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A picture is worth a thousand words: using digital tools to visualize marine invertebrate diversity data along the coasts of Mozambique and São Tomé & Príncipe

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Abstract

The amount of biological data available in online repositories is increasing at an exponential rate. However, data on marine invertebrate biodiversity resources are still sparse and scattered in these countries. Online repositories are useful instruments for biodiversity research, as they provide a fast access to data from different sources. The use of interactive platforms comprising web mapping are becoming more important not only for the scientific community, but also for conservation managers, decision-makers and the general public as they allow data presentation in simple and understandable visual schemes. The main goal of this study was to create an interactive online digital map (MARINBIODIV Atlas), through the collection of data from various sources, to visualize marine invertebrate occurrences and distribution across different habitats, namely mangroves, seagrasses, corals and other coastal areas, in Mozambique and São Tomé and Príncipe. The acquired biodiversity data were managed and structured to be displayed as spatial data and to be disseminated using the geographic information system ArcGIS, where data can be accessed, filtered and mapped. The ArcGIS web mapping design tools were used to produce interactive maps to visualize marine invertebrate diversity information along the coasts of Mozambique and São Tomé and Príncipe, through different habitats, offering the foundation for analysing species incidence and allocation information. Understanding the spatial occurrences and distribution of marine invertebrates in both countries can provide a valuable baseline, regarding information and trends on their coastal marine biodiversity.

Keywords

marine invertebrates, Mozambique, São Tomé and Príncipe, spatial geographic representation, web mapping

Introduction

There is an exponential increase in the amount of biological data available in online repositories. In biodiversity studies, digital repositories are useful resources because they provide centralization of available global knowledge, enable prompt accessibility, incorporate data from multiple sources around the world, allow more holistic data analysis and accurate reproducible studies (Maldonado et al. 2015). Digital biodiversity repositories have been continuously growing, and data are often submitted in the form of large datasets such as global, or regional species occurrences lists. These large databases are not exempt from errors, inaccuracies, and omissions, such as taxonomic uncertainties and geographical inaccuracies of species occurrences (Hortal et al. 2015). In spite of this, these repositories are extremely useful, providing uniformized data from a number of sources that greatly exceed what could be gathered manually, saving time, money and reducing the impact of more in situ sampling on biodiversity (Edwards 2004, Guralnick and Hill 2009, Chapman 2015). In fact, there has been a growing standardization and availability of biodiversity data on online repositories, enabling quick access to expand canonical data from different origins. The Global Biodiversity Information Facility (GBIF at www.gbif.org), which promotes the publishing of datasets using generally agreed data standards on biodiversity, is one of these repositories. Other online repositories are accessible and complement each other, such as the Integrated Digitized Biocollections (iDigBio at www.idigbio.org), citizen contribution-based systems like iNaturalist (at http://www.inaturalist.org) and Biodiversity4all (at www.biodiversity4all.org). Beyond big data, biodiversity repositories such as Natural History Collections (NHC) are significant scientific infrastructures with valuable data on the biodiversity of the planet since they contain curated sets of natural objects that are collected over time, in different locations, with associated relevant information digitized or in paper (Cartaxana et al. 2014). Other data sources on biodiversity include scientific articles and checklists, either digital or paper-based, often resulting from more in-depth studies. Therefore, the compilation and incorporation of biodiversity data dispersed through a variety of different sources into spatial, explicit digital formats is also a significant step in making information accessible to a wide range of purposes and audiences (Asaad et al. 2019).

