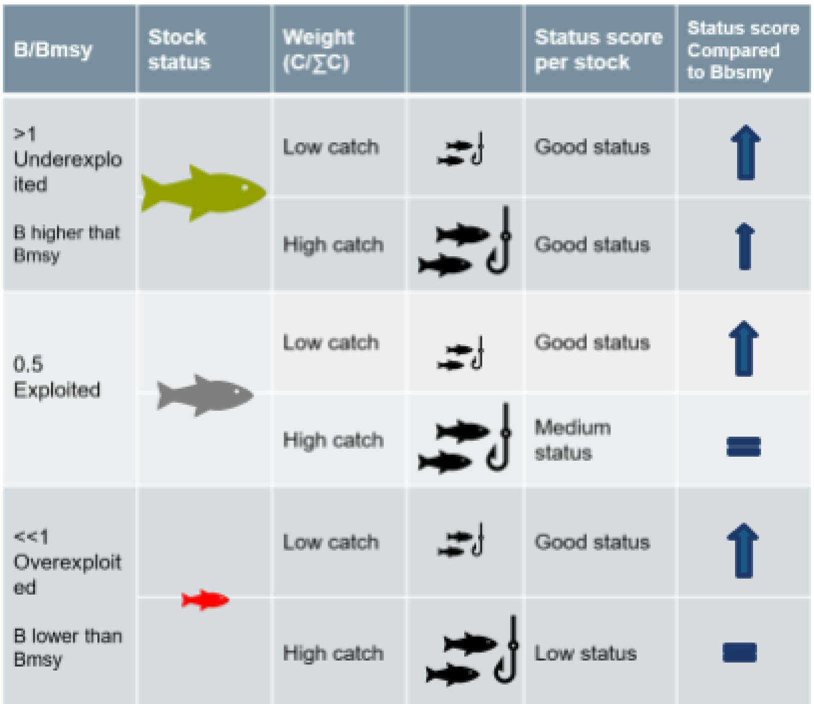
where i is an individual taxon and n is the total number of taxa in the reported catch throughout the time-series, and C is the average catch, since the first non null record, for each taxon. In addition (Eq. 3.2.7.2),

$$SS = \begin{cases} B/B_{MSY} & if \quad B/B_{MSY} < 0.95 \\ 1 & if \quad .95 \leq B/B_{MSY} \leq 1 \end{cases} , \qquad \text{(Eq. 3.2.7.2)}$$

The weight used, ($\frac{C_i}{\sum C_i}$), means that the status is overweighted if the stock *i* represents a big portion of the total catches, while the status is under weighted if the catch is low.

Nevertheless, the geometric weighted mean takes into account the condition of catching a variety of resources, so that small-catches stocks that are in bad status have a greater impact on the overall score than when using an arithmetic weighted mean, even though their catch contributes relatively little to the total amount of seafood harvested. The behavior of the geometric mean is such that improving a well-performing stock is not rewarded as much as improving a stock that performs poorly. This behavior is desirable because recovering stocks in poor conditions requires more effort and can have a greater impact on the system than if an already abundant species becomes even more abundant.

If the score $xfis$ is close to 1, the main fisheries by landing are near sustainable levels overall. Scores much below 1 highlight concerns, with low values indicating greater levels of overfishing or poor stock health (Figure 3.2.7.1). The method accounts for both the sustainability status of individual stocks and their relative contribution to the region's total catch, ensuring a balanced assessment of the status of fisheries.



B/Bmsy	Stock status	Weight (C/∑C)		Status score per stock	Status score Compared to Bbsmy
>1 Underexploited B higher that Bmsy		Low catch		Good status	
		High catch		Good status	
0.5 Exploited		Low catch		Good status	
		High catch		Medium status	
<<1 Overexploited B lower than Bmsy		Low catch		Good status	
		High catch		Low status	

Figure 3.2.7.1. Guideline of B/Bmsy scores to determine the stock status of fisheries.

The B/BMSY indicator provides data on the status of a stock, considering population biomass relative to the biomass that can deliver maximum sustainable yield (B/BMSY). The following data are used to determine B/BMSY, in order of priority:

- **Data from Department of Forestry, Fisheries and the Environment (DFFE)** of South Africa. B/BMSY data were obtained due to a PAIA request.
- **Data from the RAM Legacy Stock Assessment Database**: When available, B/BMSY values were obtained directly from the RAM Legacy Stock Assessment Database. This database contains comprehensive stock assessment information for a significant portion of global fish stocks and is regularly updated (RAM Legacy Stock Assessment Database 2021).

- **Data-Limited Approaches- CMSY with SAUP catches data** : In cases where B/BMSY from RAM data were not available, data-limited approaches were employed, in particular the CMSY approach (Froese et al., 2023). This approach is designed to estimate B/BMSY values using available catch, biomass index data and taxa resilience information. The approach is also designed to be used also when biomass index is not available, but results have recognized low reliability. The data used to calculate $B/BMSY$ (and the weights used in the geometric mean) are from Sea Around Us (2020) global marine fisheries catch data (Pauly *et al.* 2020).
- **Qualitative valuation of Stock status by DFFE (DFFE, 2020)** reports up-to-date information and analyses of the status of marine fishery resources in South Africa. The status of 61 stocks is assessed. To address the limitations of the CMSY method, these qualitative data were converted into semi-quantitative form, enabling a more robust and comparable analysis.

Moreover, the SAUP data are used to calculate the weight used as exponential in the Eq. 3.2.7.3 ($\frac{C_i}{\Sigma C_i}$).

Together, these datasets provide complementary insights, the DFFE Dataset provides updated assessments, possibly validated by local expertise and more detailed input data (e.g., biomass estimates and local stock-specific studies), while the smaller number of stocks assessed may reflect its focus on priority species. On the other hand, the RAM Dataset provides a broader coverage, useful for comparative analysis and identifying trends across species and years. However, it may rely on older assessment standardized methodologies that are not as finely tuned to regional contexts as DFFE reports.

According to FAO definition (https://openknowledge.fao.org/server/api/core/bitstreams/66538eba-9c85-4504-8438-c1cf0a0a3903/content/sofia/2024/status-of-fishery-resources.html#ref-note-1_k) , the qualitative classifications provided in the DFFE, (2020) report were systematically converted into numerical values to enable the transformation of qualitative assessments into quantitative scores. Predefined criteria, outlined as follows guided this conversion (Table 3.2.7.1):

Table 3.2.7.1: Qualitative classification of B/Bmsy scores.

B > Bmsy	B = Bmsy	B < Bmsy	B << Bmsy
Abundant	Optimal	Depleted	Heavily depleted
> 1.2	0.8 – 1.2	0.5 – 0.8	< 0.5

Once the B/BMSY indicator is assessed further weights are used in order to assess the goal:

Penalty: assign a penalty score to all catches that are not reported at species level. The level (severity) of penalty increases with the taxonomic coarseness, to obtain a more accurate final stock status score.

Gapfilling: Missing years in the SAUP catch dataset are addressed using linear interpolation to ensure continuity and completeness of the time series.

Trends indicate proportional change in status, so they typically range from -100% to +100% (or, -1.0 to +1.0), therefore we constrained values to this range (Eq. 3.2.7.4).

$$x(1 + trend) \quad , \qquad \text{(Eq. 3.2.7.4)}$$

Trend is the proportional change in status predicted to occur in 5 years, based on recent status data. In most cases, this is calculated by estimating the yearly change in status using a linear regression model (i.e., slope estimate) of the five most recent years of status data and multiplying this value by 5 to estimate the change five years into the future. To determine proportional change, Halpern et al. 2012 divided the slope estimate by the status value of the earliest year of data used in the trend calculation.

Results

The DFFE report provides B/BMSY assessments for 5 stocks, highlighting its limited scope, likely focusing on key species of high economic or ecological importance (Fig. 3.2.7.2). In contrast, the RAMLDB database offers a broader temporal range, covering 8 stocks between 2015 and 2020. This indicates a more comprehensive dataset for analyzing trends over time and across multiple species. Both datasets emphasize species critical to South African fisheries, such as hake (*Merluccius paradoxus, M. capensis)*, horse mackerel (*Trachurus capensis*), and squid *(Loligo reynaudii*). The table listing RAMLDB database shows that several stocks (e.g., *Trachurus capensis* and *Merluccius paradoxus*) are assessed annually (Fig. 3.2.7.3), enabling the monitoring of their sustainability over time.

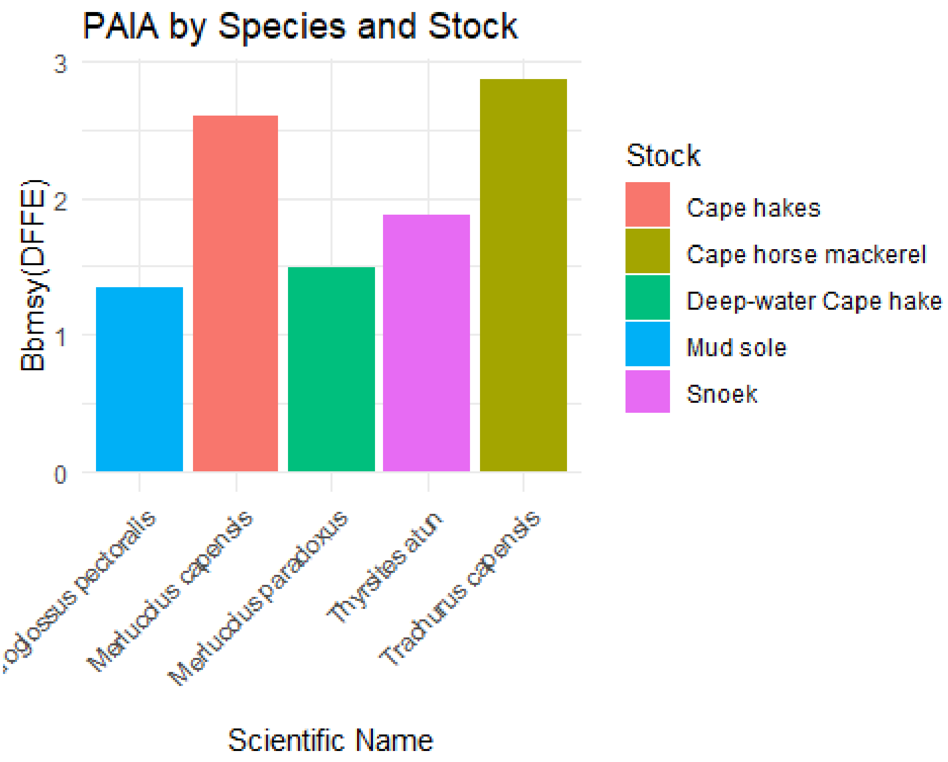


Figure 3.2.7.2: BBMSY extracted from the most official report of the South Africa DFFE, the total amount of stock assessment from this source is 5.

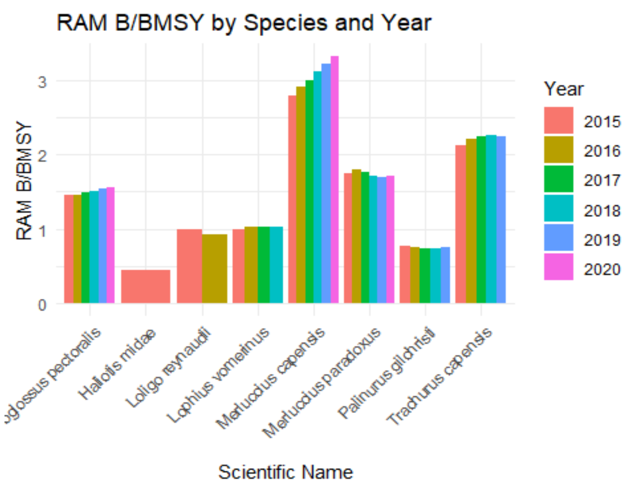


Figure 3.2.7.3: B/Bmsy data extracted from RAMLDB v4.64 latest version. Eight stocks are assessed from a period from 2015 to 2020.

- ***CMSY methodology:*** To estimate BBmsy using the CMSY method, reconstructed catch data retrieved from the SAUP database for the South African Atlantic and the Cape are used. The total number of marine exploited stocks using this method is 92.

The missing years of SAUP catch data are filled in by linear interpolation (Figure 3.2.7.4). The total number of taxa for which we performed gapfilling is 19 (Table 3.2.7.2).

This is based on the following criteria:

1. Filtering out stocks that have more than 4 NAs in the time series.
2. If the NAs are at the beginning of the time series, the first years are truncated.
3. Delete taxa with time series ending before 2016
4. Fill the missing years with a linear interpolation

Table 3.2.7.2: Taxa from SAUP catch data filled by linear interpolation.

Stock	**Note**
Notorynchus cepedianus	Start 2007
Petrus rupestris	Start 1987
Sarda sarda	Start 2007
Lampanyctodes hectoris	Delete
Polyprion americanus	Delete
Scombroidei	Delete
Tetrapturus angustirostris	Delete
Tetrapturus pfluegeri	Delete
Thunnus	Delete
Thunnus thynnus	Delete
Istiophorus platypterus	starts 2007
Istiophoridae	Delete
Hoplostethus atlanticus	starts 2004
Crassostrea	Starts 2007
Coryphaena hippurus	Starts 2001
Chelidonichthys capensis	Starts 1972
Chaceon maritae	delete
Argyrozona argyrozona	Starts 1964

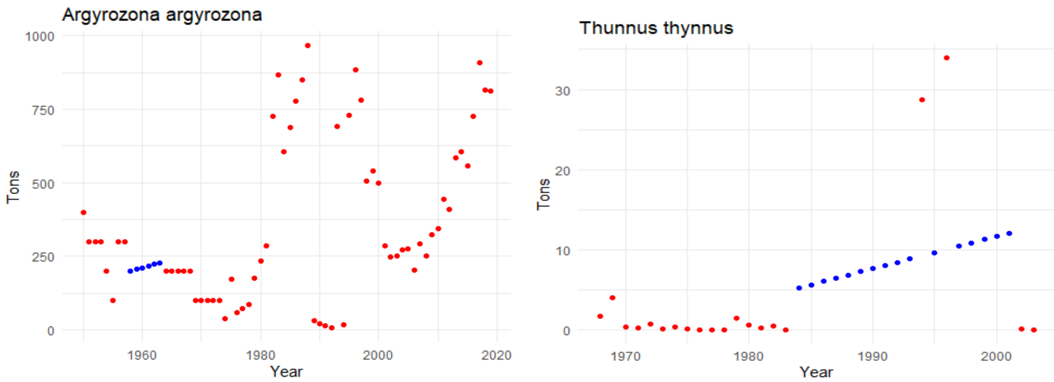


Figure 3.2.7.4: Table showing the details of the selection for each stock that had to be gapfilled. The diagrams show the data gaps filled by linear interpolation. The new data are shown in blue, while the original time series data are in red.

The resilience of each stock is extracted and assigned by FishBase; if no information is available, an average resilience is used.

Based on the taxonomic aggregation level specified in the database, a penalty factor is assigned, ranging from 6 (species) to 1 (order or higher) (https://agricultureservices.gov.mt/en/fisheries/Documents/faoSpeciesCode/faoSpeciesCodes.pdf). The penalty factor is multiplied by the gapfilled stock status value to obtain the final stock status score (Table 3.2.7.3).

Table 3.2.7.3: Penalty factor based on the taxonomic aggregation level.

	Description	Penalty (gapfilled score multiplied by value)
1	e.g., Marine fishes not identified, Miscellaneous marine molluscs	0.1
2	Class, Subclass, Subphylum (e.g., Cephalopoda, Holocephali, Crustacea)	0.25
3	Order (e.g., Chimaeriformes, Octopoda)	0.5
4	Family (e.g., Lamnidae, Squillidae)	0.8
5	Genus (e.g., Strongylocentrotus, Scyllarides)	0.9
6	Species	1 (no penalty)

Qualitative Stock assessment by DEFF 2020 report: To provide an alternative method to CMSY, we have chosen to use the DEFF data presented in the Status of South African Marine Resources 2020 report and converted the available qualitative information into quantitative data. 42 stocks are considered (Table 3.2.7.4)

Table 3.2.7.4: DEFF data from the Status of South African Marine Resources 2020 report.

DEFF_status	CommonName	Name	bbmsy
Abundant	St Joseph shark	Callorhinchus capensis	1
Abundant	Biscuit skate	Rajiformes	1
Abundant	Spearnose skate	Rajiformes	1
Abundant	Shallow-water hake	Merluccius	1
Abundant	Snoek	Thyrsites atun	1
Abundant	Hottentot seabream	Sparidae	1
Abundant	West Coast round herring	Etrumeus whiteheadi	1
Abundant	Slime skate	Rajiformes	1
Optimal	Smooth hound shark	Mustelus mustelus	1
Optimal	Blue shark	Prionace glauca	1
Optimal	Cape horse mackerel	Trachurus capensis	1
Optimal	Deep-water hake	Merluccius	1
Optimal	Kingklip	Genypterus capensis	1
Optimal	Squid	Loligo	1
Optimal	Monkfish	Lophius vomerinus	1
Optimal	Anchovy	Engraulis capensis	1
Optimal	Patagonian toothfish	Dissostichus eleginoides	1
Optimal	Yellowtail	Seriola lalandi	1
Optimal	Slinger	Sparidae	1
Optimal	Carpenter	Argyrozona argyrozona	1
Optimal	Santer Roman	Sparidae	1
Optimal	Albacore tuna	Thunnus alalunga	1
Optimal	Yellowfin	Thunnus albacares	1
Depleted	White stumpnose	Rhabdosargus globiceps	0.65
Depleted	SIlver kob	Sciaenidae	0.65
Depleted	Geelbek	Atractoscion aequidens	0.65
Depleted	Sardine	Sardinops sagax	0.65
Depleted	Swordfish	Xiphias gladius	0.65
Depleted	Yellowspot skate	Rajiformes	0.65
Depleted	Twineye skate	Rajiformes	0.65
Heavily depleted	Dusky kob	Sciaenidae	0.3
Heavily depleted	Red steenbras	Scorpaeniformis	0.3
Heavily depleted	Seventy-four	Sparidae	0.3

Heavily depleted	Dageraad	Sparidae	0.3
Heavily depleted	Soupfin shark	Galeorhinus galeus	0.3
Heavily depleted	Shortfin mako	Isurus oxyrinchus	0.3
Heavily depleted	Oceanic whitetip	Carcharhinus longimanus	0.3
Heavily depleted	Great hammerhead	Sphyrna	0.3
Heavily depleted	Bigeye tuna	Thunnus obesus	0.3
Heavily depleted	Mullets	Mugilidae	0.3
Heavily depleted	West Coast rock lobster	Jasus lalandii	0.3
Heavily depleted	Abalone	Haliotis midae	0.3

Mean catch (weight): The mean catch data is used to weight the B/Bmsy values to calculate the total annual catch for each stock and is based on data from the SAUP. This analysis does not take into account "discards" and "other" use of catches (Eq. 3.2.7.5).

$$\left(\frac{C_i}{\Sigma C_i}\right), \qquad \text{(Eq. 3.2.7.5)}$$

The total catch for the year of the analysis, 2018 is 557965.4 tons.

