Coastline in the Banc d'Arguin, Mauritania. Photo by Kristine Meise.

Methodological guidelines for climate impact modelling of tidal wetlands along the East Atlantic Flyway

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Content

1. Introduction

Global warming and extreme weather events are expected to affect coastal habitats worldwide, degrading their ecosystem functionality and possibly causing the collapse of regional fisheries and shorebird populations. Some coastal wetland systems along the East Atlantic Flyway, such as the Wadden Sea, have been extensively studied and protected against natural hazards, whilst coastal wetlands in less developed countries, such as the Banc d'Arguin in Mauritania and the Bijagós Archipelago in Guinea Bissau, remain poorly understood due to lack of local data and research capacity.

The project "Climate Resilience for Critical Sites for Migratory Birds and People along the East Atlantic Flyway (CREAF)" is a large-scale, multi-partner flyway project, working with local communities, site managers, researchers, and policymakers from 11 countries along the African Atlantic Coastline. The aim of the project is to improve the resilience of the flyway to climate change through targeted actions for local wetlands. This includes finding solutions for climate adaptation responses at sites of international importance for migratory birds that incorporate the needs of biodiversity, ecosystem services and people.

Climate impact models provide useful means to predict and mitigate the effects of climate change on coastal wetlands and biodiversity, as well as local communities and their livelihoods. By integrating data from atmospheric, ecological, and socio-economic systems, these models help policymakers and managers to make informed decisions about risk management, climate adaptation and long-term management planning. However, general models or global models may not accurately reflect the impact on the local level due to lack of consideration of site-specific processes and environmental factors. This leads to inaccurate predictions and prevents effective management of climate change impacts. Their performance can be improved by informing the model with local data, whereby long-term monitoring data are often preferential for improved predictions.

These methodological guidelines are for local site managers and researchers who are interested in modelling the impact of climate change on their coastal wetlands. They illustrate the steps that need to be taken to set up a long-term climate change impact monitoring and modelling system for tidal wetlands along the East African Flyway, with focus on the two selected sites, namely the Banc d'Arguin in Mauritania and the Bijagós Archipelago in Guinea Bissau.

2. Methodology

CREAF is a large-scale, multi-partner flyway project, working with local communities, site managers, researchers, and policymakers from multiple countries along the African Atlantic Coastline. To appropriately incorporate both natural and human aspects in each site, a co-design approach was implemented for developing the methodological guidelines. It is expected that the guidelines can assist design and implementation of local field monitoring for developing a long-term climate impact modelling system for each site.

The general procedure that was followed in developing the guidelines is illustrated in Figure 2.1. In this procedure, as Step 1, a questionnaire was prepared and sent to local experts and stakeholders to identify the most relevant climate, hydrographic, geomorphological and biological parameters that influence the health state of the coastal ecosystems in the two selected areas, namely the Banc d'Arguin in Mauritania (PNBA hereafter) and the Bijagós Archipelago in Guinea Bissau (Bijagós hereafter).

The answers from the questionnaire provided a base for drafting a network map for each study area (Step 2), showing the interconnections among the parameters and cascading effects. The network maps for the two study areas have been checked and confirmed by the local project partners before they were used for Step 3, in which a desktop investigation on the availability of parameters that are identified in Step 1 & 2 for the study areas was done. Existing global and regional open databases which could provide climate, hydrographic, geomorphological and biological parameters for the study area were reviewed.

Based on the review, a list of key parameters with identified data gaps for the two study areas was derived (Step 4) for designing and prioritising field-based monitoring aiming to fill the data gaps. Based on the outcomes from Steps 1- 4, several up-to-date open-source hydro-eco-sediment dynamic models were reviewed for their potential as climate impact models for the study areas. These models have the capacity to assess system response of each tidal wetland to not only historical and on-going climate impacts but also potential future climate change based on projections.

In the last step (Step 5), recommendations for numerical models that can serve as a base for developing the climate impact models as well as needs for further development of parameterisation schemes to address the site-specific demands for the two study areas were provided.

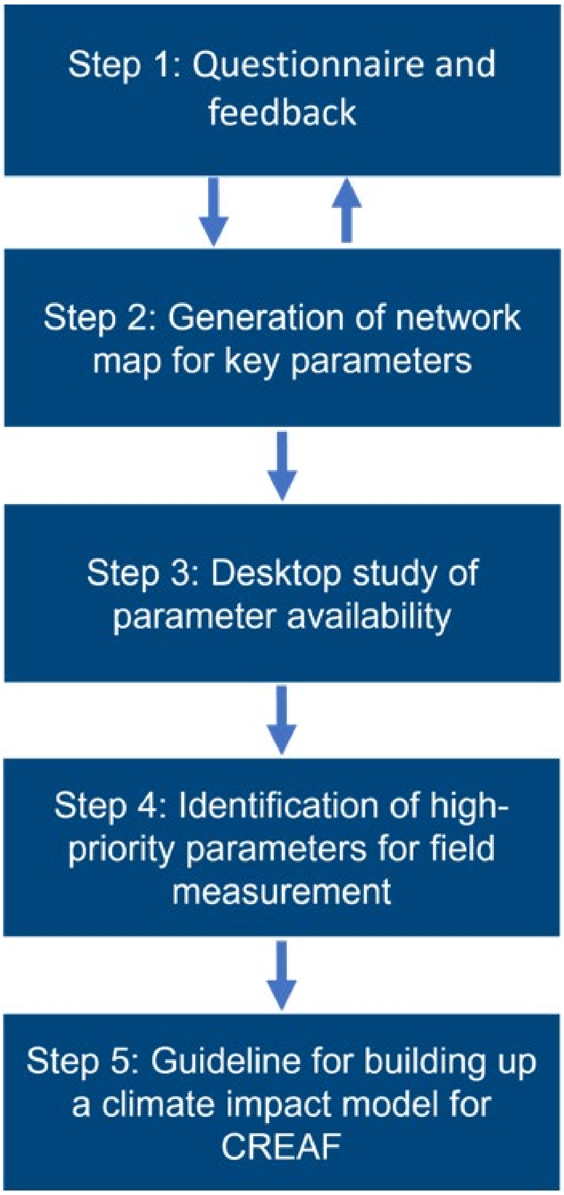

Figure 2.1. Workflow showing the five-step process for developing the methodological guideline.

3. Results

3.1 RELEVANT PARAMETERS IDENTIFIED FOR THE TWO STUDY AREAS

Based on the feedback derived from Step 1, schematic diagrams illustrating the most relevant parameters, including natural and anthropogenic factors, influencing the ecosystem functioning of each study area were derived (Figure 3.1 for PNBA & Figure 3.2 for Bijagós). Please note that the diagrams are not an accurate representation of the ecosystems but highlight key parameters for the development of numerical climate impact models.