Maps are suitable tools to communicate complex spatial information, being extremely useful to explore contents and for raising awareness about different issues. For instance, maps on species occurrences and spatial patterns are mandatory tools to provide biodiversity information for environmental resource management. The increase of georeferenced species occurrence data enables the use of geographic information system (GIS) tools that can be applied for geographic data representations through, e.g., the creation of accurate distribution maps. High quality, robust, and consistent data and information on species occurrences at different spatial and temporal levels, allow the use of GIS to manage digital biodiversity data from various sources to analyse it and display it in a spatial explicit manner (Wahid et al. 2016, Wright 2016). The advantage of GIS is that it models reality based on data, as it is designed to capture, model, store, receive, share, manipulate, analyse and present geographically referenced information (ESRI 1990). Basic GIS operations now provide a secure basis for measuring, mapping and analysing data. Data stored in a GIS database provides a simplified version of the Earth's surface. Georeferenced data can be organized by a GIS using different criteria, e.g., thematic maps or spatial objects. Each thematic layer can be saved using an appropriate data format, depending on its nature and the purpose of its use. GIS are key in determining priority for species taxonomic identification and conservation, historical mapping to analyse trends and planning the spatial use of resources. It also serves as an integral component in the spatial modelling of species distribution in the past and in possible future scenarios (Worboys and Duckham 2004).

For greater accessibility, web mapping is the method of using interactive maps made accessible on the internet by GIS. These may implement filters that allow the user to choose the data to be displayed, deriving different levels of information. For the scientific community, the public and policymakers, the use of interactive platforms consisting of web maps is becoming increasingly important, as they allow up-to-date data to be presented using clear and understandable visual systems (Cristofori et al. 2015, Cristofori et al. 2017, Demarchi et al. 2017, Vincent et al. 2018). By using different and collaborative mapping software such as free-to-use Google Maps and Bing Maps, open-source QGIS and OpenStreetMap or cloud-based ArcGIS, it is possible to create web maps. They allow maps to be generated and have several functions, to view and interact with maps and geospatial data (Sui 2014). As biodiversity and habitat loss rates increase, it is crucial that we develop a simpler and more effective way of incorporating all biodiversity data into interactive digital platforms, such as web maps, and encourage the open sharing of data, so that the scientists, analysts and policymakers can apply it to research and policy decisions (Rocha et al. 2014). Since web mapping has been an area of strong growth in the last decade, the result of this expansion is the number of biodiversity projects that use this methodology to graphically display the data (Veenendaal et al. 2017). Projects aimed at mapping biodiversity at specific locations such as China (Lin et al. 2018), Japan (NIES and JBIF 2015), Kansas (Kansas Biological Survey 2020) and the Coral Triangle (Asaad et al. 2019); on specific taxonomic groups as in the case of ants (Janicki et al. 2016); or on unique characteristics such as invasive or disease-related species monitoring (NAS - Nonindigenous Aquatic Species 2020 and Mosquito Alert 2020, respectively) are increasingly popular.

The growth of human populations within coastal areas has increased due to rural-urban migration, with people relocating to more urbanized and economic centres. This migration increases human pressure on the environment due to land and marine-based human activities. As a result, coastal and marine living resources, and their habitats are being adversely lost or damaged, reducing marine biodiversity (Celliers and Ntombela 2015).

Nearshore habitats are of great socio-economic significance, especially in sub-Saharan Africa. For instance, Mozambique's and São Tomé and Príncipe's coastal populations depend on marine resources to sustain their livelihoods, and food security (Vicente and Bandeira 2014). Marine invertebrates comprise important food sources for local populations, especially for the poorest people that depend on these resources for their livelihoods and, food security, and may have high commercial, gastronomic, and ecological importance (Paula and Silva 1998, Anderson 2009). However, data on resources related to marine invertebrate biodiversity in these countries is still scarce and dispersed. Therefore, aggregating this information, thus bringing it into practical application is of the most importance.