The final results of the BBMSY* penalty, weighted by catch over the total annual catch for the 5 years considered, are presented in table 3.2.7.5.

Table 3.2.7.5: Results of the BBMSY penalty.

	Year	status_final
1	2015	0.48
2	2016	0.52
3	2017	0.55
4	2018	0.57
5	2019	0.58

Goal calculation: The final score resulting from applying the trend to the status evaluation are presented in table 3.2.7.6.

Table 3.2.7.6: Results of the calculation of the FP-FIS subgoal.

Year	status	trend	score
2018	0.57	0.27	0.73

Due to the major limitations of the CMSY method, mainly due to the data input (only catch data and no biomass data), the new result obtained with the DEFF data is 0.96. Unfortunately, it is not possible to calculate the trend based on these data, so the final score is considered equal to the status value.

3.2.8. Food Provision – Mariculture (FP-MAR)

Scope and introduction

The objective of the FP-MAR subgoal is to measure food production from mariculture relative to its capacity and sustainability.

In this study, the production of strictly marine taxa from both the marine and brackish water FAO categories for SA-BEN were assessed. Aquatic plants such as kelps and seaweeds were excluded, as were assumed to contribute predominantly to medicinal and cosmetic uses rather than as a source of food (Halpern et al., 2012).

Methods

The data used for the calculation of the FP-MAR subgoal was taken from FAO software FishStatJ, aquaculture production - South Africa - Quantities - 2018-2022. The data are quantity (tonnes) of aquaculture production (marine and brackish) for SA-BEN. The sustainability index for each taxa was extracted from WWF SASSI list (https://wwfsassi.co.za/sassi-list/). The reference point is the value that corresponds to 1% of the potential aquaculture harvest in SA-BEN (the sum of the tonnes of all species across all years), following the approach used by Gentry et al. 2017 with the aim to account for the social and economic realities of the sector. To determine the trend, it is necessary to calculate the status for the year 2018 using a 4-year moving average based on data from 2013 to 2017. However, due to the lack of data for this period, it is not possible to calculate the trend for this subgoal.

The status of the FP-MAR subgoal is calculated as follows (Eq. 3.2.8.1)

$$x_{mar} = Y_c * S_c \quad \text{(Eq. 3.2.8.1)}$$

Where:

- Y_c is the current re-scaled met potential of harvested yield, calculated as equation 3.2.8.2:

$$Y_c = \frac{\sum_{k=1}^{N} Y_k}{Y_{ref}} \quad \text{(Eq. 3.2.8.2).}$$

Where:

- Y_{ref} is the reference value that corresponds to 1% of the potential aquaculture harvest of each species calculated as the total sum of the tonnes of all species across all years.
- Y_k is the 4-year moving window average of tonnes of production for each k mariculture species. The values begin in 2021, as that's the first year where 4 years of data are available (2018–2021).

S_c is the production weighted average of sustainability of mariculture in each country, calculated as equation 3.2.8.3:

$$S_c = \frac{\sum_{k=1}^{N} Y_k S_k}{\sum_{k=1}^{N} Y_k} \quad \text{(Eq. 3.2.8.3)}$$

Where:

- Y_k is the 4-year moving window average of tonnes of production for each k mariculture species
- S_k is the sustainability score for each k mariculture species taken from WWF SASSI list as follows: red is unsustainable (0.1), orange is partially sustainable (0.4), green is sustainable (0.9).

Results

The data retrieved from FishStatJ, aquaculture production - South Africa - Quantities - 2018-2022 had a total record of six species which are presented in table 3.2.8.1. According to the colors indicated in SASSI list, all the species analysed in this goal are sustainably farmed resulting in a score of 0.9 for each species. The value of the potential aquaculture harvest is 26,311.17 tonnes, and the reference value (1% of the potential aquaculture harvest) is 263.1. The species with the highest harvest is Mediterranean mussel (*Mytilus galloprovincialis*) with a total of 14,193.57 tonnes between 2018 and 2022, and the species with the lowest harvest is Yellowtail amberjack (*Seriola quinqueradiata*) with a total of 10.38 tonnes across the 5 years of analysis.

Table 3.2.8.1. Aquaculture production in SA-BEN from the year 2018 to 2022. Quantities are expressed in tonnes. Sustainability index is given according to WWF SASSI list.

Common name	Detailed production source	Quantity (tonnes) per year					Total	Sustainability (SASSI)
		2018	2019	2020	2021	2022		
Japanese meagre	Aquaculture production (brackishwater)	0	0	0	4.36	26.84	31.2	0.9
Mediterranean mussel	Aquaculture production (marine)	2,182.13	3,053.46	2,275.58	3,420.88	3,261.52	14,193.57	0.9
Pacific cupped oyster	Aquaculture production (marine)	466.23	382.7	318.35	390.49	589.28	2,147.05	0.9
Perlemoen abalone	Aquaculture production (brackishwater)	1,522.22	1,656.56	1,976.56	2,463.29	2,254.72	9,873.35	0.9
Rainbow trout	Aquaculture production (marine)	28.5	20.1	7.02	0	0	55.62	0.9
Yellowtail amberjack	Aquaculture production (brackishwater)	0	0	0	8.1	2.28	10.38	0.9

Results of the calculation of the status of the FP-MAR subgoal are presented in table 3.2.8.2.

Table 3.2.8.2. Results of the calculation of the FP-MAR subgoal.

Status	Trend	Score
1.0	/	1.0

Discussion

The status of the FP-MAR subgoal (1.0) suggests that aquaculture production in SA-BEN is currently operating sustainably, achieving maximum yield without compromising future provisioning capacity. However, assessing the trend is challenging due to limited data availability from the FAO, with only five years of data accessible for analysis. Moreover, the available data provides a limited number of species and lacks a complete time series for the species Japanese meagre, Rainbow trout, and Yellowtail amberjack. This highlights the need for improved monitoring and consistent reporting in the aquaculture sector in SA-BEN.

3.2.9. Livelihoods & Economies – Livelihoods (LE-LIV)

Scope and introduction

The LE goal consists of two equally significant sub-goals: livelihoods (LE-LIV) and economies (LE-ECO), both of which are evaluated across blue economy sectors. The blue economy sectors assessed in this study are taken from the list of sectors analysed for growth potential in Project Phakisa (https://www.operationphakisa.gov.za/Pages/Home.aspx) (Table 3.2.9.1). The blue economy sectors include construction (e.g., harbours and ports infrastructure, coastal development), marine transport and manufacturing (e.g., shipping and ship building), tourism, renewable energy (e.g., offshore wind energy), fisheries and aquaculture, and desalination (Table 3.2.9.1).

The overall status of the LE goal is determined by averaging the outcomes of its two sub-goals.

The livelihoods sub-goal (LE-LIV) aims to assess the jobs and revenue generated by blue economy sectors, which are highly valuable, not only to those directly employed in these sectors but also to individuals who benefit indirectly, whether through community identity, tax contributions, or the broader economic and social stability of a thriving coastal economy. It is important to mention that industries with high revenue do not always generate large-scale employment opportunities, which can be seen in the data extracted from project Phakisa (Table 3.2.9.1). On the other hand, the Economies (LE-ECO) sub-goal aims to assess the economic contribution derived from Blue jobs sectors. The reference point is the sector with highest labor productivity (economic output (GDP) generated per job in each sector).

Table 3.2.9.1. Blue economy sectors analysed in the LE goal. Data for the year 2018 were extrapolated from the project Phakisa data, taking into account the CAGR % formula.

Sector	GDP South African Rand (R) Billion (B)			CAGR, %	Jobs, 000		
	2010	2033	2018 (this study)		2010	2033	2018 (this study)
Marine transport and manufacturing	16	61	25.5	6	15	56	29.26
Tourism	15	35	20.52	4	90	225	136.95
Construction	8	21	10.94	4	162	407	247.21
Renewable energy	0	17	0	25	0	1.1	0.38

Fisheries and aquaculture	7	16	9.57	4	30	250	106.52
Desalination	0	0.1	0	1	0	1.6	0.55

The objective of the sub-goal LE-LIV is to measure the jobs produced from industries of the blue economy sectors.

The LE-LIV sub-goal has two key components:

- Number of jobs: representing the quantity of available employment.
- Per capita average annual wages: serving as an indicator of job quality.

Methods

The analysis used the GDP contribution of the blue economy sectors to assess the LE-LIV subgoal. Dividing the GDP by the number of jobs gives a measure of labor productivity. This indicator shows how much economic output (GDP) is generated per job in each sector. As the project Phakisa has data from the years 2010 and a projection for 2033, predicted values for the number of jobs were obtained from extrapolation assuming a linear growth. Predicted values of GDP were extrapolated using the formula of the Compound Annual Growth Rate (CAGR) (Eq. 3.2.9.1) taking into account the CAGR % (see table 3.2.9.1):

$$CAGR = \left(\frac{V_f}{V_i}\right)^{\frac{1}{n}} - 1 , \qquad \text{(Eq. 3.2.9.1)}$$

Where:

- V_f is the final value
- V_i is the initial value
- n is the number of years

The status of the LE-LIV sub-goal is calculated as follows (Eq. 3.2.9.2):

$$x = \frac{\frac{\Sigma J_{ic}}{\Sigma J_{ir}} + \frac{\Sigma \frac{G_{ic}}{J_{ic}}}{\Sigma \frac{G_{ir}}{J_{ir}}}}{2} , \qquad \text{(Eq. 3.2.9.2)}$$

where:

- J is the number of jobs in each blue economy sector i
- G is the GDP contribution from direct jobs in each blue economy sector

- c is the current condition (year 2018)
- r is the reference condition (year 2010)

To calculate the trend, a linear regression was performed taking into account the status of the year 2013 and year 2018, then multiplying the slope by 5 to predict the future likelihood in the next five years.

Results

According to the interpolation results, in the year 2018 the sector with the highest employment is construction (e.g., harbours and ports infrastructure, coastal development), with a total of 247,210 jobs. The sectors with the lowest employment in 2018 are renewable energy and desalination, with 380 and 550 respectively. Regarding GDP contribution, marine transport and manufacturing recorded the highest contribution, totaling R 25.5B in 2018, while desalination and renewable energy had the lowest, at R 0B(Table 3.2.9.1). Results of the calculation of the sub-goal LE-LIV are presented in table 3.2.9.2.

Table 3.2.9.2. Results of the calculation of the sub-goal LE-LIV for SA-BEN.

Status	Trend	Score
0.9	0.1	0.9

Discussion

A difference with the global OHI calculation is that in our study the per capita average annual wages were not used. Instead, we used the GDP for the calculation of the status of LE-LIV.

The status of 0.9 indicates a good status of the LE-LIV subgoal. However, it also indicates that the relative economic status or well-being in the blue economy sectors in SA-BEN has decreased by 10% compared to 2010. As this subgoal is measuring the jobs produced from marine-related industries, the results suggest that the number of jobs in the blue economy sectors in SA-BEN has increased, which was expected after the implementation of the project Phakisa in 2014 (https://www.operationphakisa.gov.za/Pages/Home.aspx). This is supported by the trend (0.1) which suggests a modest growth in job creation in the mentioned sectors. Results of the calculation of the subgoal LE-LIV can be seen in table 3.2.9.2.

3.2.10. Livelihoods & Economies – Economies (LE-ECO)

Scope and introduction

The objective of this subgoal is to measure the revenue produced from blue economy sectors and the goal is defined by a single component, the revenue from marine-related industries .

Due to data limitations, in this study, the calculation of the LE-ECO sub-goal for SA-BEN does not consider revenue directly but instead uses the GDP contribution of each blue economy sector. The key difference from the LE-LIV subgoal is that LE-LIV assesses the economic contribution of blue economy sectors in SA-BEN by considering both GDP and employment, whereas LE-ECO, evaluates economic contribution based solely on GDP. The data for the calculation of the LE-ECO sub-goal are listed in the table 5.10.1 (LE-LIV sub-goal section).

Methods

For the calculation of the LE-ECO sub-goal in SA-BEN, we divide the sum of the current GDP of each blue economy sector by the sum of the reference GDP of each blue economy sector.

The status of the LE-ECO sub-goal is calculated as follows (Eq. 3.2.10.1):

$$x = \frac{\sum G_{ic}}{\sum G_{ir}} \quad , \qquad \text{(Eq. 3.2.10.1)}$$

Where:

- G is the GDP contribution from direct jobs in each blue economy sector i
- c is the current condition (year 2018)
- r is the referent condition (year 2010)

To calculate the trend, a linear regression was performed taking into account the status of the year 2013 and year 2018, then multiplying the slope by 5 to predict the future likelihood in the next five years.

Results

Results of the calculation of the LE-ECO sub-goal for SA-BEN are in table 3.2.10.1.

Table 3.2.10.1. Results of the calculation of the sub-goal LE-ECO for SA-BEN.

Status	Trend	Score
1.0	0.3	1.0

Discussion

Results of the calculation of the LE-ECO sub-goal indicates a status of 1.0 (final calculation of 1.44). This ratio means that the blue economy sectors in SA-BEN have increased their GDP by 44% in the year 2018 compared to the year 2013. This indicates economic growth across the sectors, which was expected according to the project Phakisa initiative. According to the trend (0.3), there is a positive change over time, which could indicate economic growth, improvements in productivity, or sector expansion.

3.2.11. Natural Products (NP)

Scope and introduction

The objective of the NP goal is to assess the ability to maximize the sustainable harvest of living marine resources, which are natural products not intended for human consumption, and it includes three categories: ornamental fish, fish oil and fish meal (fofm), and inedible seaweeds and marine plants. This goal is important as the harvest of natural products contributes to the economy of the countries, and the sustainable harvest of these products is an important component of a healthy ocean.

Methods

The data used for the calculation of this goal was taken from FAO software FishStatJ, global aquatic trade - South Africa - Quantities and Values - 2019-2022. The data are quantity (tonnes) and value (USD) of raw commodities (exports only) for SA-BEN. The FAO data is subset to include commodities in these categories: ornamental fish, fish oil and fish meal, and seaweed. Data of the b/bmsy from Sea Around Us (SAU) was used for the calculation of the fish oil and fish meal status and trend. The reference point for each commodity is the maximum harvest achieved throughout the years of assessment. To calculate the trend, a linear regression was performed taking into account the status of the past and recent assessment, then multiplying the slope by 5 to predict the future likelihood in the next five years.

For the calculation of this goal, the status of each category was calculated. Commodities within each category are listed in Table 3.2.11.1. For each category, the tonnes and USD values were summarized to have one value for each category per year (2019 to 2022).

Table 3.2.11.1. Categories and individual commodities assessed in the NP goal.

Category	Commodity
Inedible seaweeds and marine plants	Agar agar nei
	Seaweeds and other algae, fit for human consumpt ion, nei
	Seaweeds and other algae, unfit for human consu mption, nei
Fish oil and fishmeal	Fish body oils, nei
	Fish liver oils, nei
	Fishmeals, nei
Ornamental fish	Ornamental saltwater fish

The status of the seaweeds and ornamental fish was calculated as follows (Eq. 3.2.11.1):

$$P_c = H_c * S_c , \qquad \text{(Eq. 3.2.11.1)}$$

Where:

- H_c is the harvest level
- S_c is the sustainability of the category (Inedible seaweeds and marine plants, Ornamental fish)

The harvest level H_c was calculated as the most recent harvest (in tonnes) relative to the maximum harvest ever achieved, under the assumption that the maximum achieved at any point in time was likely the maximum possible. The sustainability value for seaweed is 0.67 and it was taken from the OHI global assessment while to calculate the sustainability of ornamental fish, is taken into consideration the exposure term (E_c), which according to OHI global calculation in 2022 = 0.14, and the risk term (R_c), which according to OHI global calculation = 0, as follows (equation 3.2.11.2):

$$S_c = 1\text{-mean}(E_c + R_c), \qquad \text{(Eq. 3.2.11.2)}$$

According to OHI global methodology, the exposure term is the ln-transformed intensity of harvest for ornamental fish calculated as tonnes of harvest per km^2 of coral and rocky reef fish, relative to the global maximum. The risk term is based on whether ornamental fishing has unsustainable harvest practices, like the use of cyanide and dynamite.

The status of fofm was calculated as the geometric mean of the stock status scores, SS (derived from B/BMSY score for each species, see FP section) and weighted by the stock's relative contribution to overall catch, C, such that (Eq. 3.2.11.3):

$$x_{fis} = \prod_{i=1}^{n} SS_i^{\left(\frac{C_i}{\sum C_i}\right)}$$ (Eq. 3.2.11.3)

where:
- *i* is an individual species
- *n* is the total number of species in the reported catch throughout the time-series
- *C* is the total catch per year for each species within each region

B/bmsy and scores were previously calculated in the fisheries subgoal, then fofm species were extracted from the SAUP dataset. Because USD values were not present in the SAUP data that was used for fofm, the FAO global commodities dataset was used to obtain the aggregated UDS values of each category necessary to calculate their relative contribution, wc, to the overall status of the goal.

The status of the NP goal is calculated as follows (Eq. 3.2.11.4):

$$x_{np} = \frac{\sum_{c=1}^{N} P_c * w_c}{N}$$, (Eq. 3.2.11.4)

Where:
- P_c is the status score of each individual category
- w_c is the relative contribution of each product to the overall status of the goal, it was calculated as the ratio of the 4-year average US dollar value for a category across all years of data for the category, relative to the 4-year average sum of maximum values for all categories harvested in the country.
- N is the number of categories that were harvested (3)

Results

The total harvest in tonnes, USD values, and w_c coefficient for each category are described in Table 3.2.11.2.

Table 3.2.11.2. Total harvest (tonnes), value (USD 1000), and w_c for each category.

commodity	ton2019	ton2020	ton2021	ton2022	usd2019	usd2020	usd2021	usd2022	Status 2019	Status 2022	w_c (2022)

algae	1059.13	2365.25	3005.83	3464.41	2034.14	3444.43	4431.75	7742.55	0.2	0.6	0.57
fofm	48168.2	88158.42	53701.4	63387.85	62756.99	115309.7	84790.2	119270.7	0.9	0.9	0.80
ornamental	20.39	2.12	2.44	10.38	78.09	11.89	28.67	50.35	0.7	0.4	0.54

In NP, the category with major harvest products in tonnes from 2019 to 2022 was fish oil and fish meal, with a total harvest of 253,415.87 tonnes of fofm, and a total of 382,127,590 USD. In second place is algaes with a total harvest of 9,894.62 tonnes and a total value of 17,652,870 USD. In the last place is ornamental fish with a total harvest of 35.33 tonnes and a total value of 169,000 USD. The category that contributes the most to the status of the goal is fofm as w_c = 0.8, and w_c of algae and ornamentals are 0.5 each. Results of the calculation of the natural products goal are described in Table 3.2.11.3.