3.1.1 PNBA Coastal System

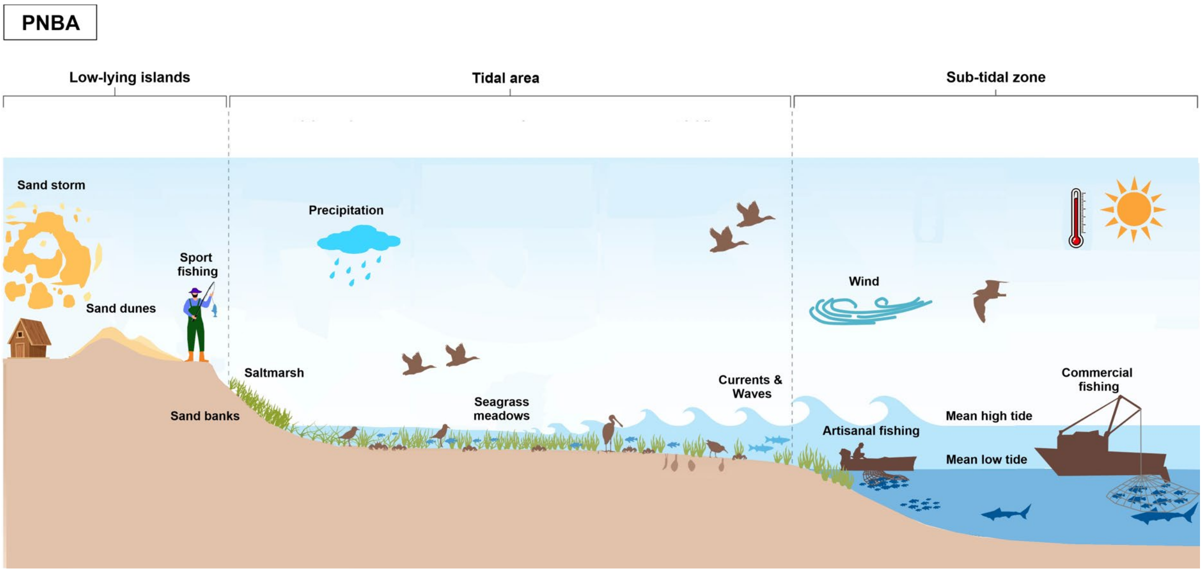

Figure 3.1. Key environmental and anthropogenic factors identified for the PNBA. Modified based on He et al. (2025).

In PNBA, seagrass meadows, widely distributed on the intertidal and subtidal zones, provide key nursing grounds for fish and food for a large variety of animals (Figure 3.1). Other important ecosystem elements include sand banks and some saltmarsh vegetation located at the upper tidal zone, and dunes in the upper foreshore. The region is frequently nourished by sandstorms from the Sahara Desert, providing an important source of sediment and nutrients for the area. Hydrodynamics and sediment transport in PNBA are regularly driven by tides, wind-driven currents and waves from open ocean. Extreme events such as drought, heat waves and sandstorms introduce disturbances to the ecosystem (Figure 3.2). On a longer-term, sea level rise imposes an increasing risk of flooding over this low-lying coastal system, promoting the formation of lagoons (Trégarot et al., 2021). Besides natural forcing, the PNBA ecosystem is also strongly impacted by anthropogenic activities, including food resource exploitation, artisanal fishing and illegal fishing in the nearshore area, and commercial fishing at the boundaries of the National Park and in the offshore area (Figure 3.1).

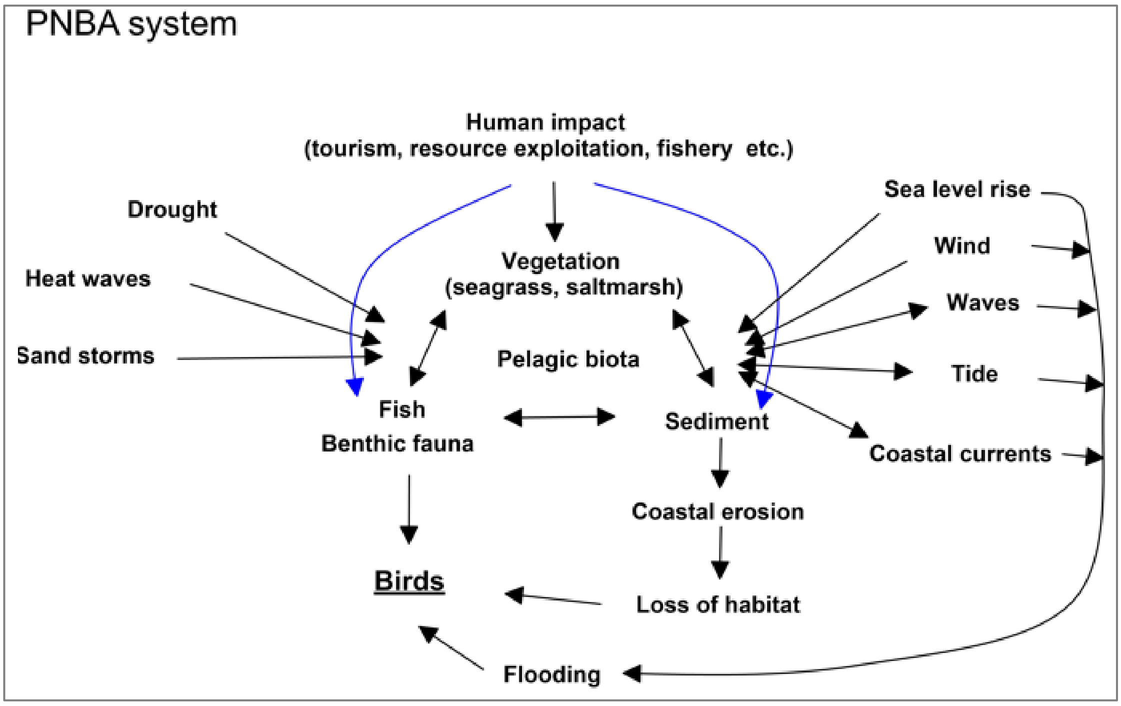

Figure 3.2. Network map showing the interconnections among the parameters and cascading effects in PNBA.

3.1.2 Bijagós Coastal System

The Bijagós ecosystem system is featured by mangrove forests and seagrass meadows in the intertidal and subtidal zones. River discharge provides important sources of sediment and freshwater to the island system. Compared to PNBA, Bijagós is more heavily impacted by human activities, including deforestation near the islands' coastline, rice farming, artisanal fishing (fish and shellfish) and commercial fishing (Figure 3.3).

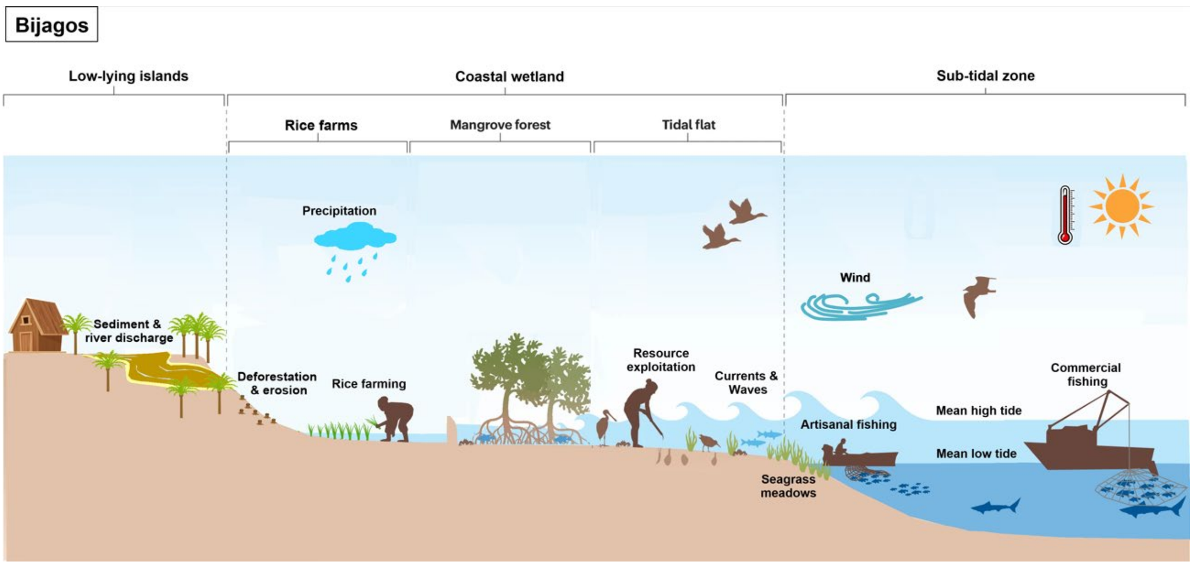

Figure 3.3. Key environmental and anthropogenic factors identified for the Bijagós (including estuaries and islands). Modified based on He et al. (2025).