The main objectives of this study were to 1) integrate comprehensive data on marine invertebrates from mangroves, seagrasses, corals, and other coastal areas of Mozambique (MOZ) and São Tomé and Príncipe (STP) into an interactive GIS mapping system, and 2) disseminate this information online through the web mapping MARine INvertebrate BIODIVersity (MARINBIODIV Atlas) along the coasts of Mozambique and São Tomé and Príncipe. We explored existing digital records of marine biodiversity from MOZ and STP included in global digital repositories, NHC records, and scientific literature; compiled them into a comprehensive datafile to generate species occurrences distribution maps; and made these available online through the MARINBIODIV Atlas web map. This data increased our understanding of marine invertebrate biodiversity along the coasts of MOZ and STP contributing with baseline information on coastal marine invertebrate occurrence and distribution in both countries. Further, the MARINBIODIV Atlas provides a new tool for science, policy making and legislating, as well as to engage Mozambican and São Tomé and Príncipe's citizens with science, and the preservation of their natural resources.

Material and methods

This study comprised the use of digital tools to (1) create an interactive geographic data representation of marine invertebrate species occurrences and distribution, and respective habitats, across the coastal zones of MOZ and STP in ArcGIS Desktop (ArcMap), by a comprehensive compilation of biodiversity data contained in digital repositories, NHC records and scientific literature, and to (2) construct an interactive digital platform map (MARINBIODIV Atlas) for online dissemination using ArcGIS Online, specifically designed for web mapping (Fig. 1).

Geospatial Data Representation

The biodiversity database involved the compilation and organization of marine invertebrate data from MOZ and STP, and by aggregating global biodiversity data contained mostly in digital repositories. Specifically, data were gathered from worldwide open-source information from online digital biodiversity repositories such as GBIF and iDigBio, NHC records from worldwide museums and scientific literature. Data were first organized, cleaned up and validated in a Microsoft Excel spreadsheet because of its simplicity. In the Excel spreadsheet each line corresponded to a single occurrence, i.e., an observation or sampling in a defined geographic location and period. Only the occurrences with taxon rank equal to genus, species, and subspecies, were considered. Data were catalogued into a Darwin Core metadata schema (DwC) based structure (Darwin Core maintenance group 2014), collated, geocoded and validated and then imported to an ArcGIS database. A large percentage of the data collected did not have geographic coordinates. Therefore, geocoding, verification and correction of geographic coordinates were accomplished using the GEOLocate Collaborative Georeferencing Web Client interface (GeoLocate Developer Resources 2019). Records with the general description of "Off" (e.g., Zambeze River, Off Mouth) were geocoded 200 to 300 meters in diameter from the locality. The uncertainty of the records was dismissed. Any records unable to geocode with GEOLocate, were either discarded or manually searched and georeferenced using Google Maps. Since data originated from multiple sources, it was necessary to uniformize it, to ensure data standardization for reliable and high standards. The data were cleaned and wrangled using the open-source desktop application OpenRefine v3.1, and the taxonomic names were validated using the WoRMS checklist. (WoRMS Editorial Board 2019).

Geographic analysis, using QGIS, entailed steps such as geographical data processing and merging different habitat layers. Habitat data collected from images instead, was georeferenced using the inbuilt QGIS *Georeferencer* function. In this case, the georeferencing process – which involves taking a raster image coverage, assigning a coordinate system and coordinates to it, and translating, transforming, and warping it into a position relative to some other spatial data – was accomplished by assigning real-world coordinates to specific pixels on the raster obtained by the coordinates on the map image itself.

For georeferencing a total of 9 ground control points were used in the raster relative to São Tomé Island, and 8 ground control points for the raster relative to Príncipe Island (Fig. 2).