Table 3.2.11.3. Results of the calculation of the NP goal

Status	Trend	Score
0.5	0.06	0.5

Discussion

The status of the NP goal is 0.5 (year 2022), indicating that the harvest of these commodities in SA-BEN requires a more sustainable approach. This is particularly evident for ornamentals, where the status declined from 0.7 in 2019 to 0.4 in 2022 (table 3.2.11.2). The goal's trend is 0.06, suggesting only minor changes in its status between 2019 and 2022, as the NP goal score for SA-BEN in 2019 was 0.43.

3.2.12. Sense of Place - Iconic Species (SP-ICO)

The objective of the SP goal is to assess the aspects of the coastal and marine system that people value as part of their cultural identity. This goal is calculated using two equally weighted subgoals: iconic species (SP-ICO) and lasting special places (SP-LSP).

Scope and introduction

The objective of the SP-ICO subgoal is to average the number of iconic species within the IUCN risk categories. The subgoal SP-ICO is focused on those species widely seen as iconic from a cultural or existence value (rather than a livelihoods or extractive reason).

Methods

The data used for the calculation of this subgoal was the risk status of iconic marine species from South Africa from IUCN (https://www.iucnredlist.org). The reference point is to have the risk status as Least Concern (LC = 1.0). To calculate the trend, a linear regression was performed taking into account the status of the past and recent assessment, then multiplying the slope by 5 to predict the future likelihood in the next five years.

The SP-ICO subgoal is calculated as follows (Eq. 3.2.12.1):

$$x_{ico} = \frac{\sum_{i=EX}^{LC} S_i \times w_i}{\sum_{i=EX}^{LC} S_i}, \qquad \text{(Eq. 3.2.12.1)}$$

Where:

- S_i is the number of assessed species
- w_i is the status (IUCN red list categories)

The list of iconic species for rgn_id 102 (which corresponds to SA) was selected from the most updated OHI global calculation (https://github.com/OHI-Science/ohiprep_v2024/blob/gh-pages/globalprep/ico/v2024/output/ico_spp_iucn_status.csv) and further supplemented after evaluation by experts and literature review.

Results

The species assessed for the SP-ICO subgoal are 13, with an average status of 0.5 (VU) under current conditions (Table 3.2.12.1). The average status at the last assessment (from year 2000 to 2020) is also 0.5 (VU), suggesting a lack of conservation strategies or that the ones already existing might not be effective for the conservation of the assessed species. The status of the iconic species subgoal is 0.5 which reflects the risk status of the iconic species assessed in this study. Of the 13 iconic species, only *Arctocephalus pusillus* is in Least Concern, and *Galeocerdo cuvier* is Near Threatened. A total of 5 species are Vulnerable, 5 species are Endangered, and one species is in Critical risk. The trend of this subgoal is 0 due to the fact that the previous assessment of the iconic species reflects that 1 species are Least concern, 1 species are Near threatened, 6 species at Endangered, 5 species are Vulnerable, and 1 species is in Critical risk. This is the same number of assessed species that fall within the same categories in the recent assessment. In particular, *Spheniscus demersus and Arctocephalus pusillus* are two species that have been included in the assessment for the first time, despite their widely recognized role as iconic species. Results of the calculation of the SP-ICO subgoal are described in table 3.2.12.2.

Table 3.2.12.1. List of iconic species from South Africa.

Species	Recent assessment		Previous assessment	
	Status	Year	Status	Year
Alopias vulpinus	VU	2022	VU	2019
Balaenoptera borealis	EN	2018	EN	2008
Balaenoptera musculus	EN	2018	EN	2008
Balaenoptera physalus	VU	2018	EN	2013
Carcharodon carcharias	VU	2022	VU	2019
Cetorhinus maximus	EN	2021	EN	2019
Dermochelys coriacea	VU	2013	CR	2000
Isurus oxyrinchus	EN	2019	VU	2009
Isurus paucus	EN	2019	VU	2006
Lamna nasus	VU	2019	VU	2006
Galeocerdo cuvier	NT	2019	NT	2009
Spheniscus demersus	CR	2024	EN	2020
Arctocephalus pusillus	LC	2015	LC	2008

Table 3.2.12.2. Results of the calculation of the SP-ICO subgoal

Status	Trend	Score
0.5	0.0	0.5

Discussion

The assessment of the SP-ICO subgoal reveals a concerning trend regarding the conservation of iconic species in SA-BEN. With a status of 0.5 (Vulnerable) both in the current and previous assessments, there is no observed improvement in iconic species conservation. This lack of positive change suggests that either existing conservation strategies are ineffective or that no significant new efforts have been implemented to enhance species protection. The reasons why there is no positive trend in SP-ICO could be habitat degradation, overfishing, lack of effective conservation strategies. However, with the declaration of the new MPAs in 2019 (https://www.marineprotectedareas.org.za/), the status of SP-ICO in SA-BEN is expected to improve in the near future.

3.2.13. Sense of Place - Lasting Special Places (SP-LSP)

Scope and introduction

The objective of the SP-LSP subgoal is to determine the percentage and condition of marine and coastal waters that are protected. The lasting special places subgoal focuses on geographic locations that hold particular value for aesthetic, spiritual, cultural, recreational or existence reasons. In this study we consider the marine protected areas covering SA-BEN region, including 10 km inland from the coastline.

Methods

The data used for the calculation of the subgoal SP-LSP is from The World Database on Protected Areas (WDPA) (https://www.marineprotectedareas.org.za/). The surveyed area included a buffer zone of 10 km inland to include the protected estuaries. For the analysis, data of 2019 is used to assess the status in order to avoid biased results. The trend is calculated based on a linear regression taking into account the total area through the years of MPA establishment, then multiplying the slope by 5 to estimate the future likelihood in the next five years. Data to calculate the trend was taken from https://www.marineprotectedareas.org.za/, which reports the year of MPAs establishment.

The SP-LSP subgoal is calculated as follows (Eq. 3.2.13.1):

$$x_{lsp} = \frac{\left(\frac{\%_{CMPA}}{\%_{Ref_{CMPA}}} + \frac{\%_{CP}}{\%_{Ref_{CP}}}\right)}{2}, \quad \text{(Eq. 3.2.13.1)}$$

Where:

- $\%_{CMPA}$ is the percentage of all marine protected area SA-BEN
- $\%Ref_{CMPA}$ is the reference value for marine protected area
- $\%_{CP}$ is the percentage of coastline protected
- $\%Ref_{CP}$ is the reference value for coastline protected

The reference value is set to 30% for both marine and coastline protected areas, in accordance with the Kunming-Montreal Global Biodiversity Framework (Decision 15/4, U.N. Doc. CBD/COP/DEC/15/4 (2022)).

Results

According to Marine Protected Areas South Africa (https://www.marineprotectedareas.org.za/) there are 41 MPAs in South Africa (Figure 3.2.13.1). The MPAs included in this study are 36 (including West Coast National Park MPA Network). The first MPA, the Tsitsikamma MPA was established in 1964, followed by 16 more established in the following fifty years. The remaining 30 have been established since the year of the assessment, 2018 (Table 3.2.13.1). The marine area of SA-BEN is 40,856.03 km^2, while the area of coastline protected of SA-BEN is 10,235.71 km^2 (Appendix 4).

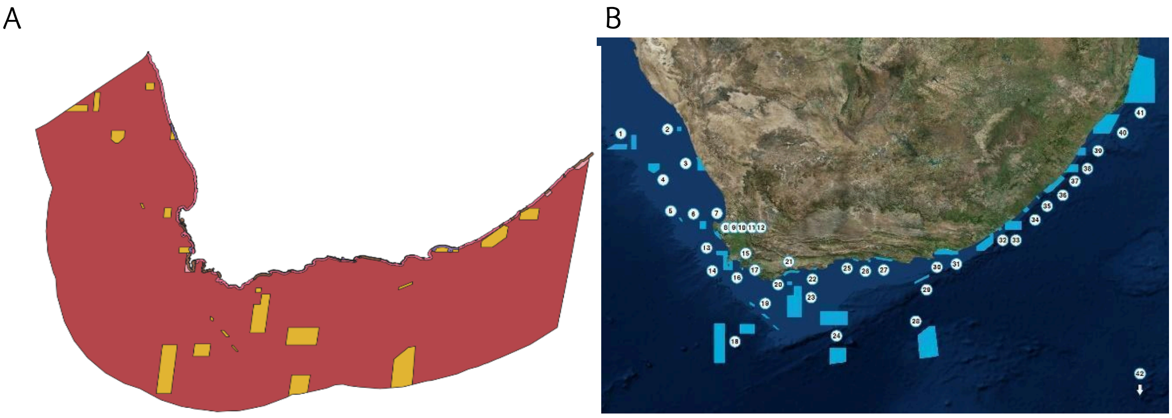


Figure 3.2.13.1. A) Map of the marine protected areas covering SA-BEN region, including 10 km inland from the coastline. B) Complete map of MPAs of South Africa.

Table 3.2.13.1. Marine protected areas from South Africa covering SA-BEN.

Name of MPA	Year of establishment	area_km2
Tsitsikamma MPA	1964	294
Table Mountain National Park MPA	1977	956
West Coast National Park MPA Network	1985	365.66
De Hoop MPA	1985	289
Rocherpan MPA	1988	1.5
Betty's Bay MPA	1990	21

Goukamma MPA	1990	34
Robberg MPA	1990	26.2
Dwesa-Cwebe MPA	1991	191.5
Hluleka MPA	1991	40.9
Helderberg MPA	2000	2.4
Sardinia Bay MPA	2000	12.9
Walker Bay MPA	2001	108
Pondoland MPA	2004	1237.3
Stilbaai MPA	2008	31.9
Amathole MPA	2011	246.5
Namaqua Fossil Forest MPA	2014	1200
Agulhas Bank Complex MPA	2018	4300
Orange Shelf Edge MPA	2019	2000
Namaqua National Park MPA	2019	500
Childs Bank MPA	2019	1335
Benguela MUD	2019	72
Cape Canyon MPA	2019	580
Robben Island MPA	2019	580
Southeast Atlantic Seamounts MPA	2019	6000
Browns Bank Corals MPA	2019	300
Agulhas Mud MPA	2019	207
Southwest Indian Seamounts MPA	2019	7500
Agulhas Front MPA	2019	6200
Port Elizabeth Corals MPA	2019	270
Addo Elephant National Park MPA	2019	1200
Amathole Offshore MPA	2019	400

Results of the calculation of the subgoal lasting special places are described in the table 3.2.13.2.

Table 3.2.13.2. Results of the calculation of the subgoal SP-LSP

Status	Trend	Score
1.0	0.0	1.0

Discussion

The status of the subgoal SP-LSP is 1.0 indicating that 30% of the marine and coastal waters are already protected, reaching the reference point established. The trend of this subgoal is 0 which reflects the data obtained for the assessment, as of the 36 MPAs assessed, 14 were established in 2019, and no more MPAs have been added.

3.2.14. Tourism & Recreation (TR)

Scope and introduction

The TR goal focuses on measuring both the number of visitors and the quality of their experiences in coastal and marine areas. While coastal tourism plays a significant role in local economies, this goal is assessed separately from its economic impact, which is covered under the coastal LE goal. Due to the limited availability of global non-economic indicators for TR, employment in the tourism sector is used as a proxy for estimating overall participation in these activities. Employment in this sector is expected to fluctuate in response to tourism demand, as changes in visitor numbers influence the need for hotel staff, travel agents, and other related professions across different regions.

Methods

To assess the subgoal, first were identified the jobs related to Biodiversity-based tourism in South Africa, which are:
1 - Accommodation services for visitors
2 - Food and beverage serving services
3 - Passenger transportation services
3.1 - Railway passenger transportation services
3.2 - Road passenger transportation services
3.3 - Water passenger transportation services
3.4 - Air passenger transportation services
3.5 - Transport equipment rental services
4 - Travel agencies and other reservation services
5 - Cultural services
6 - Sports and recreational services
7 - Retail sales of food, beverages and tobacco
8 - Retail sales of textiles, clothing, footwear and leather goods
9 - Retail sales of pharmaceutical and medical goods, cosmetic and toiletry articles
10 - Retail sales of household furniture, appliances, articles and equipment
11 - Retail sales of automotive fuel

Secondly, the data on the proportion of employees were taken from the report on the Experimental Biodiversity-Based Tourism Estimates for South Africa, 2013 to 2019 (https://www.statssa.gov.za/?page_id=1854&PPN=D0401.5). The proportion of employees is then multiplied by the sustainability index S (or TTDI), that measures the attractiveness and potential of Countries for investment and development in the travel and tourism sector, rather than its attractiveness purely as a tourist destination (Eq. 3.2.14.2). The reference point of this goal is the status value of the year with a higher proportion of employees directly involved in biodiversity-based tourism . In the SA-BEN case study, the year with higher number of employees is the year 2013 (table 3.2.14.1), and the status for this year is 1.0.

To calculate the trend, the status for each year was first estimated. A linear trend taking into account each year's status was done, then multiplying the slope by 5 to estimate the future likelihood in the next five years.

The TR goal is calculated as follows (Eq.3.2.14.1):

$$x_{tr} = \frac{T_r}{T_{90th}},$$ (Eq. 3.2.14.1)

where:

- T_{90th} is the T_r value of the year that corresponds to the 90th percentile (Eq. 3.2.14.2).

$$T_r = E \times S,$$ (Eq. 3.2.14.2)

where:

- *E* is the proportion of employees directly involved in the travel and tourism industry
- *S* is sustainability index S taken from the World Economic Forum's Travel & Tourism Development Index (TTDI) for each year that range between 4.0 - 4.13

Results

According to the Experimental Biodiversity-Based Tourism Estimates for South Africa Report, the percentage of employees involved in biodiversity-based tourism from 2013 to 2019 decreased from 14% to 11.8% (Table 3.2.14.1). However, the sustainability index did not show high variability, ranging from 4.13 to 4.0. The sustainability index is calculated on a biannual basis, therefore, for the purpose of our analysis, we performed a linear interpolation to estimate the sustainability index of the missing years. Results of the calculation of the TR goal are described in table 3.2.14.2.

Table 3.2.14.1. Proportion of employees directly involved in Biodiversity-based tourism in South Africa and sustainability index for each year.

Year	% employees	Sustainability Index
2013	14	4.13

2014	13.3	4.1
2015	13	4.08
2016	12.7	4.04
2017	13	4.01
2018	13.2	4.0
2019	11.8	4.0

Table 3.2.14.2. Results of the calculation of the TR goal.

Status	Trend	Score
0.8	-0.04	0.8

Discussion

The status of the goal TR is 0.8 indicating a good status. This result can be reflected in the sustainability index which ranges from 4.0 to 4.1 through the years of assessment. The trend is -0.04, indicating a slight decrease in the goal. This can be explained by the decrease in the percentage of employees involved in biodiversity-based tourism in SA.

3.3. Conclusions

The scores calculated for each goal are based on the status and trend. Pressures and resilience variables are not included in this report.

The current status of the Small-Scale Fishing Opportunities (SSFO) goal, reflected by a score of 0.4, indicates moderate to low potential for sustainable engagement in small-scale fishing across the studied communities in SA-BEN. While some fishing opportunities persist, multiple interlinked socio-economic and policy-related barriers are significantly constraining the sector's development. For example, poverty, unemployment, and demographic vulnerabilities collectively reduce the capacity of coastal communities to rely on fisheries as a sustainable livelihood option. Additionally, external development pressures such as rising property values and demographic shifts (e.g., retiree migration), which lead to gentrification and displacement, particularly in semi-rural and coastal areas are reducing access to small-scale fishing opportunities and disrupt long-standing community ties to fisheries. According to the NBA 2018 report, despite the economic marginality of small-scale fisheries, contributing less than 1% to SA's GDP, the sector plays an important role in food security and employment. The harvesting of marine resources such as linefish, rock lobster, and abalone offers essential protein and economic support to impoverished regions. However, the slow and incomplete implementation of the Small-Scale Fisheries Policy (SSFP), has perpetuated regulatory uncertainty and hindered long-term planning and investment in the sector. Studies by Gammage et al. (2021) highlights several pressures in SA affecting small-scale fisheries, including low economic growth, policy delivery gaps, and institutional fragmentation. These systemic issues have stalled the development of the small-scale fisheries sector. Concerns over resource scarcity, limited alternative employment opportunities, and weak institutional support are echoed throughout their analysis.

Based on the results of the BD-HAB subgoal analysis, we conclude that a status of 0.8 indicates a relatively low risk level for marine ecosystems in the SA-BEN region. This results aligns with the NBA 2018 (Sink et al., 2019) report which states that the recent expansions in MPAs, passing from less than 0.5% (approximately 4900 km^2) in 2018 to 5.4% (57900 km^2) in 2019 with the addition of approximately 53000 km^2 of protected area, have significantly improved ecosystem protection. However, the NBA 2018 report also mentions that 50% of South Africa's marine ecosystem types are threatened. The discrepancy might arise from differences in geographic coverage, classification methodologies, and assessment approaches, as the NBA covers the entire South African marine area, whereas this study focuses specifically on the SA-BEN region and has a different classification of the habitats. For example, in the NBA 2018, 150 marine ecosystem types were classified for the marine realm, and its classification system consists on ecoregions, bathyregions, substratum, and ecosystem types (Sink et al., 2019); while the classification system used in the BD-HAB for SA-BEN consists on macro-categories which were selected according to similarities in areas and its ecosystems (see table 5.3.1.) and allows us to compare the 2018 data with the 2011, a necessary step to assess the trend. The possible discrepancy highlights the need for continued and standardized monitoring methods, and also increased conservation efforts. Therefore, refining ecosystem classification, improving assessment methodologies, and addressing data gaps will be essential for accurately tracking the state of marine biodiversity and ensuring long-term ecosystem resilience in the SA-BEN region.

Based on the results of the species BD-SPP, we conclude that the status of 0.9 reflects a generally low risk level for marine species in the Benguela region, with 80% of the 367 assessed species classified as Least Concern or Near Threatened. However, this assessment has limitations in historical records and risk assessment of all species in the IUCN Red List. Another limitation is the spatial coverage of the IUCN database, as we considered only species relevant to the SA-BEN region, excluding those with broader ranges that were not specifically analyzed in our case study. This aligns with the NBA 2018 report which states that 17% of assessed species are classified as data deficient, limiting our understanding of marine species status and trend, due to knowledge gaps in taxonomy, long term population trends and life history limit. Like the NBA 2018 report, this study encompasses a broad range of marine species beyond those of economic importance, including seabirds and turtles, providing a more comprehensive understanding of marine biodiversity in Southern Benguela.

According to the results of the CP and CS goals, we conclude that tidal flats contribute the most to coastal protection and carbon storage due to their extensive coverage, high protectiveness rank, high sequestration flux, and low percentage of yearly loss. Since the data used for this assessment is derived from global habitat distribution maps (seagrass, tidal flat, and saltmarshes), it is not directly comparable to the habitat classifications in the NBA 2018 report, as those habitats are not included or classified within the report. According to the NBA 2018 report, key coastal protection habitats in SA include dunes, kelp forests, and beaches, and deep sea ecosystems are key ecosystems for carbon storage and sequestration. Therefore, to calculate the status of CP and CS goals following the OHI global methodology, we relied on global data and extracted the relevant information for SA-BEN.