Hydrodynamics and sediment transport in Bijagós are regularly driven by tides, wind-driven currents and waves from open ocean and freshwater river runoff from land. Extreme events such as drought and heat waves introduce disturbances to the ecosystem (Figure 3.4). On a longer-term, sea level rise imposes an increasing risk of flooding over this low-lying coastal system.

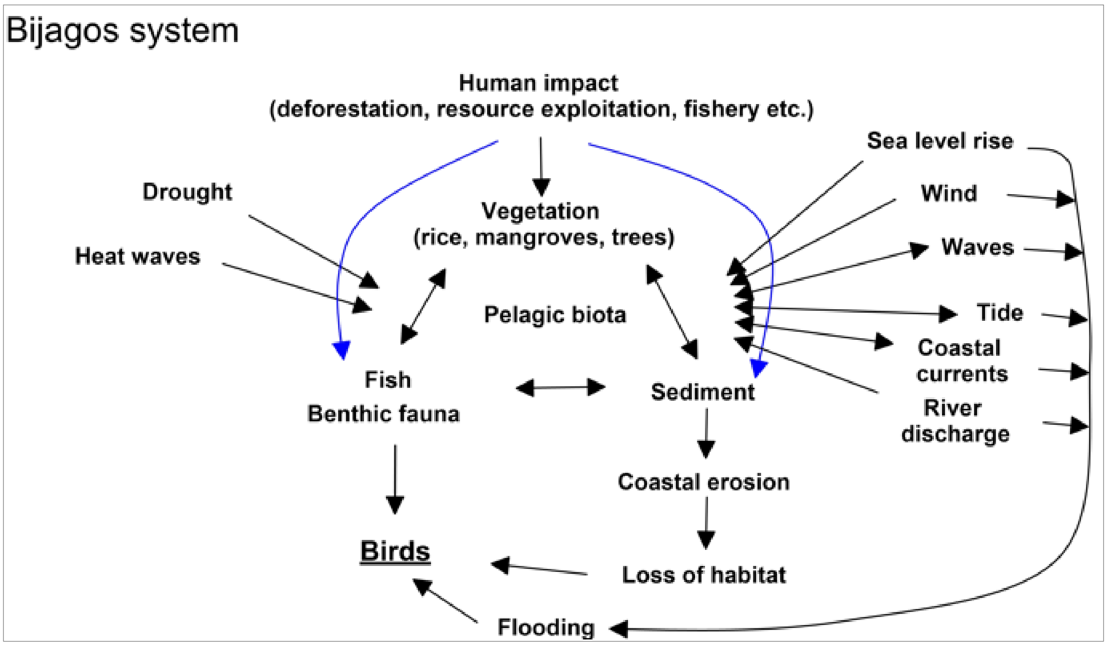

Figure 3.4. Network map showing the interconnections among the parameters and cascading effects in Bijagós.

3.2 PARAMETER AVAILABILITY

A desktop investigation on the availability of data for key parameters that are illustrated in section 3.1 for the two study areas was carried out. Existing global and regional open databases which could provide climate, hydrographic, geomorphological and biological parameters for the study area were reviewed. A detailed list of the parameters, their availability from existing datasets as well as detailed information for accessing the datasets are provided as Supplementary Materials (see excel file "Desktop_study_key_parameters.xlsx").

3.3 KEY PARAMETERS FOR FIELD MONITORING

Not all data can be extracted from existing sources. To ensure model performance, specific parameters need to be collected in the field. Long-term continuous data sets are important as they record past, present-day and future changes to the ecosystem and are crucial for improving model performance and predictive power. It is therefore recommended to set up effective long-term monitoring systems before starting with the numerical modelling. On the other hand, short-term datasets provide important information for modelling present-day, on-going changes to the ecosystem.

3.3.1 PNBA Coastal System

Table 3.1 List of key parameters for field monitoring for PNBA coastal system

Parameter	Description
Water level	Hourly time series of water level at a few fixed-point gauge stations covering at least a spring-leap cycle (> 15 days); ideally long-term
Water temperature	Hourly time series of surface and/or bottom water temperature at a few fixed-point gauge stations covering at least a spring-leap cycle (> 15 days); ideally long-term
Water salinity	Hourly time series of surface and/or bottom water salinity at a few fixed-point gauge stations covering at least a spring-leap cycle (> 15 days); ideally long-term
Waves	Hourly time series of wave properties (height, period and direction) at a few fixed-point gauge stations or buoys covering at least a spring-leap cycle (> 15 days); ideally long-term
Turbidity	Hourly time series of surface and/or bottom water turbidity at a few fixed-point gauge stations covering at least a spring-leap cycle (> 15 days); ideally long-term
Sediment	Median grain size of sediment in the seabed & mud content; sampling locations include subtidal and intertidal zones and different types of habitats (e.g. seagrass meadows, bare ground, channels, mud flats)
Macrobenthos	Functional group, abundance and biomass
Nutrients	NO_3^-/NO_2^-, PO_4^{3-}, *Chl-a,* Dissolved Oxygen (*DO*)

Based on the availability of parameters inferred from Step 3, a list of key parameters for long-term field monitoring at PNBA is provided in Table 3.1. These parameters provide an important database for analysing hydrographical conditions (e.g. tidal range, maximum and minimum water level, waves, frequency and duration of extreme events such as floods, heat waves, storm surges) and ecosystem status (e.g. nutrients level, turbidity and distribution of benthic fauna) in the coastal system. Furthermore, they are crucial for calibrating and validating numerical models established for the coastal system. It is proposed to set up several fixed-point gauge stations (e.g. along the major waterways and tidal inlets, see an example in Figure 3.5) for the PNBA to record continuous time series of these parameters (water level, temperature, salinity, waves, turbidity and nutrients) for a long-term at fixed positions. The positions of gauge stations should be chosen so that they are able to capture the major flow and wave patterns. Recommended positions include the edge of tidal inlets and major channels as well as sites facing open ocean and in sheltered ports. These gauge stations should be equipped with sensors that are able to record time series of key hydrographic parameters (Table 3.1), including tidal level and wave loggers and temperature and salinity sensors.

Existing commercial products include RBR and General Acoustics. In addition, sampling of surface sediments over the entire area with dense coverage (e.g. 10 or more sampling points per 1000 × 1000 m) on the habitats (seagrass meadows, bare ground, mud flats, tidal channels) is suggested to provide mapping of sediment properties including median grain size, mud content and organic carbon content. Further, the macrobenthic fauna should be mapped, regarding functional groups, abundance and biomass.