The habitats studied encompassed corals, mangroves and seagrasses present in the coastal zones of MOZ and STP. The spatial datasets mapping the coastal habitats, added as layers, were downloaded from the UN Environment World Conservation Monitoring Centre website at http://data.unep-wcmc.org and the ReefBase website at http://reefbase.org/gis_maps/datasets.aspx. The datasets used for each habitat were as follows: Coral - Global Distribution of Coral Reefs (Dataset ID: WCMC-008): the dataset shows the global distribution of coral reefs in tropical and subtropical regions, composed of one set of polygon occurrence data, with a temporal range from 1954 to 2018 and the reference system WGS 1984 (version 4.0 - November 2018); Coral Bleaching (Dataset: ReefBase): the dataset provides point occurrence data of observation details of coral bleaching around the world, with a temporal scope since early 2002; Monitoring Sites (Dataset: ReefBase): the dataset provides point occurrence data on coral reef monitoring sites locations from major reef monitoring programs. Reefs Location (Dataset: ReefBase): the dataset provides point occurrence data on coral reef locations; Marine Protected Areas (Dataset: ReefBase): the dataset provides point occurrence data on marine protected areas with coral reef zones. Mangrove: World Atlas of Mangroves (Dataset ID: WCMC-011): the dataset shows the global distribution of mangroves and it was produced mostly from satellite imagery, composed of one set of polygon occurrence data, with a temporal series mainly from 1999 to 2003 and the reference system WGS 1984 (version 2.0 – December 2017); Global Distribution of Mangroves USGS (Dataset ID: WCMC 010): the dataset shows the global distribution of mangrove forests derived from earth observation satellite imagery, composed of one set of polygon occurrence data, with a temporal range from 1997 to 2000 and the reference system WGS 1984 (version 1.3 – June 2015); Global Mangrove Watch (Dataset ID: GMW-001): the dataset shows a global baseline map of mangroves using satellite imagery, composed of one set of polygon occurrence data, with a temporal array from 1996 to 2016. Data retrieved on 4 April 2019 (version 2.0). Seagrass: Global Distribution of Seagrasses (Dataset ID: WCMC-013-014): the dataset shows the global distribution of seagrasses, composed of two subsets of point and polygon occurrence data, with a temporal range from 1934 to 2015 and the reference system WGS 1984 (version 6.0 - June 2018). The search was expanded to the scientific literature to resolve the lack of habitat information in São Tomé and Príncipe.

The layers with the same geometry type, e.g., "Point" or "Polygon," were merged into a single layer using the command "Merge Vector Layers" to combine all data corresponding to each habitat (corals, mangroves, and seagrasses) in a single shapefile.

The process of vectorization generated several thousands of small polygons in some places, which created overlapping polygons. To correct these, a dissolve operation was performed with Mapshaper software. (Spalding et al. 2010, Giri et al. 2011, UNEP-WCMC and FT 2017, Bunting et al. 2018, UNEP-WCMC et al. 2018).

The input layers “Global Distribution of Coral Reefs”, “Coral Bleaching”, “Monitoring Sites”, “Reefs Location” and “Marine Protected Areas” were merged into a point data layer named “Coral point-data”. Both input layers “Global Distribution of Mangroves USGS” and “Global Mangrove Watch” were merged into a polygon data layer named “Mangrove polygon-data”. All layers created manually were also joined to their respective habitat layers. Region layers were downloaded from public domain map data available online: administrative boundaries, divisions and outline of MOZ and STP as ESRI Shape file format latitude and longitude coordinates at GADM data website at https://gadm.org/data.html; Mozambican and São Tomé and Príncipe EEZ as Shapefile format at Marine Regions website at www.marineregions.org.

Online Data Dissemination

The data were imported to ArcMap as a CSV file with latitude and longitude coordinates stored in separated columns. Point coordinates’ longitude and latitude were mapped to X and Y fields, respectively. The coordinate reference system used was EPSG:4326 or WGS 1984. The ArcMap layouts are specifically designed to provide a foundation for web mapping species occurrences and distribution data across MOZ and STP habitats. Based on point data and/or polygon data, the arrangement of combined data corresponding to the three habitat layers (corals, mangroves and seagrass) provides the basis for the filtering of habitat types.

To promote online data dissemination and make it user-friendly, a digital platform web map (MARINBIODIV Atlas) was developed, to visualize marine invertebrate diversity along the coasts of Mozambique and São Tomé and Príncipe, by using the complete cloud-based ArcGIS mapping software, ArcGIS Online, designed for web mapping and exploring data through filtering and mapping different layers of information.