Based on the results of the LE-ECO (score 1.0) and LE-LIV (score 0.9) subgoals, the blue economy sectors in SA-BEN have strong performance, aligning with the objectives of Project Phakisa (https://www.operationphakisa.gov.za/Pages/Home.aspx). These findings reflect economic growth, increased productivity, and sector expansion, and the positive trends indicate sustained progress over time. Employment has shown modest but steady growth, indicating that further improvements are needed to enhance equitable well-being and job sustainability. These results highlight the ongoing transformation of the blue economy in SA-BEN, emphasizing both its successes and areas for continued development.

The major contributors to the NP goal (0.5 score) are the category of fish oil and fish meal, derived from the intersection of FAO database and SAUP database. This result contrasts with the NBA 2018 report which states that seaweeds, including microalgae, are the major contributors to natural products from marine organisms. The NBA 2018 report also mentions that in South Africa, other marine organisms play an important role in the provision of natural products. For example, marine invertebrates present a unique collection of metabolites that have potential use in the medical field. Among these, three South African marine invertebrates, the endemic hemichordate worm *Cephalodiscus gilchristi*, the ascidian *Lissoclinum* sp., and the endemic sponge *Topsentia pachastrelloides*, exhibit significant potential for commercial applications due to their bioactive properties, drawing international interest (Sink et al., 2019). Fish oil and fish meal, and ornamental fish are not mentioned in the report as contributors of natural products for SA, particularly SA-BEN.

Based on the results of the SP-ICO subgoal (Score 0.5), we conclude that these iconic species continue to face significant conservation challenges as of the 14 assessed species, only one is classified as Least Concern, while the rest range from Near Threatened to Critically Endangered (based on the IUCN data, https://www.iucnredlist.org), with no improvements recorded since the previous assessment, as it is indicated by the trend (see table 5.13.2.). The lack of change in their risk status suggests that current conservation efforts may be insufficient to improve their conditions. Continued monitoring, strengthened protection measures, and targeted conservation strategies are important for mitigating threats and ensuring the conservation of these iconic marine species in SA, particularly SA-BEN region.

Based on the results of the lasting special places (SP-LSP) subgoal, we conclude that the protection of South Africa's marine and coastal waters has significantly improved, particularly with the establishment of 14 new MPAs in 2019 for the SA-BEN, and a total of 20 new MPAs proclaimed for the whole country. According to our results, 30% of the marine waters of SA-BEN are under formal protection, meeting the established reference point for this study. However, according to the NBA 2018 report, the protection level is not equal for all MPAs, with 31% now classified as Well Protected and 41% as Moderately Protected. Nevertheless, previously unprotected ecosystems have seen progress, with a significant reduction in the number of Not Protected ecosystem types, decreasing from 47% in 2018 to 13% today (Sink et al., 2019). These MPAs provide vital ecological, socio-economic, and climate resilience benefits, including safeguarding marine biodiversity, supporting local communities, preserving cultural values, and aiding in climate change mitigation.

Based on the results of the TR goal, we conclude that the sector is expanding and holds significant potential, particularly following the establishment of Operation Phakisa in 2014. Operation Phakisa is a South African government initiative aimed at accelerating the implementation of key solutions for critical development challenges outlined in the National Development Plan (NDP) 2030. It focuses on setting clear targets and action plans through collaboration with stakeholders from the public and private sectors, academia, and civil society organizations. One of its objectives is the establishment of new Marine Protected Areas (MPAs) to support sustainable fisheries, enable responsible use by various economic sectors, and protect offshore species and ecosystems (https://www.operationphakisa.gov.za/Pages/Home.aspx). Results of the TR goal aligns with the NBA 2018 report which states that the marine wildlife tourism sector in SA has increased, including activities such as tour guiding, scuba diving, shark cage diving, and turtle, bird, and whale watching. South Africa's oceans are home to unique species found nowhere else in the world, offering extraordinary marine wildlife encounters that attract both local and international tourists.

According to the FP-FIS subgoal assessment, the final score varies depending on the dataset used. Although both datasets focus on species critical to SA-BEN fisheries, such as hake, horse mackerel, and squid, the DFFE report provides B/BMSY assessments for a limited number of key species, while the RAMLDB database offers a broader temporal range, covering more stocks and enabling long-term trend analysis. The final FP-FIS subgoal score reflects these differences. The CMSY method, constrained by its reliance on catch data alone, results in a status of 0.57 and a trend of 0.27, resulting in a final score of 0.73. Using DFFE data, the status improved to 0.96, though the trend could not be calculated. These results highlight the importance of robust data sources in accurately assessing fisheries sustainability.

According to the FP-MAR subgoal assessment, the final score (1.0) indicates that aquaculture in SA-BEN operates in a sustainable manner. These results are expected as indicated by WWF SASSI List (https://wwfsassi.co.za/sassi-list), where the six analysed species are sustainably farmed with a sustainable score of 0.9 each. According to WWF SASSI List, the Japanese meagre (*Argyrosomus* *japonicus*), Rainbow trout (*Oncorhynchus mykiss*) and Abalone (*Haliotis midae*) are farmed in semi-closed ponds, cages, fenced-off pieces of river, and special tanks that are housed undercovered and with a recirculating system, with low environmental impact due to negligible nutrients discharge, low risk of salinization, disease outbreak, and escape. Mediterranean mussel (*Mytilus galloprovincialis*) and Pacific oyster (*Crassostrea gigas*) are farmed using suspended ropes with limited damage to the environment (waste settled on the seafloor). The WWF SASSI list indicates that Yellowtail amberjack (*Seriola quinqueradiata*) is not farmed in SA-BEN, however, as the FAO dataset includes the species, we assumed a sustainable index of 0.9 for the species. Although it was not possible to calculate the trend due to lack of data, we conclude that aquaculture in SA-BEN has been increasing, as according to InvestSA, the South Africa's investment promotion agency from the Department of Trade, Industry and Competition (https://www.investsa.gov.za/wp-content/uploads/2021/03/FACT-SHEET_AQUACULTURE_2020.pdf), the aquaculture sector contributes approximately 0.8% to national fish production and less than 0.2% to GDP and has been identified as a priority for development under Operation Phakisa due to its significant growth potential. Aquaculture (both marine and freshwater) is practiced on around 200 farms, producing more than double between 2006 and 2016. Key species include abalone, catfish, trout, finfish, mussels, oysters, and tilapia. In 2018, fish and seafood exports reached US$500 million, with molluscs, particularly abalone, accounting for nearly one-third. South Africa is a leading global producer of premium farmed abalone (*Haliotis midae*), yielding approximately 1,700 tonnes annually.

The assessment of the CW goal was conducted taking into account only the marine debris measure due that plastic pollution data was available. The microplastic pollution component was extracted from the calculation of the CW goal for the Atlantic. According to the assessment, the status of the CW goal is 0.5, suggesting that the impact of plastic pollution in marine environments is moderated relative to national plastic production levels. The IUCN-EA-QUANTIS (2020) report mentions that plastic leakage into oceans and rivers in SA is estimated at approximately 107,000 tonnes per year, representing around 5% of the country's total annual plastic waste generation. The result of the assessment supports a study conducted by Ryan et al. (2020) where they have characterized beach plastic and other anthropogenic litter (from micro to megalitter items) in the West Coast National Park, SA. The study revealed that the overall plastic density (1.2 kg/m) was lower than global model predictions, showing a large discrepancy between the standing stock of beach litter and the global estimate of land-based leakage, suggesting that solid waste leakage from SA is overestimated by roughly an order of magnitude. Although there was no data on oil spill pollution, existing research highlights significant pollution pressures from petroleum activities and general coastal contamination in SA (Adeniji et al., 2017). The NBA 2018 report mentions that petroleum-related activities, including seismic surveys, oil spills, and infrastructure installation, have direct and indirect threats to marine ecosystems, particularly on the Agulhas Bank. The greatest concern is the potential for oil spills, which could severely impact marine biodiversity. Beyond petroleum activities, coastal pollution remains a critical but poorly understood challenge. Microplastics, chemical pollutants, and wastewater discharge have been documented across SA coastal waters, affecting marine life and potentially entering the human food chain (Sink et al., 2019). However, there is limited national-scale research to fully understand the long-term ecological, economic, and health impacts. Addressing these pollution sources requires better regulatory measures and a stronger focus on land-based pollution management to protect marine resources and ensure sustainable coastal development. While the current status score for the CW goal suggests minimal impacts from marine debris relative to national production, it is important to note that this assessment does not incorporate pressures and resilience factors that could significantly alter the final score if adequately measured and integrated.

4. Integrated calculation of OHI at the regional level: Galicia

4.1 Introduction

Galicia is one of the 17 autonomic regions of Spain, located in the northwestern Iberian Peninsula, and represents one of the most productive and socioeconomically significant marine regions in Europe. Its 1,498km of intricate coastline (Elorrieta & Rubio, 2007) is defined by the Rías, coastal inlets which support a mosaic of habitats, ranging from extensive intertidal zones and estuaries to kelp forests and offshore upwelling systems. The richness in biodiversity and habitats is mostly due to Galicia's location on the boundary of the Canary upwelling system, leading to a fertile coastal environment with a high rate of primary production (Bode, 2011). These dynamic oceanographic and geomorphological conditions fuel planktonic productivity and support diverse trophic networks, making Galicia a key area for fisheries, aquaculture, and coastal tourism within the Northeast Atlantic region (Labarta, 2019).

However, Galicia's marine and coastal ecosystems are also exposed to complex and growing anthropogenic pressures (Villasante et al. 2022). These include overexploitation of some key fisheries resources, habitat modification due to coastal development, pollution from land-based and maritime sources, and the cumulative effects of climate change impacts (Álvarez-Iglesias, 2020). The intensification of human activities over the past century—particularly industrialization, port expansion, and the rapid development of aquaculture—has increased competition for marine space and challenged the region's capacity to maintain ecosystem integrity. At the same time, Galicia remains deeply dependent on the ocean for its social and economic wellbeing, where the shellfishing and fishing industry employs 20% of the population (IGE-INE, 2024), providing a direct livelihood to tens of thousands of people (de Santiago et al. 2025).

The Ocean Health Index (OHI) (Halpern et al., 2012) provides a framework to study ocean health by combining ecological, economic, and social dimensions into a single composite measure of ocean system performance. We conducted the first regional OHI+ assessment at the scale of the Galician coastline to understand the health of Galicia's relationship with the Atlantic ocean, considering both the marine ecosystem benefits obtained from it as well as the damages caused by anthropogenic interactions with it. The OHI conceptualizes ocean health as the sustainable capacity of marine ecosystems to deliver a set of benefits to people, expressed through ten goals representing key ecosystem services: (1) food provision, (2) artisanal fishing opportunities, (3) natural products, (4) carbon storage, (5) coastal protection, (6) tourism and recreation, (7) livelihoods and economies, (8) sense of place, (9) clean waters, and (10) biodiversity. Each goal is quantified using a standardized methodology that integrates current status, recent trends, cumulative pressures, and resilience indicators to estimate both present and likely future conditions.

Applying the OHI at the regional level has the potential to capture spatial heterogeneity and local dynamics that are often masked in global or national assessments. The Galician marine system is particularly suited for this type of regionalized evaluation, as it encapsulates the intersection between high ecological productivity, dense human occupation, and a strong maritime culture. Moreover, Galicia's administrative and data structures - through the Instituto Galego de Estatística (Galician Statistics Institute), the Consellería do Mar (Galician Sea government), and the Instituto Español de Oceanografía (Spanish Oceanography Institute) offer a good foundation for regional data integration of these results and the use for the decision making process. The availability of complete and reliable data allows for a more refined and realistic depiction of the ocean health conditions and trends compared with more coarse, global-scale models which might not reflect the local particularities.

From a governance perspective, Galicia has been a pioneer in developing regional marine management frameworks within the broader context of the European Union's Integrated Maritime Policy and the Marine Strategy Framework Directive (EU, 2008). Initiatives such as the Blue Economy strategy (Estratexia Galega de Economía Azul) (Xunta de Galicia, 2024), which aims to align economic growth with ecological sustainability, promoting innovation in fisheries, aquaculture, renewable energy, and marine biotechnology, has been recently approved. Despite these advances, key gaps remain in connecting ecological indicators with socioeconomic performance in a coherent, quantitative framework to monitor the health status of the Galician coasts. Applying the OHI approach addresses theses gaps by facilitating the translation of datasets from diverse domains into a single, integrative measure that can guide decision-making toward ecosystem-based management and sustainable blue growth.

In this study, the OHI framework is applied to Galicia's coastal and marine systems with the objective of assessing the integrated health of its ocean-related sectors. The analysis focuses on four representative goals—Biodiversity–Species (BD-SPP), Economy (ECO), Livelihoods (LIV), and Tourism and Recreation (TR).

The Biodiversity–Species (BD-SPP) goal evaluates the conservation status of marine species using IUCN Red List data, providing an indicator of ecosystem integrity and resilience. Galicia's marine biodiversity includes numerous commercially and ecologically important species—such as the European hake (*Merluccius merluccius*), sardine (*Sardina pilchardus*), octopus (*Octopus vulgaris*), and various shellfish species—that are vital to not just the local economy but the functioning of the Galician bays. However, pressures from overfishing, habitat degradation, invasive species, and climate-induced changes in ocean temperature and pH threaten these marine resources and many other species in the region, putting also at risk the livehoods of thousands of people who rely on them (Halpern, 2007). Assessing biodiversity status through an integrated indicator such as the

Biodiversity goal provides an essential ecological baseline for understanding the current state of Galicia's coast and its future trajectory.

The Economy (ECO) goal measures the performance of the marine and coastal economy relative to its historical maximum, incorporating indicators such as Gross Value Added (GVA) and sectoral output across maritime industries. Galicia's economy is profoundly maritime in character: fisheries, aquaculture, and seafood processing collectively represent over 5% of the regional GDP (IGE-INE, 2024), while emerging sectors such as offshore renewable energy and marine biotechnology are increasingly significant (Red Eléctrica de España; 2021).

The Livelihoods (LIV) goal complements the economic perspective by focusing on employment and income stability in marine-dependent sectors. The social dimension is particularly relevant for Galicia, where coastal communities maintain a strong cultural and occupational connection to the sea (Carril, 2013). The region's workforce has demonstrated notable adaptability in the face of external shocks, such as the 2008 financial crisis and the COVID-19 pandemic, but remains vulnerable to structural changes in global markets and environmental variability (Amoedo and Sánchez-Carreira, 2023).

Finally, the Tourism and Recreation (TR) goal captures the cultural and recreational benefits derived from the coastal environment, a sector that has grown steadily in recent decades. Galicia's "beach and sea" tourism model is being progressively diversified toward cultural, gastronomic, and eco-tourism, aligning with sustainable tourism strategies at the European and regional levels (Turespaña, 2022; Eurostat, 2023).

Together, these four goals provide a multidimensional understanding of Galicia's ocean health—linking biodiversity conservation, economic productivity, social well-being, and cultural value within a unified analytical framework. The methodological consistency of the OHI enables comparison not only across goals but also through time, allowing trends in regional ocean health to be tracked and contextualized within larger European and global patterns.

The main objectives of this work are therefore 1) To adapt and apply the OHI framework to the Galician coastal and marine system at a regional scale, integrating ecological, economic, and social data sources; 2) To assess the current status and trends of selected OHI goals (Biodiversity–Species, Economy, Livelihoods, and Tourism & Recreation) for Galicia; and 3) To identify the strengths and limitations of the OHI methodology in capturing local ocean health dynamics and to discuss implications for regional policy and marine governance.

Through this analysis, the OHI serves not only as an evaluative tool but also as a strategic instrument for supporting Galicia's transition toward a sustainable relationship with the ocean. The integrated perspective offered by the OHI aligns with the principles of ecosystem-based management, where the sustainability of ocean benefits depends on maintaining ecological integrity, economic viability, and social equity (Long et al., 2015). In the context of accelerating global change and increasing maritime pressures, the regional application of the OHI provides evidence-based estimates for the science–policy interface on the behalf of the sustainable management of Galicia's marine and coastal resources.

4.2 MATERIAL AND METHODS

4.2.3 Biodiversity – Species (BD-SPP)

Scope and introduction

To assess the conservation status of marine and coastal species within a region by evaluating their risk of extinction based on IUCN Red List categories.

Methods

To assess the Species subgoal of the OHI for Galicia we estimated the condition of marine species within the Galician marine environment by measuring spatial overlap between species ranges and a standardized marine planning unit framework. The species ranges employed were the global species distribution data (IUCN, 2019) provided by the International Union for Conservation of Nature (IUCN). The study area was defined through a buffer extending from the Galician coastline to the outer limit of the Exclusive Economic Zone (EEZ). Both the buffer and the distribution maps were processed in R and transformed to a consistent projected coordinate reference system (EPSG:3857) to ensure accurate area calculations. Within this buffer, a uniform spatial grid was generated with cells measuring 55 kilometers by 55 kilometers, and each grid cell was clipped to the EEZ boundary.

The global species range maps from the IUCN include polygon representations of species' native or resident ranges along with associated metadata such as conservation status and habitat type. These shapefiles were preprocessed to retain only those species classified as marine (i.e., where the "marine" attribute was true) and assigned to one of the IUCN threat categories considered in OHI assessments: Least Concern (LC), Near Threatened (NT), Vulnerable (VU), Endangered (EN), Critically Endangered (CR), and Extinct (EX). Categories such as Data Deficient (DD) were excluded from the analysis due to their inherent uncertainty or lack of relevance in this spatial context. For each valid species shapefile, we applied a spatial intersection between the species distribution and the clipped grid and computed the area of overlap in square kilometers. Risk weights were assigned to each species polygon based on its IUCN category, following a standardized scale where LC was weighted as 1.0 (indicating the lowest conservation concern) and EX was weighted as 0.0 (indicating complete loss). Intermediate categories received progressively lower scores: NT = 0.8, VU = 0.6, EN = 0.4, CR = 0.2.

For each species, we aggregated data across all intersected grid cells to calculate a mean weighted risk score. This was done by multiplying the area of each grid intersection by the corresponding risk weight, summing these values across the entire range of the species within the buffer, and dividing by the total area of overlap. The outcome of these calculations is a risk score that reflects the average conservation concern of the species, based on both its spatial extent and IUCN status. To convert this risk score into a biodiversity score suitable for OHI reporting, we applied a linear normalization formula that rescales the mean risk to a 0–1 scale: score = (mean risk – 0.25) / (1.0 – 0.25). This transformation ensures that species with average risk weights at or above the threshold of 0.25 receive proportionally higher biodiversity scores, with upper and lower bounds enforced to constrain scores between 0 and 1.

To identify potential invasive species within the dataset, we cross-referenced observed species against two authoritative sources. First, we extracted marine invasive species listed in Bañón et al. (2013) in his publication regarding marine exotic species in Galicia. Second, we incorporated species from the official invasive species list maintained by the Government of Spain, Catálogo Español de Especies Exóticas Invasoras (Gobierno de España, 2013). Scientific names from both sources were standardized to lowercase and cleaned of formatting inconsistencies. These were merged with a manually curated list of additional species of interest. The combined list was then matched against our primary dataset to identify species present in the study area that are recognized as invasive. To ensure broader taxonomic coverage, we also searched for partial matches using a set of predefined taxonomic keywords (e.g., Herpestidae, Channa, Ludwigia).