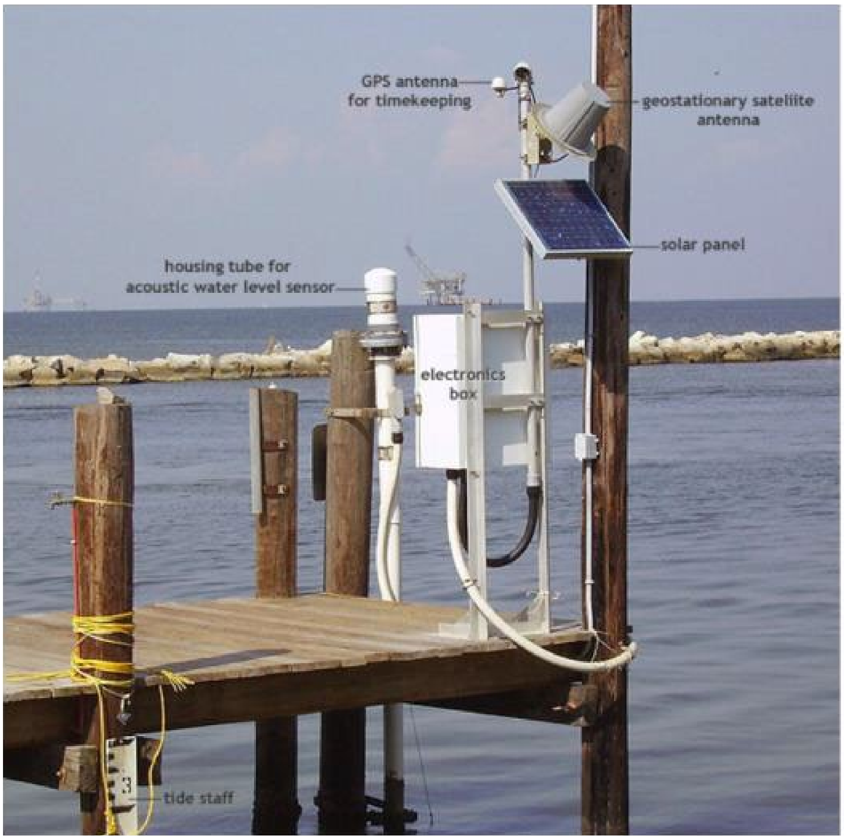

Figure 3.5. The figure shows an example of fixed-point gauge station by a NOAA water level monitoring station on Dauphin Island, Alabama (www.climate.gov/news-features/climate-tech/reading-between-tides-200-years-measuring-global-sea-level).

3.3.2 Bijagós Coastal System

Based on the availability of parameters inferred from Step 3, a list of key parameters for long-term field monitoring at Bijagós is provided in Table 3.2. These parameters provide an important database for analysing hydrographical conditions (e.g. tidal range, maximum and minimum water level, waves, frequency and duration of extreme events such as floods, heat waves, storm surges) and ecosystem status (e.g. nutrients level, turbidity and distribution of benthic fauna) in the coastal system. Furthermore, they are crucial for calibrating and validating numerical models established for the coastal system. Like the case in the PNBA system (section 3.3.1), it is proposed to set up several fixed-point gauge stations (e.g. along the major waterways, tidal inlets and river mouths, see example in Figure 3.5) to record continuous time series of these parameters (water level, temperature, salinity, waves, turbidity, river discharge and nutrients). In addition, sampling of surface sediments over the entire area with particular focus on the habitats (mangroves, seagrass meadows, bare ground, mud flats, tidal channels, rivers) is suggested to provide mapping of sediment properties including median grain size, mud content and organic carbon content as well as macrobenthic fauna regarding functional groups, abundance and biomass.

Table 3.2 List of key parameters for field monitoring for Bijagós coastal system

Parameter	Description
Water level	Hourly time series of water level at a few fixed-point gauge stations covering at least a spring-leap cycle (> 15 days); ideally long-term
Water temperature	Hourly time series of surface and/or bottom water temperature at a few fixed-point gauge stations covering at least a spring-leap cycle (> 15 days); ideally long-term
Water salinity	Hourly time series of surface and/or bottom water salinity at a few fixed-point gauge stations covering at least a spring-leap cycle (> 15 days); ideally long-term
Waves	Hourly time series of wave properties (height, period and direction) at a few fixed-point gauge stations or buoys covering at least a spring-leap cycle (> 15 days); ideally long-term
Turbidity	Hourly time series of surface and/or bottom water turbidity at a few fixed-point gauge stations covering at least a spring-leap cycle (> 15 days); ideally long-term
Sediment	Median grain size of sediment in the seabed & mud content; sampling locations include subtidal and intertidal zones and different types of habitats (e.g. seagrass meadows, bare ground, channels, mud flats, mangroves, rivers)
River discharge	River discharge from the major rivers at fixed-point gauge stations; water temperature and salinity, suspended sediment concentration/turbidity covering at least a spring-leap cycle (> 15 days); ideally long-term
Macrobenthos	Functional group, abundance and biomass
Nutrients	NO_3^-/NO_2^-, PO_4^{3-}, *Chl-a,* Dissolved Oxygen *(DO)*

3.3.3 Parameter Explanation

Continuously recorded time series of water level, temperature, salinity, surface waves and turbidity are crucial for analysing hydrographical conditions (e.g. tidal range, maximum and minimum water level, waves, frequency and duration of extreme events such as floods, heat waves, storm surges) and ecosystem status (e.g. nutrients level, turbidity and distribution of benthic fauna and flora) in the coastal system (Chefaoui et al., 2021). Furthermore, they are crucial for calibrating and validating numerical models established for the coastal system (section 3.4). Reliable risk assessment of flooding, coastal erosion and ecosystem functionality cannot be derived without these data (Trégarot et al., 2021).

3.4 OPEN-SOURCE HYDRO-ECO-SEDIMENT DYNAMIC MODELS

Several widely used open-source hydrodynamic models, that are used for simulating currents and water properties in coastal and estuarine regions, have been reviewed (Table 3.3). These models can be generally categorised into two types, namely structured and unstructured, according to the computational grid system that is used to divide the coastal zone into cells for computation of water flows, waves and sediment transport (Figure 3.6). Structured models use regular, rectangular grids, making them computationally efficient for large areas like the open ocean but poor in coastal areas characterised by complex coastlines. Unstructured models use flexible, irregular grids (triangles/polygons) which can resolve intricate coastal geometry but are more computationally expensive and complex to set up.

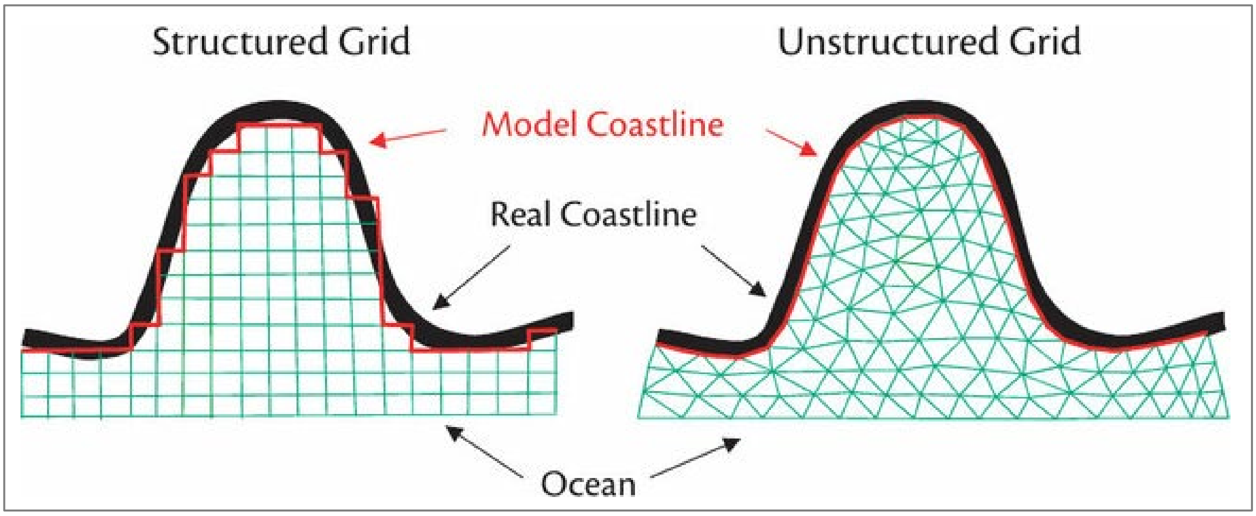

Figure 3.6. Numerical modelling of coastal areas is discretised into a grid system consisting of cells as basic elements for computation. Water flows, waves and sediment transport are computed at each cell by information exchange with its neighbouring cells. Left: example of a structured model grid; Right: example of an unstructured model grid (Chen et al., 2006).

ROMS (Shchepetkin and McWilliams, 2005) and Delft3D (Deltares, 2019) are examples of structured models, which solve the free-surface, hydrostatic, flux form of the primitive equations over variable bathymetry using stretched terrain following in the vertical plane and orthogonal curvilinear coordinates in the horizontal plane (Figure 3.6, left panel).