Results

A total of 766 marine species overlapped spatially with the Galician marine planning units within the EEZ buffer. Among these, 31 species had sufficient temporal records (more than one observation) to assess population trends. Of these, 13 species exhibited decreasing trends, while 18 showed increasing trends, resulting in an overall trend score of zero, indicating a balance between species increases and declines.

No matches were found between our species dataset and the regional invasive species lists from Bañón et al. (2013) and the Catálogo Español de Especies Exóticas Invasoras (Gobierno de España, 2013), suggesting an absence of invasive species within the study area.

Table 4.2.3.1 Results of the calculation of the BD-SP goal.

Status	Trend	Score
100	0.57	--

Discussion

The Biodiversity–Species (BD-SPP) assessment for Galicia produced a very high status score, suggesting that marine species within the region's EEZ are generally in good condition. However, this result should be interpreted cautiously, as several methodological factors likely contribute to an overly positive picture of biodiversity health.

The use of the IUCN is recommended by the global method, however a key limitation arises from the use of global IUCN range maps, which depict potential distributions rather than confirmed local occurrences. Many of the area polygons present in the files extend into areas where species are no longer present, particularly in heavily exploited or altered coastal zones. As a result, the spatial overlap approach tends to exaggerate species presence and inflate conservation status. This issue is compounded by the use of global IUCN threat categories to assign risk weights. While valuable at broad scales, these categories may not capture local population declines or region-specific pressures (Herkt, 2017). A species considered "Least Concern" globally may, in reality, be declining or overfished in Galician waters. For some of the species where timeseries is available, for example in the case of the salmon, a neutral trend is observed in the calculation while previous work done in the Galician populations (Javierre, 2020), shows a population decrease, indicating an overestimation in the calculations that is uneven across species.

Another factor is the averaging method used to derive the regional score. Because the analysis gives equal weight to every species, the large number of common, low-risk taxa dominates the calculation, masking declines in smaller groups of vulnerable or ecologically important species (Edgar, 2025). The exclusion of Data Deficient taxa further enhances this bias by removing species that are poorly known but potentially at risk. Limited temporal information also weakens the trend estimate; many species lack consistent monitoring records, reducing the sensitivity to detect long-term changes. This is illustrated by the large count difference in species that contribute to the status calculation versus the trend (766 vs. 31).

Recent ecological studies indicate that Galician marine ecosystems are undergoing significant transformations, including warming-driven shifts in species composition, declines in benthic communities, and the arrival of non-native species (Bañón et al., 2024). These dynamics are not well captured by the current OHI framework, which emphasizes static range and category data. Together, these issues suggest that the high BD-SPP score reflects methodological optimism rather than a complete ecological reality.

Conclusions

The OHI Biodiversity–Species assessment for Galicia indicates a very high status of 100, reflecting that most marine species are categorized as low-risk based on global IUCN ranges, while the trend of 0.57 suggests a moderate positive trajectory; however, these scores likely overestimate actual biodiversity health due to methodological limitations and limited local data.

4.2.9 Livelihoods and Economy - Economy

Scope and introduction

The aim of this goal is to measure the amount of benefit obtained by society from ocean related activities.

Methods

In the global OHI, the status of the Economy sub-goal (ECO) is calculated as current adjusted revenue relative to a moving baseline, five years prior in the case of the 2024 assessment, with values adjusted for inflation and national GDP. The trend is estimated as the GDP-corrected slope of sector revenues over the past five years, weighted by each sector's contribution. For the Galician regional assessment, we extracted the annual economic accounts dataset from the Galician statistics institute (IGE, 2024). The dataset provides annual estimates of gross value added (GVA)-produto interno bruto (PIB) disaggregated by economic activity (rama de actividade) over the period 2000–2022.

The first step was to identify which activities are considered part of the blue economy. Following the established classifications in the global methodology, the selected activities comprised fishing, aquaculture, fish processing, coastal tourism (including accommodation, food services, travel agencies, and sports and recreation), maritime transport, port and harbour services, shipbuilding, ship repair, water and waste management and energy. To operationalize the proposed classification, the selected activities were grouped into thematic sectors. Each sector was then assigned a proportional weight reflecting the extent to which its activity can be attributed to the blue economy. For example, marine living resources were considered to contribute fully to the blue economy (100 percent), whereas other activities were weighted according to their estimated coastal or marine dependence: coastal tourism (66.8%), maritime transport and port services (27.4% each), shipbuilding (90%), ship repair (15%), and water and waste management (100%). These percentages were derived from the report developed by Sherpa do Mar (2020), which provides benchmark estimates of the relative contributions of different marine-related sectors. In this report however, not all sectors are included. Therefore, with regard to the energy sector, a rough estimation was conducted to identify the share of production attributable to coastal areas. This involved mapping the geographic distribution of wind farms and estimating the proportion of energy production originating from installations located within coastal zones. The same procedure was applied to other subsectors, including hydraulic, waste-to-energy, and cogeneration from biomass and biogas. The results are summarized in Table 4.2.9.1, which compares the marine-related share of each energy source against total production.

Table 4.2.9.1. Proportion of marine-related share of each energy source against total production.

	Marine percentage	Total percentage	Marine percentage over the total
Windmills	31.4	30.5	9.6
Hydraulic	6	29	1.74
Residuals	5	5	0.25
Cogeneration (biogas and biomass)	43.7	35	15.3
		Total:	26.9

In addition, the pulp and paper industry was incorporated into the estimation for two main reasons. First, the Ence factory is located directly on the Ría of Pontevedra, in one of the region's most productive shellfish areas, thereby exerting a significant influence on the coastal and marine environment. Second, the facility contributes to biomass energy production, which is directly relevant to the energy component of the blue economy.

Prior to estimation, the dataset was cleaned and formatted. Placeholder and non-numeric entries, such as ".." or blank fields, were recorded as missing values. Numeric variables were standardized by removing formatting characters and coercing them into numeric format. Yearly columns were then renamed with consistent four-digit labels for time-series analysis. Annual Blue GDP was calculated as the weighted sum of GVA across all blue economy sectors. Specifically, for each year, the GVA of all activities within a sectoral group was aggregated and multiplied by the corresponding weight, and these weighted values were summed across groups. To facilitate comparability, the resulting time series was normalized by dividing each annual observation by the maximum Blue GDP observed in the 2000–2022 period, yielding an index bounded between 0 and 1.

From this normalized series, two indicators were derived. The first, the status indicator, was defined as the normalized Blue GDP in 2022 relative to a reference year within the preceding decade. Where no suitable benchmark was available, the most recent available year was employed. The second, the trend indicator, was estimated as the slope coefficient of a linear regression fitted to normalized Blue GDP for the years 2018–2022, thereby capturing the average annual rate of change over the most recent five-year period.

Results

The estimation of the Galician Blue Economy showed temporal dynamics in the contribution of marine-related sectors to the regional economy, as illustrated in Figure 4.2.9.1. In this figure, the evolution of revenues per sector and year across the different blue economy activities and the pulp and paper industry (ENCE) are plotted. The time series shows a marked increase in the contribution of coastal tourism and marine living resources during the 2000–2008 period, followed by a contraction associated with the 2008 global financial crisis. From 2010 onwards, most sectors recovered gradually, although the shipbuilding and ship repair industries exhibited slower growth compared to tourism and aquaculture.

The incorporation of the energy sector, with marine-related shares disaggregated by source, highlighted the relevance of coastal wind power and biomass/biogas-based cogeneration to the regional blue economy. Together, these two sources accounted for more than 25% of marine-attributed energy production.

In the case of Galicia, the pulp and paper industry has a higher economic benefit than marine transport or shipbuilding, hence the importance of including it in the assessment. This further emphasises the significance of coastal industrial facilities with direct impacts on marine and estuarine ecosystems.

The calculation of the normalized Blue GDP index showed that 2022 represented the historical maximum in the 2000–2022 period. Consequently, the status indicator reached a value of 1, reflecting the highest level of blue economy performance observed within the available time series.

The trend indicator, based on the slope of normalized Blue GDP over 2018–2022, was estimated at 0.034, indicating a positive but moderate growth trajectory over the past five years. This suggests that, while the regional blue economy continues to expand, the rate of increase has stabilized compared to earlier periods of more rapid growth.

The final results of the ECO goal calculation are summarized in Table 4.2.9.2.

Overall, the results indicate that Galicia's blue economy is currently performing at peak levels, with a stable and slightly upward trajectory in recent years. The strong performance of coastal tourism, aquaculture, and renewable marine energy sources are the primary drivers of this positive outcome, while shipbuilding and repair remain comparatively weaker contributors.

Figure **4.2.9.1**: *Revenue per sector and year across the blue economy sectors and the paper industry (ENCE)*

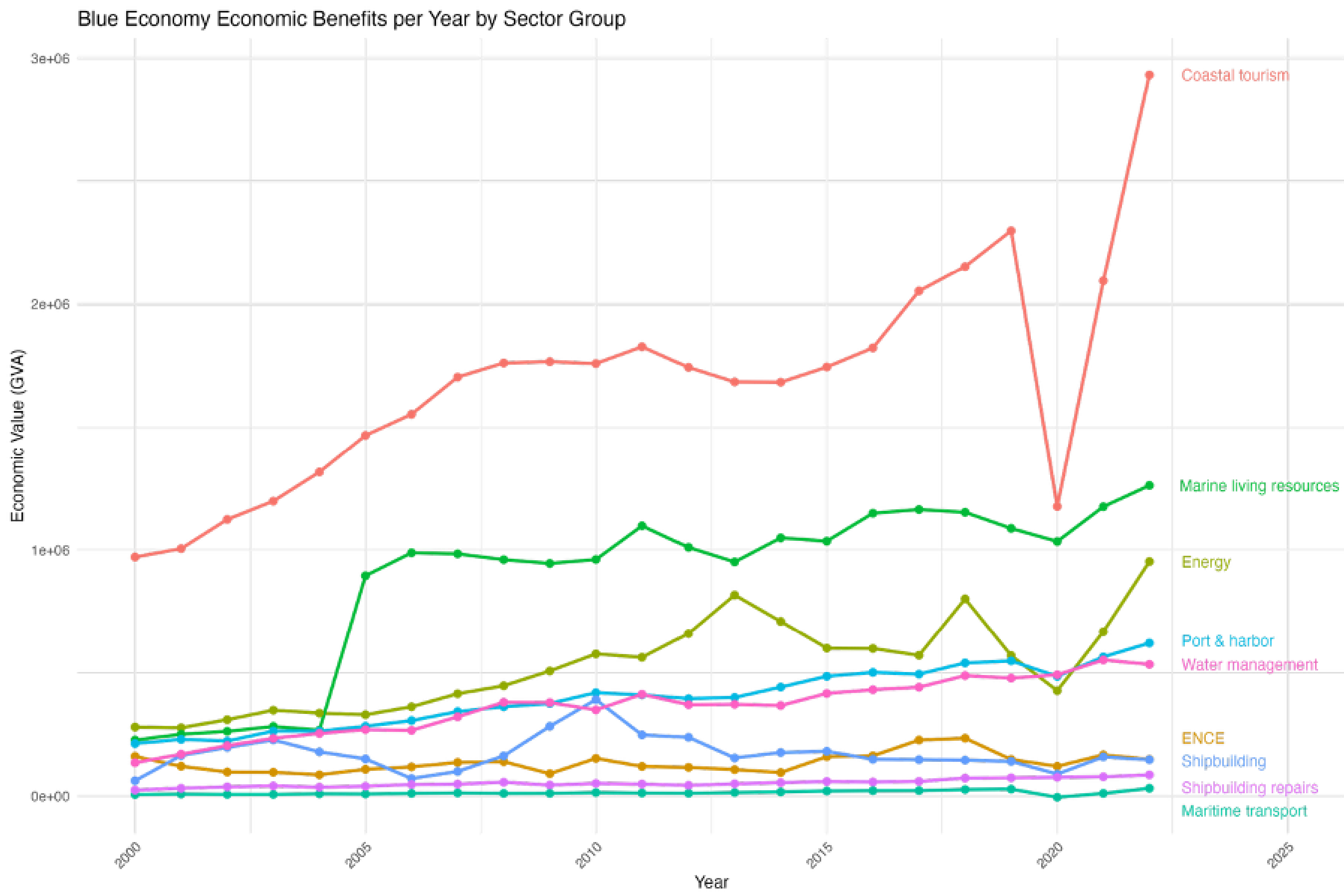


Table 4.2.9.2 . Results of the calculation of the ECO goal.

Status	Trend	Score
100	0.03	--

Discussion

The results of the assessment indicate that the Galician economy is performing well, even in the aftermath of the COVID-19 pandemic. As in most regions, the pandemic generated severe disruptions across economic sectors, with the exception of ship repair, which remained stable. Tourism experienced the steepest decline, followed by the energy sector. This outcome is consistent with the restrictive mobility measures imposed during the pandemic, when both governments and society at large discouraged non-essential travel. Consequently, demand for tourism collapsed, and this decline indirectly affected the energy sector through reduced transport activity and lower overall consumption.

Although many sectors have since recovered, the heavy losses sustained during the pandemic may explain the current slow but positive growth trend. Despite recovery, the sectors continue to compensate for past contractions, which dampens the apparent growth rate. An alternative explanation for this high score could be that Galicia may already be approaching its maximum potential in terms of blue economy development. Under this interpretation, the current level of economic activity represents the upper limit of what can be achieved with the existing infrastructures, meaning that further expansion would require substantial new investment or structural transformation.

Tourism illustrates this dynamic particularly well. Since the late 1990s, the number of visitors to Galicia has more than doubled (INE; IGE). In 2025, hotel occupancy rates reached 76% (Clusturismo Galicia, 2025), and the upward trend continues both in the number of arrivals and overnight stays (Agencia de Estratexia e Innovación Turística de Galicia, 2025). This growing demand has not only generated direct economic benefits but has also spurred additional investment in tourism infrastructure, as reflected in the regional government's recent allocation of 146 million euros to support modernization initiatives in the sector (Xunta de Galicia — Turismo de Galicia, 2024).

The decision to include the Ence pulp and paper factory in the calculation was motivated by two considerations. First, its location directly on the Ría positions it as a significant actor influencing one of Galicia's most productive shellfish areas. Second, the facility contributes to biomass-based energy generation, which directly links it to the energy component of the blue economy. Incorporating Ence therefore provides a more comprehensive representation of industrial activities with direct coastal and marine impacts, while also capturing the role of non-traditional sectors in the transition towards renewable energy and a more sustainable interaction with coastal areas.

Conclusions

Galicia's score of 100 for the Economy subgoal reflects a resilient blue economy that has largely recovered from the pandemic with a slight positive trend indicating that Galicia is approaching its current growth potential, particularly in tourism and sustainable industrial activities.

4.2.10 Livelihoods and Economy - Livehoods

Scope and introduction

The aim of this goal is to measure the number of jobs and their quality from ocean related activities.

Methods

The global methods for the Livelihoods subgoal (LIV) assess the quantity and quality of marine-related jobs, combining total jobs and average PPP-adjusted wages per sector. Jobs are summed across sectors and compared to a moving baseline, typically five years prior, to account for temporal changes, while wages are benchmarked to the highest observed value across regions. Sector-level data are aggregated and combined to calculate overall status. Trend is estimated using linear slopes over the most recent five years for jobs and wages, weighted by sectoral employment, and averaged to derive the regional livelihoods trend, reflecting short-term changes in coastal employment.

In this regional assessment the jobs and salaries data was obtained from the Galician Institute of Statistics (IGE) dataset (https://www.ige.gal/igebdt/selector.jsp?COD=9610) to assess the livelihoods subgoal for the region. From the dataset, we selected two key variables: total salaries ("D.11 Soldos e salarios") and number of jobs ("Postos de traballo"). Data was reshaped into a long format with one row per sector, year (2015–2023), and variable, and non-numeric characters were removed to convert values into numeric form.

Sector-level data were aggregated to the regional level for the years 2018–2022, summing jobs across sectors and averaging wages across sectors to obtain mean adjusted wages per job. The reference value for wages was defined as the maximum mean wage observed across all sectors and years, while the reference for jobs was determined using a moving baseline approach: the jobs value in a recent past year, with a preferred gap of five years and alternative gaps ranging from one to ten years.

The status of the livelihoods subgoal for each year was calculated as the mean of two components: jobs status (current jobs relative to the reference jobs) and wages status (current average wages relative to the global maximum), with values constrained between 0 and 100. The final livelihoods subgoal status was computed as the mean of annual statuses over 2018–2022. The trend was estimated by fitting a linear model of livelihoods status versus year, with the slope scaled according to the OHI convention (slope × 5 / 100) to represent the 5-year trend.

Results

The Galician marine and coastal sectors exhibited a generally positive socio-economic trajectory between 2018 and 2022. Weighted employment initially had a slight decrease in 2019 relative to the moving baseline, followed by a steep fall in 2020 to then switch to a steady recovery in the subsequent years, reaching its maximum in 2022. The steep fall seen in 2020 corresponds to the Covid outbreak, and it is mostly notable for the tourist sector. Wages remained comparatively stable, peaking in the final year of the assessment. Aggregated livelihoods status, calculated as the mean of jobs and wages statuses, ranged from approximately 53% in 2019 to 100% in 2022, yielding an overall mean status of 82% for the five-year period. The trend in livelihoods status showed a moderate positive slope, indicating gradual improvement over time.

Sectors assigned higher shares, such as marine living resources (fishing and mariculture) and coastal tourism, contributed most significantly to the aggregated status, whereas lower-weighted sectors, including energy and transport, had a proportionally smaller impact.

Figure 4.2.10.1: Weighted value (€) for wages per sector and year across the blue economy sectors and the paper industry (ENCE)

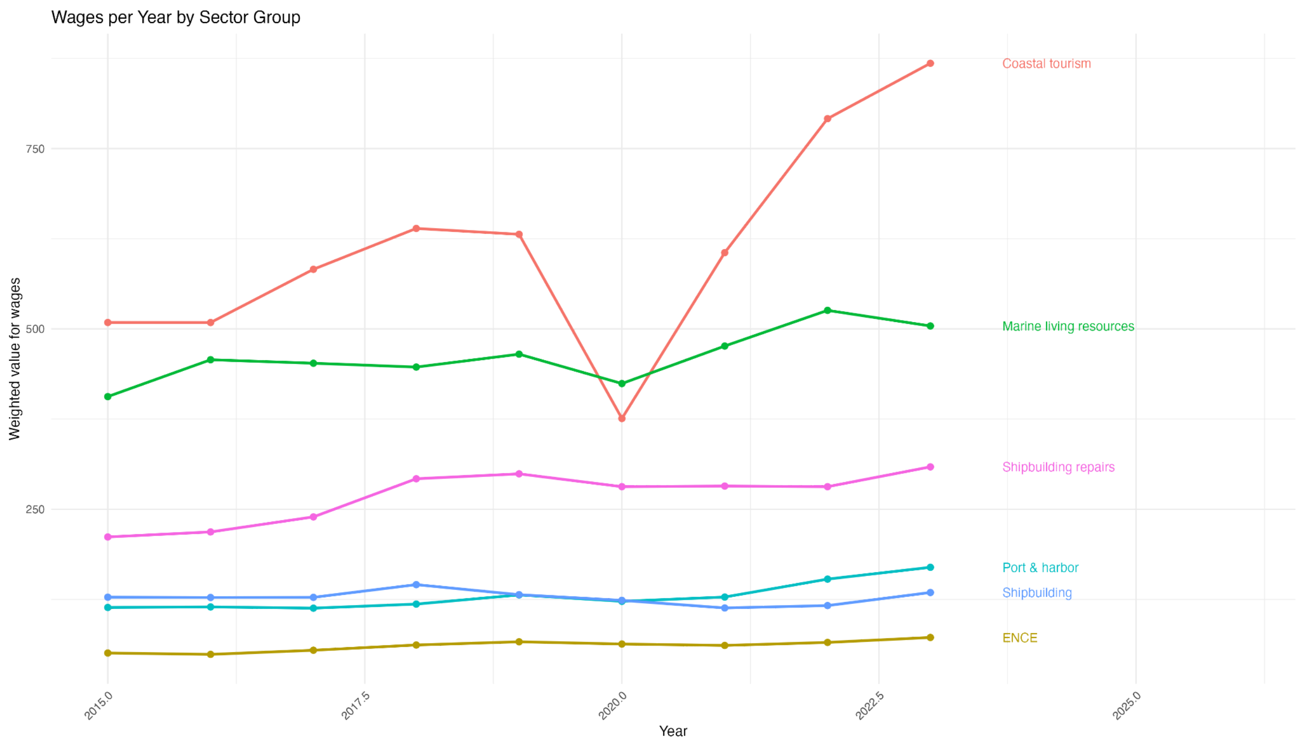


Figure 4.2.10.2: Weighted value for number of jobs per sector and year across the blue economy sectors and the paper industry (ENCE)

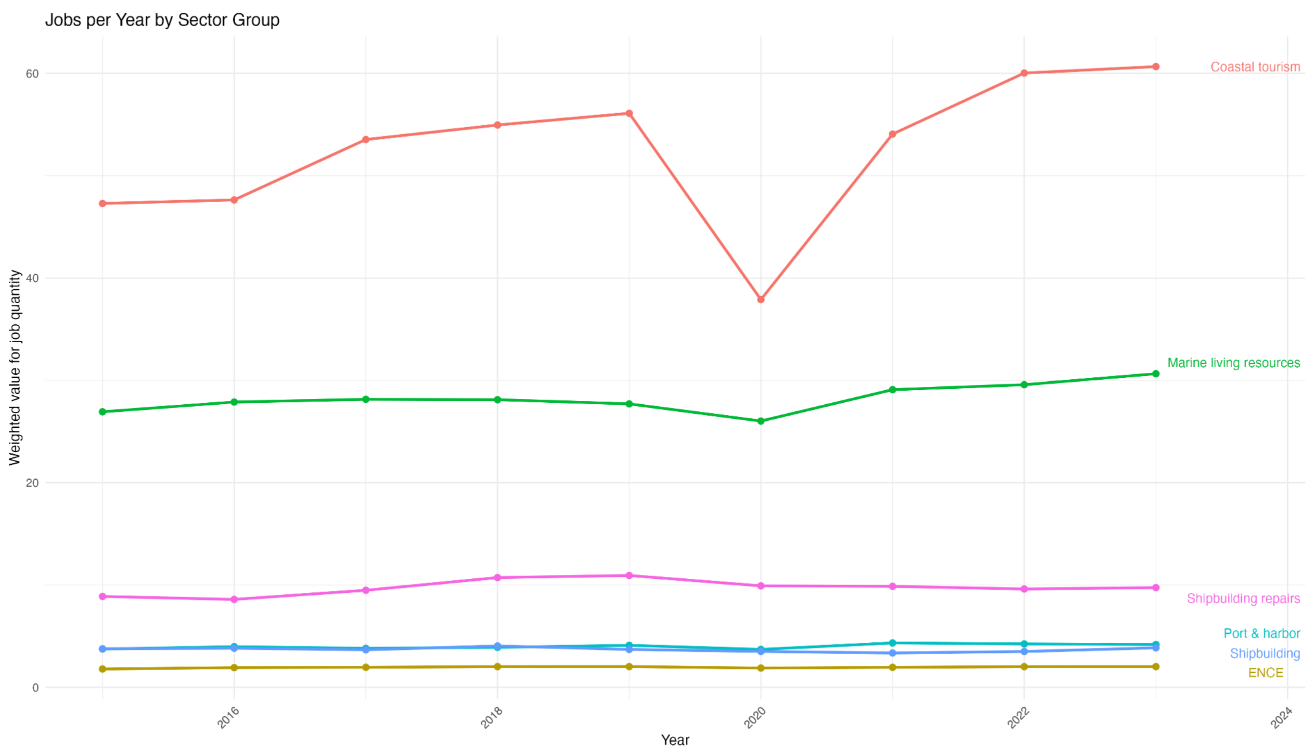


Figure 4.2.10.3: Sectoral variability in Jobs vs. Wages for the time period 2015-2025

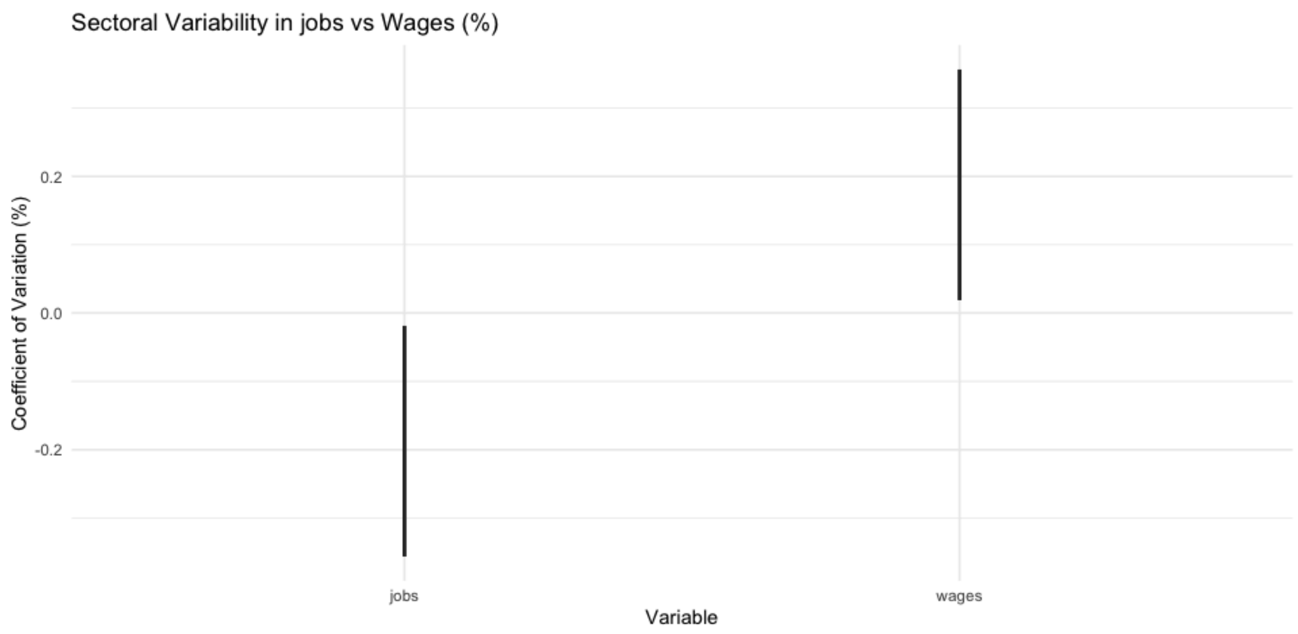


Table 4.2.10.1 . Results of the calculation of the LIV goal.

Status	Trend	Score
83	0.27	--

Discussion

The analysis of marine and coastal livelihoods in Galicia reveals a generally positive socio-economic trajectory for the period 2018–2022. The overall mean status of 82 indicates that the region's marine sectors are performing well. This strong performance could be due to a steady recovery following the disruptions caused by the COVID-19 pandemic.

As occurred in the Economy subgoal, the temporal patterns observed show the vulnerability of the sectors to external events. Weighted employment initially experienced a minor decline in 2019, followed by a steep drop in 2020, primarily driven by the tourism sector. This sharp decline corresponds with the onset of COVID-19 restrictions, which heavily affected tourism activity as seen in other goals. The subsequent recovery through 2021 and 2022 shows the resilience of the sector in terms of economy to rebound once pandemic-related constraints eased. Wages, in contrast, showed relative stability over the same period, peaking in 2022.

The stability observed was tested by a comparison of variances across and within the sectors (figures 4.2.10.1, 4.2.10.2 and 4.2.10.3). This confirmed what was previously seen where salaries seem to be more stable in comparison to jobs, where the pandemic had a major effect in the latter. As salaries are fixed by law in Spain, we expect the number of jobs to fluctuate more depending on the overall economic status of the region. However, these fluctuations have not come without a consequence on the Galician population where the loss of job positions during the pandemic had a direct effect on the domestic economy (Amoedo and Sánchez-Carreira, 2023).

Sectoral contributions to overall livelihoods status were not uniform. Marine living resources, such as fishing and mariculture, along with coastal tourism, accounted for the largest share of the aggregated status due to their higher employment weights. In contrast, sectors with lower shares, including energy and transport, contributed less to the overall status, even when performing relatively well.

The trend analysis, based on linear slopes of status over time, indicated a moderate positive trajectory for livelihoods, signalling gradual improvements across both jobs and wages. Based on the variance seen, we can attribute this improvement to the restoration of job positions previously lost. The positive trend, combined with a high final-year status, shows the recovery of Galicia's marine economy, even in the face of unprecedented challenges such as the Covid pandemic.

Conclusions

Overall, the livelihood goal shows a good status score (83) with a positive trend (0.27), a sign of a slow but steady recovery after the Covid outbreak.

4.2.14 Tourism & Recreation

Scope and introduction

The Tourism and Recreation (TR) goal aims to capture the number of people, and the quality of their experience, visiting coastal and marine areas. The goal is assessed separately from its economic benefits.

Methods

For the 2022 Global OHI calculations, the TR goal was assessed using employment data as a proxy for coastal tourism activity. Specifically, the model calculated a tourism score (x_tr) based on the product of the proportion of the workforce employed in tourism-related sectors (E) and a sustainability score (S), normalized against the 90th percentile value across all regions (T_90th):

$$Xtr=TrT90th$$

E is the proportion of the employees directly involved in the sector, and S is sustainability:

$$Tr = E \times S$$

This approach assumes that higher employment in tourism sectors correlates with greater coastal tourism and recreation activities. Due to data limitations, in the global assessment the model utilized national-level tourism employment data without distinguishing between coastal and inland tourism. The World Travel & Tourism Council (WTTC) provided the employment data, which included both direct and total (direct plus indirect) employment impacts of tourism.

For the Galician regional assessment, employment data were obtained from the Instituto Galego de Estatística (IGE, 2024), using the monthly series of social security affiliations by sector and province. To assess the impact of coastal tourism, only the employment data for coastal provinces was used for calculations (A Coruña, Lugo and Pontevedra), excluding inland provinces (Ourense). Records were filtered to include only tourism-related economic activities, specifically accommodation services, food and beverage services, and travel agencies. The reasoning behind this filtering is that in Spain, tourism is predominantly driven by the "sun and beach" model, especially in coastal regions such as Galicia, where the vast majority of international visitors seek leisure experiences centered around accommodation and dining (Turespaña, 2022; Eurostat, 2023). Therefore, these sectors will most directly capture employment generated by tourism demand in Galicia. This decision aligns with the Tourism Satellite Account framework, which emphasizes the need to focus on industries with a clear, direct link to tourist consumption to avoid statistical ambiguity. For the Galicia case study, excluding broader or mixed-use sectors, such as cultural or retail services, helps reduce the risk of overestimating tourism-related employment.

Annual totals were aggregated by province, and the proportion of tourism employment (Ep) was calculated as a percentage of total employment. These data were linked to corresponding coastal subregions (rgn_id), and missing region-year combinations were filled using a complete grid expansion.

Sustainability scores (S_score) were sourced from the World Economic Forum's Travel & Tourism Development Index (World Economic Forum, 2024), which provides national-level sustainability performance metrics from 2013 to 2024. Due to the absence of subnational TTDI data, scores were uniformly applied across all regions. Missing values for certain years were imputed using a linear regression model, with regional GDP growth as a predictor. GDP growth data were obtained from the Instituto Nacional de Estadística (INE, 2024), covering the years 2015 to 2022, and replicated across the coastal regions.

A composite tourism sustainability metric (T_r) was calculated for each region and year by multiplying Ep and S_score. To normalize this metric, each value was divided by the 90th percentile 5of T_r within its region, capping the result at 1 to produce x_tr. Trends were estimated using linear regression over the most recent five-year period (2018–2022).

Results

Figure **4.2.14.1***: employment percentage in the tourism sector in Galicia per province. Black line marks the average for Galicia*

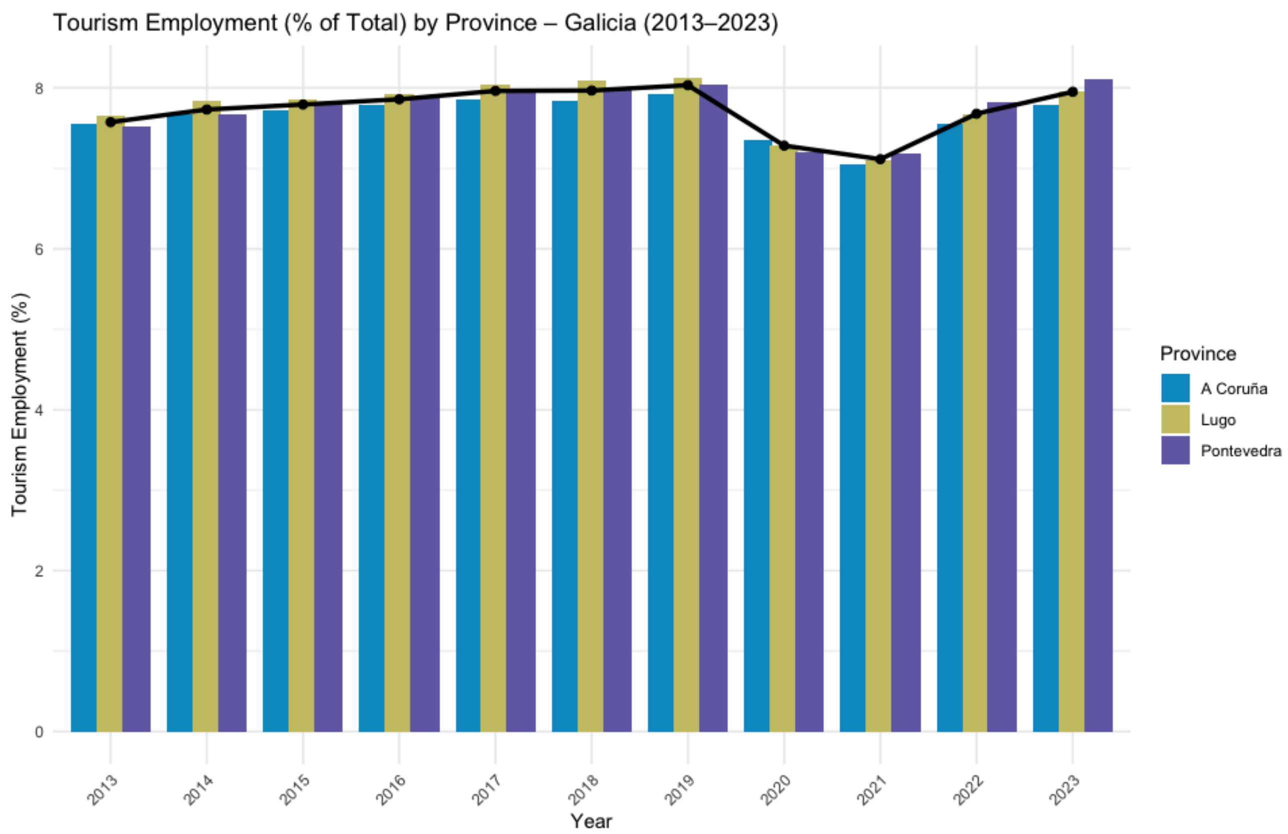


Table 4.2.14.1. Proportion of employees directly involved in tourism in Galicia and sustainability index for each year.

Year	% employees	Sustainability Index
2018	8.01	5.4
2019	8.06	5.4
2020	7.34	5.89
2021	7.11	5.2
2022	7.61	5.33

Table 4.2.14.2. Results of the calculation of the TR goal.

Status	Trend	Score
0.96	0.02	--

Discussion

The methodology relies on employment data as a proxy for tourism activity, specifically the proportion of the workforce in tourism-related sectors, combined with sustainability scores from the Travel & Tourism Development Index (TTDI). The assumption is that higher tourism-related employment correlates with more tourism activity and a more vibrant sector. For Galicia, employment data were sourced from the Instituto Galego de Estatística (IGE, 2024), focusing on key tourism sectors like accommodation services, food and beverage services, and travel agencies. This focus aligns with Galicia's dominant "sun and beach" tourism model, centered around coastal leisure tourism.

Sustainability scores for Galicia were based on national-level TTDI scores, with missing years imputed based on regional GDP growth. These scores were used to calculate a composite tourism sustainability index (T_r), which was normalized and capped to produce the final x_tr score. While the TTDI data is at the national level, it was assumed that Spain's overall tourism model reflects Galicia's, particularly as most of Spanish tourism relies on coastal regions. This assumption makes the national-level TTDI a reasonable proxy. Even though there are general recommendations regarding the exclusion of the Covid outbreak (UWNTO, 2021), COVID-19 years (2020 and 2021) were included, as disruptions like this are expected to become more frequent due to climate change (IPCC, 2021).

The results show a stable status score over the period from 2018 to 2022, with a final value of 0.96, indicating that Galicia's tourism sector is performing near the upper limits of the normalized scale. Although the sustainability score fluctuated slightly, it remained resilient, with the highest score in 2020, likely impacted by the pandemic's influence on tourism and employment patterns.

Interestingly, while the trend for individual regions was negative, the aggregated trend for Galicia was positive (0.02), indicating a slight but steady improvement in the tourism sector's sustainability. This is because the aggregation of subregional data smooths out local variability, and the post-pandemic recovery likely played a significant role in the positive trajectory observed for Galicia as a whole.

Conclusions

The consistently high status score (0.96) and the positive overall trend (0.02) suggest that tourism in Galicia is not only recovering after the Covid outbreak but also growing in a sustainable way.