FVCOM (Chen et al., 2006), FESOM (Danilov et al., 2004) and SCHISM (Zhang et al., 2016) are unstructured coastal ocean models which use flexible, non-uniform grids (Figure 3.6, right panel), allowing them to more precisely capture complex coastlines, estuaries, and seabed features for accurate simulations of tides, currents and waves.

It is worth mentioning that wave models and sediment transport models are integrated into most of the models mentioned in Table 3.3, so that they can be used to simulate hydrodynamics and sediment transport at the same time. Sediment is represented using separate cohesive and non-cohesive categories, each with an unlimited number of user-defined size classes. Each class has fixed attributes of grain diameter, density, settling velocity, critical shear stress for erosion, and erodibility constant. Specification of sediment classes should be based on field data (Tables 3.1 and 3.2). Sediment transport is divided into two modes, namely bedload and suspended load transport. Bedload transport applies to medium to coarse sands where the sediment particles roll or jump along the seabed. Suspended transport involves the entrainment of the fine-grained sediment (clay, silts, and fine sands) into the water column, contributing to turbidity measured in the water column (Tables 3.1 and 3.2).

Table 3.3 List of widely used open-source coastal ocean hydrodynamic models reviewed in this study.

Model	Descriptions
ROMS	Structured hydrodynamic model, available at github.com/myroms/roms, can be coupled with wave, sediment and water quality models, suitable for large-scale regional modelling
Delft3D	Structured hydrodynamic model, available at oss.deltares.nl/web/delft3d/get-started, can be coupled with wave, sediment and water quality models, suitable for fine-scale and regional modelling
FVCOM	Unstructured hydrodynamic model, available at github.com/FVCOM-GitHub/FVCOM, can be coupled with wave, sediment and water quality models, suitable for local-scale and regional modelling
FESOM	Unstructured hydrodynamic model, available at github.com/FESOM/fesom2, suitable for large-scale regional modelling
SCHISM	Unstructured hydrodynamic model, available at github.com/schism-dev/schism, integrated with wave, sediment and water quality models, suitable for fine-scale and regional modelling

To include biological factors into hydro-morphodynamic modelling, it is necessary to couple the physical models with ecosystem models. Table 3.4 provides a list of widely used open-source coastal ocean ecosystem models reviewed in this study. An ecosystem model is a simplified mathematical representation of an ecological system. Such models dynamically simulate the biogeochemical cycling of carbon, nitrogen, phosphorus and silicon in the pelagic and benthic food webs, and are forced by solar radiation, temperature and transport processes.

The models listed in Table 3.4 represent advanced marine biogeochemical models that build upon the basic NPZD (Nutrient-Phytoplankton-Zooplankton-Detritus) framework, offering a complex and realistic representation of marine food webs by including multiple functional groups (e.g. phytoplankton, zooplankton, bacteria, benthic fauna), multiple nutrients (N, P, Si, C, O), fixed or dynamic stoichiometry (here, stoichiometry refers to elemental ratios e.g., Redfield ratio C:N:P, in planktons), multiple trophic pathways and benthic processes, moving beyond the simple nutrient-phytoplankton-zooplankton core.

It is worth noting that the first four models in Table 3.4 (ERSEM from Butenschön et al. (2016), ERGOM from Neumann (2000), CoSiNE from Chai et al. (2002) and ECOSMO from Daewel and Schrum (2013)) are comprehensive ecosystem models considering both pelagic and benthic compartments, while the latter two models (OMEXDIA from Soetaert et al. (1996) and TOCMAIM from Zhang and Wirtz (2017)) are benthic models dedicated to have more detailed representation of sedimentary processes such as carbon burial, remineralisation and bioturbation.

Combining hydrodynamic and ecosystem models is normally done by so-called couplers. One example is the Framework for Aquatic Biogeochemical Models (FABM) developed by Bruggeman & Bolding (2014). FABM provide a generic, easy to use coupling layer that connects a hydrodynamic model with multiple ecosystem models. Its primary role is to specify in detail how hydrodynamic and ecosystem models communicate. Accordingly, it consists of a thin layer of code for communication and data exchange, enveloped by an extensive set of application programming interfaces (APIs) through which models pass information. Most of the hydrodynamics models in Table 3.3 can be coupled with the ecosystem models in Table 3.4 through FABM.

Table 3.4 List of widely used open-source coastal ocean ecosystem models reviewed in this study.

Model	Descriptions
ERGOM	A biogeochemical model specifically strong in representing processes related to hypoxia and anoxia, available at ergom.net/downloads.html
ERSEM	A marine biogeochemical and ecosystem model. It describes the cycling of carbon, nitrogen, phosphorus, silicon, oxygen and iron through the lower trophic level pelagic and benthic ecosystems, available at github.com/pmlmodelling/ersem
CoSiNE	A numerical biogeochemical model used to simulate marine ecosystems, available at github.com/wenfanwu/1D_Ecosystem_Model_for_ERL_paper
ECOSMO	A numerical biogeochemical model with an intermediate-complexity NPZD (nutrient, phytoplankton, zooplankton, detritus) type biology including sediment-water column exchange processes originally formulated for the North Sea and Baltic Sea, available at zenodo.org/records/6387608
OMEXDIA	Originally a water-saturated soil biogeochemical model that considers key processes for dissolved oxygen (DO), such as re-aeration, mineralisation in marine waters, available at codebase.helmholtz.cloud/agrio/fabm-omexdia/-/tree/v0.1.1?ref_type=tags

TOCMAIM	Mechanistic TOC-MAcrobenthos Interaction Model for simulating benthic fauna in response to organic carbon sedimentation, available at doi.org/10.17632/2vvny3xd85.2.

3.5 RECOMMENDATIONS FOR BUILDING CLIMATE IMPACT MODELS

In this chapter, recommendations are provided for building up a regional climate impact model for the study areas. The Bijagós coastal system is illustrated as an example (Figure 3.7). A similar procedure applies to the PNBA coastal system. Construction of the climate impact model follows three major steps, namely (1) setup of the model domain including parameter setting, (2) model calibration and validation using historical observation data, and (3) future projections. In addition, machine-learning-aided mapping of macrobenthos and specific habitats (mudflats, seagrass meadows, saltmarsh, mangroves) is recommended to fill data gaps for both historical reconstruction and future projections.

3.5.1 Model Setup for the Study Area

Unstructured hydro-eco-morphodynamic models (e.g. SCHISM, FVCOM) are recommended in this project to resolve the complex coastline, tidal channels and flats between the islands. The model domain covers the entire continental shelf and its adjacent open ocean (Figure 3.7) with a relatively coarse resolution (e.g. 10 km) in the open ocean and increasing resolution towards the coastal system. Ideally, a spatial resolution of 50-100 m is needed to resolve the complex topography including the channels, key habitats (e.g. seagrass meadows, mangrove forests) and tidal flats. The model has an open boundary at the open ocean, which is driven by tides, wind-induced circulation and waves.

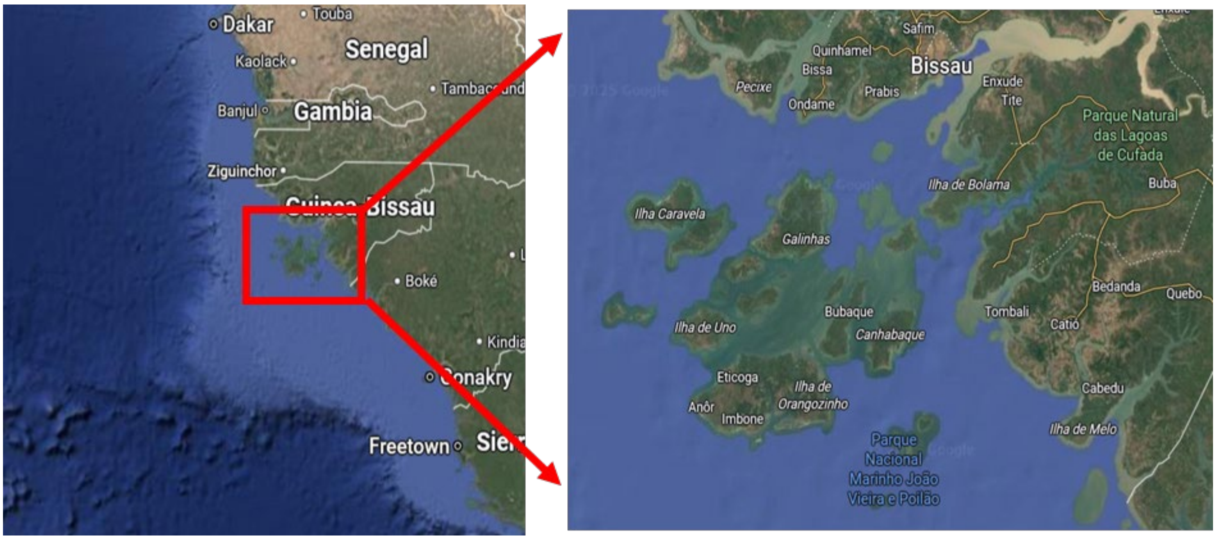

Figure 3.7. Model domain of the Bijagós coastal system, with relatively coarse resolution in the open ocean and increased spatial resolution in the coastal area to resolve the complex coastline and tidal flats and channels between the islands.

For historical reconstructions, the Copernicus Marine Environment Monitoring Service (CMEMS, see Supplementary Materials "Desktop_study_key_parameters.xlsx" for details) data can be used to specify the initial fields of temperature and salinity as well as to provide open ocean boundary conditions (water level, currents, temperature and salinity in the open ocean). The CMEMS data is a reanalysed product of the global ocean eddy-resolving model (with 1/12-degree horizontal resolution and 50 vertical levels), covering the past few decades. For initial setting of temperature and salinity fields to start the simulations, the World Ocean Atlas 2018 (WOA2018) climatological data can also be used.

Historical atmospheric forcing including wind, air pressure, precipitation, and net solar radiation for the entire model area can be derived from the European Centre for Medium Range Weather (ECMWF) ERA-interim (cds.climate.copernicus.eu/datasets). The spatial resolution of ERA-interim data is 0.25° × 0.25° and the temporal resolution is 1 day.

Fifteen primary tidal constituents including diurnal (with period of ~ 24 hours), semi-diurnal (with period of ~ 12 hours) and shorter period ones can be extracted from the global TPXO9-atlas (www.tpxo.net/global/tpxo9-atlas) or FES2014 (www.aviso.altimetry.fr/en/data/products/auxiliary-products/global-tide-fes/description-fes2014.html).

At the upstream river boundaries, freshwater and sediment loads shall be specified according to available observation data (see Supplementary Materials "Desktop_study_key_parameters.xlsx").

Distribution of sediment properties, including fractions of sands and fine-grained mud, shall be specified according to available field data (see Supplementary Materials "Desktop_study_key_parameters.xlsx"). Thresholds for resuspension of each specified sediment class as well as associated settling velocity can be determined based on the grain size of the specified sediment class.

3.5.2 Model Calibration and Validation

After setting up the model, some of the key model parameters such as bottom roughness, critical thresholds for sediment suspension and settling velocity should be calibrated with field data to reduce the error between simulation results and observation (e.g. water level and suspended sediment concentration recorded at gauge stations).

After calibration based on short-term time series of field observation, the model performance should be assessed against longer-term time series of observation. Model results of water level, salinity, temperature, suspended sediment concentration should be compared with field data for validation. An example of model validation is illustrated in Figure 3.8. The Taylor diagram provides a direct impression on the performance of simulations in terms of correlation, standard deviation and root mean square errors compared to field observation.

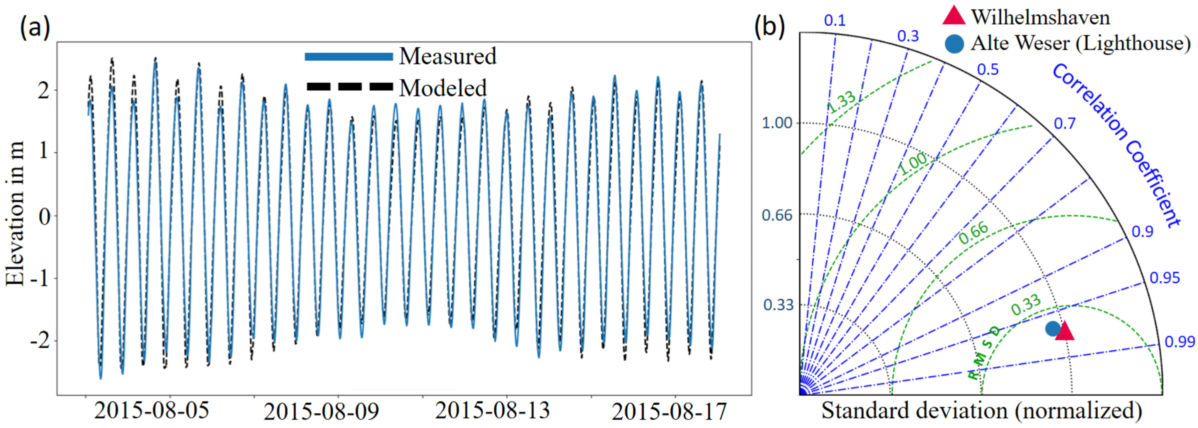

Figure 3.8 Example of model validation against observation data (water level recorded at gauge stations). Source: Arlinghaus et al. (2024). CC BY 4.0.

3.5.3 Model Projections of Future Scenarios

CMIP6 (Coupled Model Intercomparison Project Phase 6) represents the latest international effort by climate scientists to coordinate and compare advanced models of Earth's climate system, generating standardised simulations to understand historical changes and project future climate change scenarios, incorporating new Shared Socioeconomic Pathways (SSPs) for better policy-relevant climate information, which is crucial for IPCC reports.

Most CMIP6 models provide simulation results at resolution of 1.25° latitude and 2.5° longitude. These can be used to specify open ocean boundary conditions and large-scale atmospheric forcing for the climate impact model for future projections in West Africa. Under these future conditions in the open ocean and atmosphere, responses in the coastal systems will be simulated by the regional climate impact model. If needed, finer-scale and higher resolution regional climate projections can be derived based on climate downscaling of simulation results from the CMIP6. However, such downscaling for regional areas requires substantial efforts in terms of time, computational and human resources.

3.5.4 Machine-learning-aided Mapping of Benthic Fauna and Flora

According to the impacts of benthos on sediment dynamics and to achieve an appropriate level of model complexity, benthos shall be sorted into functional groups. A functional group comprises species from different taxa that impact their environment in similar ways. In a case study by Arlinghaus et al. (2024) for the Wadden Sea, benthos was categorised into four major functional groups, namely biomixers, stabilisers, accumulators, and seagrass. Biomixers and accumulators consist of macrobenthos, while stabilisers are represented by biofilm which is mainly assembled by microphytobenthos (MPB) of all contributing species. Similar grouping can be adopted for subtidal ecosystems in West Africa, with additional consideration of mangroves and saltmarshes.

Field datasets of macrobenthos species, abundance and biomass should be collected at various locations in the study area. After identification of dominant species, complete mapping of their abundance and biomass for the entire study area can be done by extrapolation from these field locations. Species distribution modelling (SDM) is commonly used for this purpose, which produces probabilities of species occurrence. Various methods have been applied, spanning from statistical methods to machine learning (Waldock et al., 2021). Species abundance modelling (SAM) is developed from SDM and has an increased solution space, since the output represents decimal values covering the whole range of measured abundance spectrum or biomass spectrum, respectively. Existing studies show the best results when using decision trees (Luan et al., 2020; Waldock et al., 2021). For this reason, it is recommended to use a decision-tree-based SAM to generate a complete map of dominant benthic species in the study area, following the example by Arlinghaus et al. (2024) for the Wadden Sea.