4.3 Conclusions for Galicia OHI

The Ocean Health Index (OHI) assesses the condition of Galicia's marine and coastal system, integrating ecological, economic, social, and cultural dimensions into a single score. This analysis shows the status and trend of four key goalsBiodiversity–Species (BD-SPP), Economy (ECO), Livelihoods (LIV), and Tourism and Recreation (TR). Pressure and resilience variables, and therefore the final score, has not been calculated yet and will be provided in further reports. The results reveal a generally positive status across most goals, yet they also expose significant gaps in data availability and methodological issues, indicating a need for improving these frameworks into more adaptive, region-based methodologies based on data availability.

The Biodiversity–Species goal attained the highest score (100), suggesting that the biodiversity in Galicia's marine ecosystems is at its maximum compared to historic values. However, this outcome must be interpreted with caution. The reliance on global IUCN Red List data introduces substantial spatial and temporal uncertainty, as these datasets often lack the resolution necessary to detect local or regional trends (Herkt, 2017). Consequently, the apparent absence of threatened or invasive species may reflect data limitations rather than true ecological stability.

Empirical studies from Galician waters have documented climate-driven biogeographical shifts, including the northward migration of thermophilic species and a gradual tropicalization of coastal and shelf ecosystems (Bañón et al., 2024; Álvarez-Iglesias et al., 2020). Moreover, pressures such as coastal eutrophication, habitat fragmentation, and bottom-trawling impacts continue to alter benthic community structures (Javierre, 2020). These transformations have been shown to have a detrimental effect in living populations, either through direct interference with the organism or through habitat destruction (Halpern, 2007).

To improve the accuracy of biodiversity evaluations, systematic regional monitoring is essential. Relying on global distribution status might lead to bias, as the local populations might suffer different pressures depending on its location. Integration of data from other organisms such as research institutions, local universities, and citizen science initiatives could generate high-resolution time series on species distribution, abundance, and habitat conditions. Future OHI iterations should incorporate such locally grounded datasets to capture the true trend of Galician biodiversity. One possible way for this approach could be sourcing the species trends from regional assessments rather than considering the global trend and status. In this way, we expect the values to represent in a more accurate way the actual status of the species in the area.

Just like in the Species subgoal, the Economy subgoal achieved a perfect score (100) and positive trend (+0.03). Coastal tourism, Marine-dependent industries—including fisheries, aquaculture, shipbuilding, renewable offshore energy, and water management—remain major contributors to regional GDP and export performance (IGE, 2024; Xunta de Galicia, 2024). The post-pandemic recovery of these sectors demonstrates remarkable resilience and adaptability, supported by targeted policy frameworks such as the Estratexia Galega de Economía Azul 2030 (Galicia Confidencial, 2022).

Nevertheless, this economic prosperity is structurally dependent on the continued productivity of marine ecosystems. Overexploitation of fish stocks, degradation of nursery habitats, and pollution from aquaculture and coastal development could erode the ecological foundation upon which these industries depend (Halpern, 2007). The results therefore underline a critical tension: economic resilience does not guarantee ecological sustainability.

One problem encountered during this analysis was the lack of information over how much of the region's economy does the blue economy represent per sector. In the report produced by Sherpa do mar (Sherpa do Mar, 2020), values for the NW region of the iberian peninsula are found. Due to the similarities between the North of Portugal and Spain, it was assumed that the values were a reasonable representation of the Galician's situation. However, for the Energy sector the percentages were estimated based on the infrastructures located in coastal areas versus the total production (kw) for the whole region. The result is an approximate value, and for the future it would be recommended to revise this estimate, as this sector is growing very steadily in Galicia and the reality of today might now reflect the future situation.

To ensure long-term stability, economic planning should integrate natural capital accounting and ecosystem service valuation, aligning regional development with EU frameworks such as the Marine Strategy Framework Directive (MSFD) and the European Green Deal. Incorporating ecological risk assessments into economic indicators could promote a more precautionary and adaptive approach to marine resource management.

The Livelihoods subgoal scored 83, with a positive trend (+0.27), signifying steady improvement in employment and income within marine-related sectors. This reflects the enduring importance of ocean-based activities to the socioeconomic fabric of coastal Galicia, where thousands of households depend directly on fisheries, mariculture, port logistics, and tourism (IGE, 2024). Fishing and shellfishing activities employ around 20% of the population (IGE-INE, 2024), with 37% of women represented in the shellfishing sector (Villasante, 2021).

The positive performance of this goal also demonstrates social resilience during periods of disruption, notably the COVID-19 pandemic, also shown in the subgoal Economies. The sustained recovery of employment in marine industries aligns with European patterns of blue economic rebound and confirms the sector's strategic relevance to regional stability. However, structural challenges remain, including labour precarity which peaks at global crisis events (Amoedo and Sánchez-Carreira, 2023), gender inequality in maritime professions (Piñeiro-Antelo and Santos, 2021), and the aging of the fishing workforce (Lindkvist, Antelo 2007). In Galicia, over the last decades the number of people working in the Fishing or shellfishing industry had decreased greatly, in the case of Muros for example, the number of people working in the sector decreased by 50% between 1993 and 2007 (Lindkvist, Antelo 2007).

The Tourism and Recreation goal also performed strongly, with a status of 0.96 and a positive trend (+0.02). Galicia's tourism sector has diversified and modernized in recent years, combining cultural heritage, gastronomy, and eco-tourism. The post-pandemic rebound in visitor numbers, coupled with the expansion of sustainable tourism initiatives—such as eco-certifications, local product branding, and environmental awareness campaigns—illustrates a shift toward a more responsible and resilient model (Turespaña, 2022; Clusturismo Galicia, 2025).

Nevertheless, the increasing intensity of tourism activity (Agencia de Estratexia e Innovación Turística de Galicia, 2025) raises environmental concerns, including seasonal pressure on coastal infrastructures, marine litter generation, and degradation of sensitive coastal habitats. There has been an attempt to create indicators to illustrate the current state of the tourism sector in reference to the coastal areas, such as the indicators released by the IGE for the tourism sector, where the nights spent at a tourism accommodation can be assessed by region but also for coastline size (IGE, 2025). The growth observed in the touristic demand through these indicators and other socioeconomic variables has led to an increase in the investments in touristic infrastructure (Xunta de Galicia — Turismo de Galicia, 2024) to the tourist demand. However, the increase in tourism is expected to accelerate the degradation of the ecosystems (Campos et al., 2023). Tourism, when effectively managed, has the potential to reinforce cultural identity and environmental stewardship, turning visitors into stakeholders in ocean conservation rather than sources of degradation. If the implementation of these investments is solely done taking into account the human local population carrying capacity and not the ecosystem's, it is expected rather than ease, the human pressures on the coastal areas will become greater, causing further impacts in our ecosystems.

When considered together, the four goals reveal a complex socio-ecological system characterized by economic and social vitality coexisting with ecological uncertainty. Galicia's marine economy demonstrates resilience, innovation, and inclusivity, yet its sustainability ultimately depends on maintaining ecosystem integrity. The disparity between high socioeconomic scores (ECO, LIV, TR) and the uncertain ecological basis (BD-SPP) highlights a decoupling between human benefits and ecosystem health.

The OHI framework proves valuable in identifying such trade-offs, allowing for the quantification of synergies between biodiversity conservation, economic prosperity, and social well-being. It also offers a transparent platform for multi-stakeholder dialogue, fostering policy coherence between different sectors. However these findings need to be taken with a pinch of salt, as the current methodology might be overestimating the results. These findings emphasize the need for local-based, adaptive management approaches that integrate scientific evidence, local knowledge, and participatory governance to create a common force in environmental conservation.

The regional application of the OHI demonstrated its flexibility and communicative power, yet also exposed its dependence on data availability and scale compatibility. The use of global datasets (particularly for biodiversity) may lead to inflated or unrepresentative results. To improve these calculations, it would be recommended to, for example, implement data on the local populations that might not be reflected in the global assessments.

The OHI framework is characterized by its flexibility to adapt for regional assessments, yet it also exposed its dependence on data availability and scale compatibility of these regions with the global methodology. The use of global datasets (particularly for biodiversity) may lead to inflated or unrepresentative results. Regarding the IUCN distribution maps, it has been shown that there are multiple factors affecting their accuracy (Hughes et al., 2021). In the work of Hughes and colleagues, administrative boundaries or geographical features such as rivers can lead to an over or underestimation of species distributions, and this variability also depends on the species order (Odonata, mammals...). To enhance robustness, future implementations should prioritize regional data or its integration with global datasets. Nevertheless, this integration should also be handled carefully, since the integration of the local data with global data can also lead to overestimation or underestimation (Hughes et al., 2021). Investing in an interoperable data systems and robust methodology that link economic, ecological, and social databases will allow Galicia to develop a dynamic OHI dashboard, facilitating continuous monitoring of ocean health indicators and supporting evidence-based policymaking.

From a governance standpoint, these findings reinforce the urgency of aligning Galicia's blue economy policies with ecosystem-based principles. Achieving long-term ocean health requires integrating marine conservation objectives into all levels of decision-making—from local fisheries management to regional marine spatial planning. The OHI offers a scientifically credible and socially communicable instrument for tracking progress toward the United Nations Sustainable Development Goals (SDGs 14, 8, and 13).

In conclusion, Galicia stands at a crossroads: it has built a prosperous and resilient blue economy, but its ecological foundation remains vulnerable to climate change and cumulative anthropogenic pressures. Sustaining the region's ocean health will depend on maintaining the delicate balance between economic growth, social inclusion, and environmental integrity. The region's future prosperity—and the well-being of its coastal communities—will ultimately depend on its ability to safeguard the ecological systems that have long defined its cultural identity, economic vitality, and connection to the sea.

5. Overall Conclusions

The regional application of the Ocean Health Index framework to Galicia and the Southern Benguela highlights the complex interplay between ecological, economic, and social dimensions of ocean health across the Atlantic. Both regions demonstrate strengths in certain areas, while revealing critical gaps and challenges that must be addressed to ensure long-term sustainability.

In Southern Benguela, marine biodiversity and habitats show generally positive status (BD-SPP: 0.9; BD-HAB: 0.8), supported by expanded Marine Protected Areas and resilient ecosystems. Blue economy sectors, aquaculture, and tourism exhibit steady growth (LE-ECO: 1.0; LE-LIV: 0.9; TR: 0.73–1.0), reflecting socio-economic benefits derived from ocean resources. However, small-scale fisheries (SSFO: 0.4), natural products (NP: 0.5), and iconic species (SP-ICO: 0.5) face ongoing pressures from policy gaps, limited institutional support, and conservation challenges, highlighting the need for targeted interventions. Pollution from marine debris and other environmental stressors remains moderate, with data limitations underscoring the importance of improved monitoring and integration of resilience variables in future assessments.

Galicia presents a contrasting scenario: its biodiversity appears robust according to global datasets (BD-SPP: 100), yet ecological uncertainty persists due to limited local resolution and ongoing climate-driven changes in species distributions. The region's blue economy, livelihoods, and tourism demonstrate strong performance (ECO: 100; LIV: 83; TR: 0.96), supported by adaptive governance, targeted policy frameworks, and social resilience. Nevertheless, structural challenges such as labor precarity, demographic shifts, and ecological pressures from habitat degradation and intensified tourism highlight the delicate balance between human prosperity and environmental integrity.

Taken together, these case studies illustrate that high socio-economic performance does not automatically equate to ecological sustainability. Both regions underscore the importance of integrating **locally grounded ecological data, adaptive management strategies, and multi-stakeholder governance** to ensure that human benefits do not compromise long-term ecosystem health. The OHI proves valuable in quantifying these trade-offs and fostering dialogue between economic, social, and environmental priorities, yet its utility is contingent upon data availability, methodological rigor, and scale-appropriate adaptation.

Ultimately, sustaining ocean health across the Atlantic requires a **balanced approach** that simultaneously supports economic development, social well-being, and ecological integrity. By identifying both achievements and vulnerabilities, this research highlights the critical role of evidence-based policies, standardized monitoring, and proactive conservation strategies in safeguarding the oceans for current and future generations. The experiences of Galicia and Southern Benguela serve as instructive models, demonstrating both the potential and the limitations of regional applications of the Ocean Health Index, and providing a foundation for continued improvement in ocean health assessment and management.

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7. Appendices

Appendix 1. Data extracted from Gammage et al. (2023) for the calculation of the SSFO goal.

Local Municipality	Community	Population Composition (reversed)	Poverty	Personal Disruption	Labour Market Status	Housing Characteristics (reversed)	Retiree Migration
Swartland	Yzerfontein	-1.14	-0.58	-0.68	-1.01	-0.82	0.88
Saldanha Bay	Stofbergsfontein (Small Area 0159)	-0.41	0.52	0.08	-0.25	0.81	-0.64
Saldanha Bay	Langebaan	-0.17	-0.41	-0.47	-0.36	-0.88	-0.19
Saldanha Bay	Blue Water Bay	-0.84	-0.81	-0.88	-0.91	-1.05	-0.72
Saldanha Bay	Parker's Town	-1.43	-0.71	-0.84	-0.92	-1.33	-0.46
Saldanha Bay	Saldanha SP	-0.48	-0.61	-0.72	-0.82	-0.97	-0.7
Saldanha Bay	White City	1.13	0.39	0.19	0.76	-0.4	-0.85
Saldanha Bay	Diazville	1.36	1.21	0.89	1.59	1.01	-1.1
Saldanha Bay	Jacob's Bay	-1.12	-0.85	-1.67	-1.11	-1.09	-0.26
Saldanha Bay	Paternoster	0.87	0.91	0.13	0.48	-0.34	-0.82

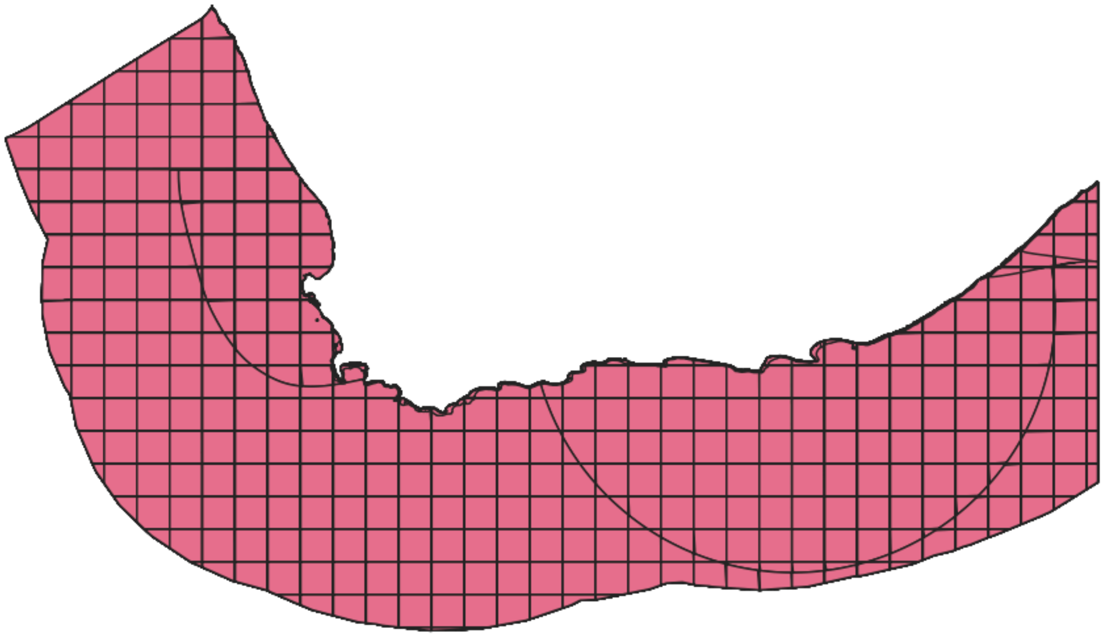
Saldanha Bay	Britannia Bay	-0.8	-0.68	-1.26	-0.4	-0.84	1.08
Saldanha Bay	Shelly Point	-1.12	-1.25	-1.13	-0.82	-0.89	1.14
Saldanha Bay	Stompneusbaai	0.65	0.32	-0.18	-0.2	-0.85	-0.95
Saldanha Bay	Columbine	0.08	-0.45	-1.07	-0.86	-0.45	-0.49
Saldanha Bay	Sandy Point	-0.62	-0.04	0.32	-0.11	0.51	-0.52
Saldanha Bay	Steenbergs Cove	0.98	0	0.22	0.49	-0.13	-0.82
Saldanha Bay	West Point	-0.49	-1.17	-0.49	-1.36	-0.25	-0.28
Saldanha Bay	Laingville	1.43	1.35	1.34	1.77	-0.3	-1.08
Bergrivier	Laaiplek	-0.73	-0.9	-0.63	-1.21	-0.74	0.15
Bergrivier	Noordhoek (Velddrif)	1.32	0.99	1.02	1.07	0.14	-0.93
Cederberg	Elands Bay	0.98	1.13	1.86	1.31	0.16	-0.72
Cederberg	Lamberts Bay (incl Malkopbaai)	0.89	0.28	0.17	0.44	-0.19	-0.43
Matzikama	Doring Baai	1.13	0.2	0.65	1.11	0.27	-0.58
Matzikama	Strandfontein (Matzikama)	0.11	0.39	-0.36	-0.01	0.5	-0.49

Matzikama	Papendorp (Small Area 008)	1.19	1.16	1.27	1.66	0.2	-0.52
Cape Aghulhas	Arniston	0.46	0.83	0.92	1.05	-0.25	-0.46
Cape Aghulhas	Struisbaai	-0.13	0.13	0.12	0.24	-0.04	0.14
Cape Aghulhas	Agulhas	-1.02	-1.53	-1.48	-1.53	-0.57	1.49
Overstrand	Pearly Beach (Small Area 0044)	-1.18	-1.24	-1.15	-0.53	-0.68	1.83
Overstrand	Eluxolweni (Small Area 0075)	0.26	2.17	2.51	2.32	4.47	-1.28
Overstrand	Franskraalstrand	-1.17	-1.41	-0.94	-1.03	-0.74	1.49
Overstrand	Van Dyksbaai	-0.56	-0.99	-0.91	-0.41	-0.47	1.4
Overstrand	GansBaai (incl Blompark & Masakhane)	0.39	1.36	1.06	1.37	1.48	-0.94
Overstrand	De Kelders	-1.02	-1.23	-1.39	-0.75	-0.76	1.29
Overstrand	Hermanus (incl Westdene)	-0.97	-1.14	-1.15	-0.84	-0.74	1.72
Overstrand	Fernkloof	-2.15	-0.81	-1.15	-1.07	-1	1.22
Overstrand	Mount Pleasant	0.71	0.91	0.34	0.8	-0.32	-0.92

Overstrand	Hawston	0.67	0.6	0.49	1.13	-0.21	-0.82
Overstrand	Fisherhaven	-1.39	-1.03	-0.83	-0.69	-1.02	1.03
Overstrand	Kleinmond	0.06	0.59	0.5	1.29	1.3	0.25
Overstrand	Betty's Bay	-1.26	-0.98	-0.65	-0.32	-0.8	1.09
Overstrand	Pringle Bay	-1.58	-0.79	-0.84	-0.4	-0.81	1.09
Bitou	Nature's Valley	-0.24	-0.84	-0.87	-1.03	-0.64	0.99
Bitou	Plettenberg Bay (excl Pine Tree)	-1.47	-0.6	-0.67	-0.59	-0.51	0.05
Bitou	Pine Tree	-1.41	-0.73	-0.89	-0.8	-0.71	0.89
Bitou	Knysna (excl Hornless & Xolweni)	1.2	0.33	0.28	0.39	-0.44	-0.88
Bitou	Hornlee	0.59	0.49	0.71	0.48	1.08	-0.54
Bitou	Xolweni	1.24	2.25	2.67	1.7	3.14	-1.24
Knysna	Sedgefield	0.03	-0.2	-0.07	-0.25	0.59	0.1
George	Kleinkrantz	0.04	0.12	0.24	0.06	0.92	-0.41
George	Wilderness Heights	-1.83	0.03	-0.8	-0.62	0.47	1.58
George	Touwsranten	1.73	0.21	1.14	1.23	1.88	-0.97
George	Wilderness SP	-1.44	-0.93	-0.88	-0.97	-0.64	0.72
Mossel bay	Groot Brak River	0.73	0.08	-0.17	-0.07	-0.02	0.05

Mossel bay	Klein Brak River	-0.27	-0.69	-0.74	-0.68	0.33	0.81
Mossel bay	Hartenbos	-0.18	-0.74	-0.49	-0.77	-0.64	0.57
Mossel bay	Mossel bay	0.34	-0.31	-0.13	-0.42	-0.49	-0.08
Hessequa	Gouritsmond	-0.05	0.18	0.5	0.28	-0.69	0.2
Hessequa	Stilbaai	-0.89	-1.29	-1.51	-1.09	-0.62	2.14
Hessequa	Melkhoutfontein	0.51	0.38	0.18	-0.13	0.57	-0.93
Hessequa	Groot Jongensfontein	-1.02	-1.31	-2.73	-1.24	-0.59	2.75
Hessequa	Vermaaklikheid (Small Area 175031)	-0.16	0.58	0.69	-0.21	1.98	-0.33
Hessequa	Port Beaufort (incl Witsand)	-1.32	-1.24	-1.48	-1.44	-0.63	1.2

Appendix 2. Map of the 0.5 grid cell used to calculate the BD-SPP subgoal.



Appendix 3. List of species with historical records to calculate the trend in the BD-SPP.

SCI_NAME	YRCOMPILED1	STATUS 1	YRCOMPILED2	STATUS 2
Acroteriobatus annulatus	2018	LC	2016	VU
Alopias pelagicus	2018	VU	2009	EN
Alopias superciliosus	2018	VU	2009	VU
Alopias vulpinus	2018	VU	2019	VU
Alveopora allingi	2009	VU	2008	VU
Balaenoptera borealis	2012	EN	2008	EN
Balaenoptera musculus	2012	EN	2008	EN
Balaenoptera physalus	2014	EN	2013	VU
Carcharhinus brachyurus	2020	NT	2003	VU
Carcharhinus brevipinna	2020	NT	2009	VU
Carcharhinus leucas	2020	NT	2009	VU

Carcharhinus limbatus	2020	NT	2009	VU
Carcharhinus longimanus	2018	VU	2015	CR
Carcharhinus obscurus	2018	VU	2009	EN
Carcharias taurus	2020	VU	2009	CR
Carcharodon carcharias	2018	VU	2019	VU
Caretta caretta	2015	VU	2015	VU
Centrophorus squamosus	2020	VU	2003	EN
Centroscymnus owstonii	2012	LC	2003	VU
Cetorhinus maximus	2018	EN	2019	EN
Clinus spatulatus	2022	EN	2014	EN
Deania quadrispinosa	2020	NT	2009	VU
Dermochelys coriacea	2013	CR	2000	VU
Diomedea dabbenena	2016	CR	2017	CR
Diomedea epomophora	2016	VU	2017	VU
Diomedea exulans	2016	VU	2017	VU
Diomedea sanfordi	2016	EN	2017	EN
Enteromius gurneyi	2007	LC	2017	VU
Haploblepharus edwardsii	2018	NT	2009	EN
Haploblepharus fuscus	2018	VU	2009	VU
Haploblepharus kistnasamyi	2018	CR	2009	VU
Hippocampus capensis	2011	EN	2012	EN
Hippocampus histrix	2012	VU	2012	VU
Istiophorus platypterus	2021	LC	2011	VU
Isurus oxyrinchus	2018	VU	2009	EN
Isurus paucus	2018	VU	2006	EN
Lamna nasus	2018	VU	2006	VU
Leucoraja wallacei	2018	LC	2009	VU

Lithognathus lithognathus	2014	LR	1996	EN
Makaira nigricans	2021	VU	2011	VU
Mobula alfredi	2018	VU	2019	VU
Mobula birostris	2018	EN	2020	EN
Mobula kuhlii	2018	EN	2020	EN
Mobula mobular	2018	EN	2020	EN
Mobula tarapacana	2018	EN	2019	EN
Mobula thurstoni	2018	EN	2019	EN
Morus capensis	2000	EN	2017	EN
Mustelus mustelus	2020	VU	2009	EN
Mycteroperca albomarginatus	2012	VU	2004	VU
Mycteroperca marginatus	2018	EN	2004	VU
Nebrius ferrugineus	2020	VU	2003	VU
Odontaspis ferox	2016	VU	2009	VU
Oreochromis mossambicus	2019	NT	2007	VU
Oxynotus centrina	2020	VU	2007	EN
Phalacrocorax capensis	2013	EN	2017	EN
Phalacrocorax neglectus	2012	EN	2017	EN
Phoebetria fusca	2016	EN	2017	EN
Physeter macrocephalus	2019	VU	2008	VU
Procellaria aequinoctialis	2011	VU	2017	VU
Procellaria conspicillata	2010	VU	2017	VU
Pterodroma baraui	2010	EN	2016	EN
Pterodroma incerta	2016	EN	2018	EN
Rhincodon typus	2016	VU	2005	EN
Rhynchobatus djiddensis	2018	VU	2006	CR
Scylliogaleus quecketti	2018	VU	2009	VU

Sousa plumbea	2022	EN	2017	EN
Spheniscus demersus	2013	EN	2018	EN
Sphyrna zygaena	2018	VU	2009	VU
Squalus acanthias	2019	VU	2016	VU
Stegostoma tigrinum	2016	EN	2016	EN
Thalassarche carteri	2016	EN	2017	EN
Thalassarche chlororhynchos	2016	EN	2017	EN
Thalassarche chrysostoma	2013	EN	2017	EN
Thalassarche salvini	2016	VU	2017	VU
Thunnus maccoyii	2021	CR	2011	EN
Thunnus obesus	2021	VU	2011	VU
Turbinaria mesenterina	2009	VU	2008	VU
Urogymnus asperrimus	2016	VU	2005	VU
Acanthopagrus berda	2014	LC	2014	LC
Acroteriobatus blochii	2018	LC	2016	LC
Actitis hypoleucos	2007	LC	2016	LC
Ambassis gymnocephalus	2021	LC	2011	LC
Anguilla bicolor	2019	NT	2019	NT
Anguilla marmorata	2019	LC	2019	LC
Anguilla mossambica	2019	NT	2019	NT
Aphrodroma brevirostris	2011	LC	2016	LC
Ardenna carneipes	2019	NT	2018	NT
Ardenna gravis	2021	LC	2018	LC
Arenaria interpres	2019	LC	2016	LC
Calidris canutus	2006	NT	2017	NT
Calidris ferruginea	2015	NT	2016	NT
Calidris pugnax	2006	LC	2015	LC

Calonectris borealis	2016	LC	2017	LC
Calonectris diomedea	2016	LC	2017	LC
Caranx sexfasciatus	2018	LC	2010	LC
Catharacta antarctica	2016	LC	2017	LC
Cerithidea decollata	2016	LC	2010	LC
Chaetodon marleyi	2010	VU	1996	LC
Chanos chanos	2017	LC	2017	LC
Charadrius marginatus	2007	LC	2012	LC
Charadrius pallidus	2021	NT	2016	LC
Charadrius pecuarius	2007	LC	2012	LC
Chelon melinopterus	2012	LC	2012	LC
Chelonia mydas	2023	EN	2004	EN
Chelonodontops laticeps	2020	LC	2014	LC
Crenimugil crenilabis	2012	LC	2012	LC
Daption capense	2013	LC	2017	LC
Dasyatis chrysonota	2018	LC	2009	NT
Eleotris melanosoma	2018	LC	2019	LC
Elops machnata	2016	LC	2012	LC
Epinephelus coeruleopunctatus	2018	LC	2008	LC
Epinephelus coioides	2018	NT		LC
Epinephelus malabaricus	2018	NT	2006	LC
Favonigobius reichei	2017	NT	1996	LC
Fregetta grallaria	2000	LC	2016	LC
Fregetta tropica	2006	LC	2016	LC
Fulmarus glacialoides	2010	LC	2017	LC
Galeocerdo cuvier	2018	NT	2009	NT
Galeorhinus galeus	2019	VU	2006	CR

Gerres filamentosus	2016	LC	2012	LC
Glossogobius callidus	2016	LC	2007	LC
Halcyon senegaloides	2010	LC	2012	LC
Halobaena caerulea	2020	LC	2018	LC
Haploblepharus pictus	2018	LC	2009	LC
Himantopus himantopus	2019	LC	2016	LC
Hydroprogne caspia	2006	LC	2004	LC
Larus cirrocephalus	2007	LC	2016	LC
Larus dominicanus	2013	LC	2012	LC
Larus hartlaubii	2007	LC	2004	LC
Limosa lapponica	2006	LC	2004	NT
Macronectes giganteus	2010	LC	2009	LC
Macronectes halli	2010	LC	2009	LC
Microcarbo africanus	2007	LC	2004	LC
Microcarbo coronatus	2021	NT	2018	LC
Microphis brachyurus	2018	LC	2017	LC
Mugil cephalus	2018	LC	2017	LC
Mugilogobius mertoni	2020	LC	2012	LC
Myxus capensis	2007	LC	1996	LC
Numenius phaeopus	2006	LC	2012	LC
Oceanites oceanicus	2006	LC	2004	LC
Oxyurichthys keiensis	2010	NT	1996	LC
Pachyptila belcheri	2011	LC	2009	LC
Pachyptila desolata	2011	LC	2009	LC
Pachyptila vittata	2011	LC	2009	LC
Pelagodroma marina	2008	LC	2004	LC
Phalacrocorax carbo	2019	LC	2008	LC

Phalaropus fulicarius	2007	LC	2004	LC
Phoebetria palpebrata	2016	NT	2012	NT
Phoenicopterus roseus	2019	LC	2018	LC
Poroderma africanum	2018	NT	2020	LC
Pristis zijsron	2021	CR	2013	CR
Procellaria cinerea	2021	NT	2018	NT
Psammogobius biocellatus	2012	NT	1996	LC
Pterodroma lessonii	2011	LC	2009	LC
Pterodroma mollis	2013	LC	2012	LC
Puffinus puffinus	2010	LC	2009	LC
Redigobius dewaali	2016	LC	2007	LC
Stercorarius longicaudus	2013	LC	2012	LC
Stercorarius parasiticus	2006	LC	2004	LC
Stercorarius pomarinus	2008	LC	2004	LC
Sterna dougallii	2017	LC	2016	LC
Sterna hirundo	2019	LC	2018	LC
Sterna paradisaea	2018	LC	2018	LC
Sterna vittata	2014	LC	2013	LC
Sternula albifrons	2007	LC	2004	LC
Sternula balaenarum	2021	VU	2018	LC
Syngnathus watermeyeri	2017	CR	2010	CR
Thalassarche cauta	2022	NT	2018	NT
Thalassarche melanophris	2016	NT	2014	NT
Thalassarche steadi	2016	NT	2013	NT
Thalasseus bergii	2013	LC	2012	LC
Tringa nebularia	2007	LC	2004	LC
Tursiops truncatus	2019	LC	2012	LC

Xema sabini	2017	LC	2014	LC
Xenus cinereus	2007	LC	2004	LC

Appendix 4. Marine protected areas from SA-BEN assessed in this study.

Realm	Name	Designation	Area reported (Km^2)
Coastal	Dassen Island Nature Reserve	Ramsar Site, Wetland of International Importance	7.370615973
Coastal	Dyer Island Provincial Nature Reserve and Geyser Island Provincial Nature Reserv	Ramsar Site, Wetland of International Importance	2.885357213
Coastal	Blombos Private Nature Reserve	Nature Reserve	0.605360204
Coastal	The Lagoon 2 Private Nature Reserve	Nature Reserve	0.394841778
Coastal	Vergaderingskop Private Nature Reserve	Nature Reserve	2.353683694
Coastal	Langverwacht Private Nature Reserve	Nature Reserve	0.084173421
Coastal	Lake Pleasant Private Nature Reserve Section No.5	Nature Reserve	0.05481781
Coastal	Lake Pleasant Private Nature Reserve Section No.4	Nature Reserve	0.055424796
Coastal	Robben island Marine Protected Area	Marine Protected Area	612.2990959
Coastal	Namaqua National Park Marine Protected Area	Marine Protected Area	549.3969276
Coastal	Addo Elephant Marine Protected Area	Marine Protected Area	1127.089168
Coastal	Amathole Offshore Marine Protected Area	Marine Protected Area	4213.282556
Coastal	Witsand Local Nature Reserve	Nature Reserve	0.082196794
Coastal	Geyser Island Provincial Nature Reserve	Nature Reserve	0.04706906
Coastal	Jacob's Rock Provincial Nature Reserve	Nature Reserve	0.013219866
Coastal	Lambert's Bay Penguin Island Provincial Nature Reserve	Nature Reserve	0.074283096
Coastal	Mossel Bay Seal Island Provincial Nature Reserve	Nature Reserve	0.006967224
Coastal	Paternoster Rocks Provincial Nature Reserve	Nature Reserve	0.109015213
Coastal	Quoin Rock Provincial Nature Reserve	Nature Reserve	0.009384625
Coastal	Seal Ledges Provincial Nature Reserve	Nature Reserve	0.010351217

Coastal	Vondeling Island Provincial Nature Reserve	Nature Reserve	0.147748835
Coastal	Robberg Nature Reserve	Nature Reserve	1.962810585
Coastal	Cape St. Francis Provincial Nature Reserve	Nature Reserve	0.364792078
Coastal	Hluleka Marine Protected Area	Marine Protected Area	40.86204644
Coastal	Dwesa-Cwebe Marine Protected Area	Marine Protected Area	265.0787942
Coastal	Table Mountain National Park Marine Protected Area	Marine Protected Area	955.8585428
Coastal	Pondoland Marine Protected Area	Marine Protected Area	1237.140987
Coastal	Betty's Bay Marine Protected Area	Marine Protected Area	20.13841038
Coastal	De Hoop Marine Protected Area	Marine Protected Area	288.8740651
Coastal	Goukamma Marine Protected Area	Marine Protected Area	33.96574546
Coastal	Helderberg Marine Protected Area	Marine Protected Area	2.397610654
Coastal	Jutten Island Marine Protected Area	Marine Protected Area	0.972632151
Coastal	Langebaan Lagoon Marine Protected Area	Marine Protected Area	34.8325337
Coastal	Malgas Island Marine Protected Area	Marine Protected Area	0.547734383
Coastal	Marcus Island Marine Protected Area	Marine Protected Area	0.254953864
Coastal	Robberg Marine Protected Area	Marine Protected Area	23.23117028
Coastal	Sardinia Bay Marine Protected Area	Marine Protected Area	12.90911883
Coastal	Sixteen Mile Beach Marine Protected Area	Marine Protected Area	106.9115692
Coastal	Tsitsikamma Marine Protected Area	Marine Protected Area	293.6589632
Coastal	Kleinmond Coastal Nature Reserve	Nature Reserve	0.233099554
Coastal	Sylvic Nature Reserve	Nature Reserve	0.911354503
Coastal	Amathole Marine Protected Area	Marine Protected Area	247.752027
Coastal	Brenton Blue Butterfly Nature Reserve	Special Nature Reserve	0.014554516
Coastal	Stilbaai Marine Protected Area	Marine Protected Area	34.88677931
Coastal	Walker Bay Whale Sanctuary Marine Protected Area	Marine Protected Area	112.4869762
Coastal	Geelkrans Nature Reserve	Forest Nature Reserve	1.868434751
Coastal	Algoa Bay Black Rocks Provincial Nature Reserve	Nature Reserve	0.010790475

Coastal	Algoa Bay Seal Island Provincial Nature Reserve	Nature Reserve	0.050430472
Coastal	Joan Muirhead Nature Reserve	Nature Reserve	0.74416409
Coastal	Duikerklip Provincial Nature Reserve	Nature Reserve	0.039346788
Coastal	Dyer Island Provincial Nature Reserve	Nature Reserve	0.31217355
Coastal	Elephant Rock Provincial Nature Reserve	Nature Reserve	0.013923289
Coastal	False Bay Seal Island Provincial Nature Reserve	Nature Reserve	0.0302281
Coastal	Franscois and Annelle Marits Private Nature Reserve	Nature Reserve	0.018513344
marine	Port Elizabeth Corals Marine Protected Area	Marine Protected Area	270.3958409
marine	Browns Bank Corals Marine Protected Area	Marine Protected Area	339.4251463
marine	Childs Bank Marine Protected Area	Marine Protected Area	1210.71531
marine	Agulhas Front Marine Protected Area	Marine Protected Area	6255.537966
marine	Agulhas Bank Complex Marine Protected Area	Marine Protected Area	4313.627872
marine	Agulhas Muds Marine Protected Area	Marine Protected Area	206.9095843
marine	Robben island Marine Protected Area	Marine Protected Area	612.2990959
marine	Orange Shelf Edge Marine Protected Area	Marine Protected Area	1842.21604
marine	Benguela Muds Marine Protected Area	Marine Protected Area	92.48719621
marine	Cape Canyon Marine Protected Area	Marine Protected Area	583.3207061
marine	Southwest Indian Seamount Marine Protected Area	Marine Protected Area	7558.09914
marine	Southeast Atlantic Seamount Marine Protected Area	Marine Protected Area	7725.151282
marine	Namaqua Fossil Forest Marine Protected Area	Marine Protected Area	494.2282419
marine	Namaqua National Park Marine Protected Area	Marine Protected Area	549.3969276
marine	Addo Elephant Marine Protected Area	Marine Protected Area	1127.089168
marine	Amathole Offshore Marine Protected Area	Marine Protected Area	4213.282556
marine	Hluleka Marine Protected Area	Marine Protected Area	40.86204644
marine	Dwesa-Cwebe Marine Protected Area	Marine Protected Area	265.0787942
marine	Table Mountain National Park Marine Protected Area	Marine Protected Area	955.8585428
marine	Pondoland Marine Protected Area	Marine Protected Area	1237.140987

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