A number of predictor variables at the sampled positions, e.g. temperature, salinity, chl a content, inundation time, shear stress, and mud content can be used in the SAM/SDM. Some of these variables can be derived from field measurements and the others from numerical simulations. Abundance and biomass of the identified dominant species are target variables. For each of the species, a separate regression tree model shall be run. Based on the field data, two SAMs, with one for abundance and one for biomass, shall be applied for each dominant species in order to calculate the mean biomass which is needed for the parameterisation of benthos impacts on sediment. Future distribution of abundance and biomass can be projected using the constructed SAMs based on predicted changes in temperature, salinity, sediment properties, current velocities and nutrients. It is recommended to use 80-90 % of the species data points for model training and the remaining 10-20 % to test the model performance.

For future climate change scenarios, SAMs constructed based on historical data can be applied to estimate the spatial distribution of key species based on the simulation results. The derived maps of key functional groups are then used as input to the hydro-eco-morphodynamics model to assess the climate change impact on the study areas.

3.6 OUTLOOK

The climate impact model, to be built for the East Atlantic Flyway coastal systems, is expected to provide information on not only physical changes (tidal currents, wind, waves, coastal erosion and deposition, coastline change) but also ecosystem responses to a changing climate. The latter includes distribution of key habitats such as mangrove forests, seagrass meadows, mudflats and major functional groups of benthic fauna as well as potential fish stock that are of crucial importance for birds. These results could help identify the risks for specific breeding locations and foraging locations (e.g. submergence of mudflats) and assist coastal planning and mitigation measures in these valuable ecosystems along the East Atlantic Flyway.

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Annex 1

Table A.1: Key parameters for PNBA

Parameter	Variable	Description	Source	Notes
Bathymetry	Elevation	Gridded bathymetry data, global ocean bathymetry	www.gebco.net/	Elevation data in meters on a 15 arc-second interval, intertidal zone might be missing
Bathymetry	Elevation	Mauritanian Institute of Oceanographic Research and Fisheries (French: Institut Mauritanian de Recherches Océanographiques et de Pêches, IMROP)	www.imrop.mr/	Bathymetric data for multiple studies, potentially contact for bathymetric or other observational data
Sediment	Bathymetric map sediment distribution map (3 classes) bedrock map sediment thickness map	Paper on cruise results	Aleman et al. (2014) Post-glacial filling of a semi-enclosed basin: The Arguin Basin (Mauritania), Marine Geology doi.org/10.1016/j.margeo.2013.12.011	Detailed maps

Parameter	Variable	Description	Source	Notes
Ecosystem mapping	Seagrass meadows Mangroves Saltmarsh Mudflat Intertidal bare Sediment Sebkha	Map of marine and terrestrial biocenosis of the National Park of Banc d'Arguin, Mauritania, based on Sentinel-2 imagery	Pottier et al. (2021) Mapping coastal marine ecosystems of the National Park of Banc d'Arguin (PNBA) in Mauritania using Sentinel-2 imagery, International Journal of Applied Earth Observation and Geoinformation doi.org/10.1016/j.jag.2021.102419	Land Cover maps for 2017 and 2018.
Water level	Tide gauge	Station in Nouakchott, Mauritania; hourly & daily data; 2007-01-06 to 2025-01-02	uhslc.soest.hawaii.edu/data/?rq#uh806	University of Hawai'i Sea Level Center
Waves	Among others: significant wave height stokes drift velocity x,y direction period	Global Ocean Waves Reanalysis. Global wave re-analysis describing past sea states since years 1980. resolution 0.2° × 0.2°. Hourly/Monthly	data.marine.copernicus.eu/product/GLOBAL_MULTIYEAR_WAV_001_032/description	hourly 1 Jan 1980 to 1 Jun 2025 can be used for forcing

Parameter	Variable	Description	Source	Notes
Wind	Among others: wind speed x,y wind stress x,y	hourly Level-4 sea surface wind and stress fields at 0.125 and 0.25 degrees horizontal spatial resolution. Scatterometer observations and their collocated European Centre for Medium-Range Weather Forecasts (ECMWF) ERA5 reanalysis model variables are used to calculate temporally-averaged difference fields.	data.marine.copernicus.eu/product/WIND_GLO_PHY_L4_MY_012_006/description	hourly 1 Jun 1994 to 21 Apr 2025 can be used for forcing
Physical parameters	Among others: temperature salinity sea surface height velocity x,y	Global Ocean Physics Reanalysis. The GLORYS12V1 product is the CMEMS global ocean eddy-resolving (1/12° horizontal resolution, 50 vertical levels) reanalysis covering the altimetry (1993 onward).	data.marine.copernicus.eu/product/GLOBAL_MULTIYEAR_PHY_001_030/description	daily/monthly 1 Jan 1993 to 29 Jul 2025 can be used for forcing
Atmosphere	Among others: surface downward longwave/ shortwave radiation air temperature (2m) precipitation	ERA5 hourly data on single levels from 1940 to present, reanalysis	doi.org/10.24381/cds.adbb2d47	hourly Reanalysis: 0.25° x 0.25° (atmosphere), 0.5° x 0.5° (ocean waves) Mean, spread and members: 0.5° x 0.5° (atmosphere), 1° x 1° (ocean waves) 1940 to present

Parameter	Variable	Description	Source	Notes
Mangroves www.globalmangrovewatch.org (nice maps and information on mangroves)	Extent	The Global Mangrove Watch has generated a global baseline map of mangroves for 2010 using ALOS PALSAR and Landsat (optical) data, and changes from this baseline for epochs between 1996 and 2020 derived from JERS-1 SAR, ALOS PALSAR and ALOS-2 PALSAR-2. Annual maps are planned from 2015 and onwards.	data-gis.unep-wcmc.org/portal/home/item.html?id=5e72c1881c524cd4bd0ca28a809514a2	Bunting et al (2018). DOI: 10.3390/rs1010669
Mangroves	Biomass	Global Distribution of Modelled Mangrove Biomass (2014). A climate-based model for potential mangrove above-ground biomass	data-gis.unep-wcmc.org/portal/home/item.html?id=5cf653c59d664349ad1776313bf0e458	Hutchison (2014). DOI: 10.1111/conl.12060
Mangroves	Canopy height	Global distribution, biomass, and canopy height of mangrove-forested wetlands based on remotely sensed and in situ field measurement data	www.earthdata.nasa.gov/data/catalog/ornl-cloud-cms-global-map-mangrove-canopy-1665-1.3	Simard et al. (2019). doi.org/10.3334/ORNLDAAC/1665 Date Accessed: 2025-08-22
Mangroves	General information	Mauritania has three species of mangroves: Avicennia germinans Conocarpus erectus Rhizophora racemosa	NA	Spalding, M. (2010). World atlas of mangroves. Routledge.

Parameter	Variable	Description	Source	Notes
Seagrass meadows	Mapping of seagrass meadows & densities	Species: Cymodocea nodosa, Halodule wrightii, Ruppia maritima and Zostera noltei	NA	Mauritania with 52,300 ha with the majority occurring inside the national park of Banc d'Arguin (Figure 3) Data from this research are kept under GRID Arendal and the NITs of Mauritania, Senegal, The Gambia, Guinea Bissau, Guinea, Sierra Leone and Cabo Verde. Sidi et al (2023). doi.org/10.3390/d15010005
Seagrass meadows	Presence/ absence data	presence data for single locations in the Bay	Halodule wrightii: www.gbif.org/occurrence/search?dataset_key=e5c183ea-9aab-4fd1-a07b-3fbe18fcbe4c&taxon_key=2864094 Cymodocea nodosa: www.gbif.org/occurrence/search?dataset_key=e5c183ea-9aab-4fd1-a07b-3fbe18fcbe4c&taxon_key=5328492	Biodiversity data of the Banc D'Arguin National Park. Information for education, conservation and management. Adapted from https://doi.org/10.1016/j.gecco.2021.e01890
Seagrass meadows	Species	The dwarf eelgrass Zostera noltii is the most dominant intertidal species and the main primary producer of the system	NA	Wolff et al (1993). The functioning of the ecosystem of the Banc d'Arguin, Mauritania: a review. Hydrobiologia 258:211–22.

Parameter	Variable	Description	Source	Notes
Saltmarsh	Extent	Global Distribution of Saltmarshes. from occurrence data (surveyed and/or remotely sensed). The dataset consists of one polygon layer, one point layer, and an accompanying Access database that contains species information (linked exclusively to the point dataset).	data-gis.unep-wcmc.org/portal/home/item.html?id=addd1baa160c4d318b84c3b714d3e583	Mcowen et al (2017). A global map of saltmarshes (v6.1). Biodiversity Data Journal 5: e11764. Paper DOI: doi.org/10.3897/BDJ.5.e11764; Data DOI: doi.org/10.34892/07vk-ws51
Sand storms	Dust particles	The WMO Barcelona Dust Regional Center offers a wide range of dust products that serve the need for detailed dust information on a regional scale.	dust.aemet.es/products/dust-products-catalogue	List of different models and observations for Dust from the Sahara. For Example: ECMWF-ERA5 - CAMS
Commercial Fishing	Swept Area Ratio	Global Fishing Watch provides mapping of trawling activities on global shelf seas based on AIS data	globalfishingwatch.org/	Spatial resolution 1 x 1 degrees, not covering smaller vessels < 15 m length. AIS might be turned off during fishing resulting in incomplete data

Table A.2: Key parameters for Bijagós

Parameter	Variable	Description	Source	Notes
Bathymetry	Elevation	Gridded bathymetry data, global ocean bathymetry	www.gebco.net/	Elevation data in meters on a 15 arc-second interval (ca. 450m in Guinea-Bissau).
Water level	Tide gauge	Network of tide gauges with total of 15 stations since April 2021	www.malmon-desira.com/	Information at doi.org/10.1016/j.ecss.2025.109318
Waves	Among others: significant wave height stokes drift velocity x,y direction period	Global Ocean Waves Reanalysis. global wave reanalysis describing past sea states since years 1980. resolution 0.2° × 0.2°. Hourly/Monthly	data.marine.copernicus.eu/product/GLOBAL_MULTIYEAR_WAV_001_032/description	hourly 1 Jan 1980 to 1 Jun 2025 can be used for forcing
Wind	Among others: wind speed x,y windstress x,y	Hourly Level-4 sea surface wind and stress fields at 0.125 and 0.25 degrees horizontal spatial resolution. Scatterometer observations and their collocated European Centre for Medium-Range Weather Forecasts (ECMWF) ERA5 reanalysis model variables are used to calculate temporally averaged difference fields.	data.marine.copernicus.eu/product/WIND_GLO_PHY_L4_MY_012_006/description	hourly 1 Jun 1994 to 21 Apr 2025 can be used for forcing

Parameter	Variable	Description	Source	Notes
Physical parameters	Among others: temperature salinity sea surface height velocity x,y	Global Ocean Physics Reanalysis. The GLORYS12V1 product is the CMEMS global ocean eddy-resolving (1/12° horizontal resolution, 50 vertical levels) reanalysis covering the altimetry (1993 onward).	data.marine.copernicus.eu/product/GLOBAL_MULTIYEAR_PHY_001_030/description	daily/monthly 1 Jan 1993 to 29 Jul 2025 can be used for forcing
Atmosphere	Among others: surface downward longwave/ shortwave radiation air temperature (2m) precipitation	ERA5 hourly data on single levels from 1940 to present, reanalysis	doi.org/10.24381/cds.adbb2d47	hourly Reanalysis: 0.25° x 0.25° (atmosphere), 0.5° x 0.5° (ocean waves) Mean, spread and members: 0.5° x 0.5° (atmosphere), 1° x 1° (ocean waves) 1940 to present
Mangroves www.globalmangrovewatch.org (nice maps and information on mangroves)	Extent	The dataset contains five layers. One each for 1996, 2007, 2010 and 2016 Global Mangrove Watch mangrove extents and a composite layer that combines those four timesteps (i.e., the maximal extent).	data-gis.unep-wcmc.org/portal/home/item.html?id=6688fafdbbd84b59850cdf07c406cf24	Suggested Citation: Worthington, T.A. et al, 2020: DOI: doi.org/10.1038/s41598-020-71194-5

Parameter	Variable	Description	Source	Notes
Mangroves	Extent	Global Distribution of Mangroves USGS (2015) derived from earth observation satellite imagery	data-gis.unep-wcmc.org/portal/home/item.html?id=c1ab54bba4184c49ac7831c915106aec	Giri C, et al (2011): DOI: 10.1111/j.1466-8238.2010.00584.x. Data DOI: doi.org/10.34892/1411-w728 Data URL: data.unep-wcmc.org/datasets/4
Mangroves	Biomass	Global Distribution of Modelled Mangrove Biomass (2014). A climate-based model for potential mangrove above-ground biomass	data-gis.unep-wcmc.org/portal/home/item.html?id=5cf653c59d664349ad1776313bf0e458	Hutchison et al (2014): DOI: 10.1111/conl.12060;
Mangroves	Canopy height	global distribution, biomass, and canopy height of mangrove-forested wetlands based on remotely sensed and in situ field measurement data	www.earthdata.nasa.gov/data/catalog/ornl-cloud-cms-global-map-mangrove-canopy-1665-1.3	Simard et al (2019): DOI: doi.org/10.3334/ORNLDAAC/1665 Date Accessed: 2025-08-22
Seagrass meadows	Mapping of seagrass studies and densities	Species: Halodule wrightii	N/A	Species: Halodule wrightii DOI: doi.org/10.3390/d15010005

Parameter	Variable	Description	Source	Notes
Saltmarsh	Extent	Global Distribution of Saltmarshes. from occurrence data (surveyed and/or remotely sensed). The dataset consists of one polygon layer, one point layer, and an accompanying Access database that contains species information (linked exclusively to the point dataset).	data-gis.unep-wcmc.org/portal/home/item.html?id=addd1baa160c4d318b84c3b714d3e583	Mcowen et al (2017): DOI: doi.org/10.3897/BDJ.5.e11764; Data DOI: doi.org/10.34892/07vk-ws51
River discharge	Rivers	Analysis of tides in Guinea Bissau, with particular focus in the Bijagos archipelago.	Dièye et al. (2025) Tidal amplification and distortion in Guinea-Bissau, West Africa doi.org/10.1016/j.ecss.2025.109318	Geba (sometimes called Bissau estuary) average annual Flow: 400m³/s Other rivers have relatively low runoff: Cacheu, Mansoa, Buba, Tombali and Cacine
River discharge	Water volume	Rio corubal: 8 m³/s in May, 1120m³/s in September	www.adaptation-fund.org/wp-content/uploads/2016/03/AFB.PPRC_.18.9-Proposal-for-Guinea-Bissau.pdf	NA
River discharge	Water volume	Rio Geba: annual value: 0.8bn m³	www.adaptation-fund.org/wp-content/uploads/2016/03/AFB.PPRC_.18.9-Proposal-for-Guinea-Bissau.pdf	NA
Commercial fishing	Swept area ratio	Global Fishing Watch provides mapping of trawling activities on global shelf seas based on AIS data	globalfishingwatch.org/	Spatial resolution 1 x 1 degrees, not covering smaller vessels < 15 m length. AIS might be turned off during fishing resulting in incomplete data