Results

The MARINBIODIV Atlas web map is an interactive digital platform that can be used to visualize the occurrences and distribution of invertebrate species along the coastlines of MOZ and STP. It provides a variety of filters layers to manipulate the data, allowing the visualization of occurrences against specific criteria (e.g., type of habitat, taxonomic classification, among others). The web map contains 11 layers that can be selected or unselected to filter the data in display. These layers are grouped in 3 main sub-groups: 1) species occurrences, 2) habitats, and 3) MOZ and STP boundaries. To provide geographical context, the continents, and oceans are also represented in the background (Figs 3, 4).

The web map's homepage uses a full-screen canvas template, presenting part of Africa as well as the Atlantic and Indian oceans comprising the study areas. Filtering can be done through the collapsible layers' menu, at the top right side of the map, which includes five layers (species occurrences, MOZ and STP areas and EEZ). The occurrences in the map are clustered, i.e., symbols scale proportionally to the number of occurrences of a given species at a location. Species, genus or family can be searched through the filter symbol at the top left of the map (Fig. 5). See Fig. 6 for all widgets of this web map.

The species occurrence layers are separated into 13 main classes represented by specific symbols: barnacle, bivalve, cephalopod, coral, crab, echinoderm, gastropod, lobster, medusa, sea anemone, sea spider, shrimp and worm (Fig. 7). These icons do not correspond to single species, but rather to morphotypes, i.e., groups of species that have a similar shape within a broader taxonomic group. Symbols vary in size according to the number of individuals per occurrence (by using the proportional symbol scale as referred above). By hovering over each symbol an informative box is displayed with details and statistics on each occurrence like scientific name, taxon rank, latitude, longitude, depth, locality, country, environment, habitat, event date, numbers of individuals, gastronomical value and an external link to the WoRMS website for general information (Fig. 8).

Habitats are divided into three groups: corals, mangroves and seagrasses, with polygon-data and point-data layers, each represented with specific symbology (Figs 9, 10). They can be merged and/or seen individually.

Fig. 11 represents the administrative boundaries of both STP and MOZ, including their names, outlining their borders, and exclusive economic zones.

The interactive digital platform is hosted and available at MARINBIODIV Atlas.

Discussion

Computer Science provides tools for biologists to analyse and report findings on species, and their behaviours. The integration of marine invertebrate's data from heterogeneous sources and formats led to a few challenges in terms of handling and curating large volumes of data, as well as the manipulation of data, images and geospatial reference information. To address these challenges different methods and approaches were used to attain international standards associated with biodiversity datasets.

The ArcGIS Online software makes it easier to create habitat layers, combine multiple habitat layers, add background layers, and define marker symbology. This platform provides a strong set of tools, used to develop the MARINBIODIV Atlas. Key limitations were related to habitat shapefiles, compiled from multiple varying scale and quality data sources, for which image analysis was performed. While some used consistent methodology across all regions, others included observational data from different regional, national, and international sources. In relation to the coastline, these factors may generate a mismatch in the position of the layers, which we tried to correct by creating representative polygons through the use of satellite imagery. Overall, most polygons used here are relatively well spatially aligned to the coastline layer. In spite of our best efforts to reduce spatial representation bias, accuracy may vary among locations, considering that the sources were different, and related errors were not consistent across the datasets, including cloud cover, background noise, Landsat scanline error, misclassification of certain areas due to striping artifacts, among others. Nevertheless, precision is best measured on the seaward side compared to the landward side, due to the greater presence of terrestrial vegetation (Asaad et al. 2019). In addition to the three habitats (mangrove, seagrass, and coral), a lack of other mapped habitat types across the MOZ and STP coastlines may generate limitations to fully assess the ecological and biological significance of the marine region.

The MARINBIODIV Atlas developed in this study, enables a dataset of curated marine invertebrate biodiversity data to be accessed and visualized through a web browser with detailed geographical and taxonomic coverage. This web map provides different filter layers, allowing the visualization of occurrences and distribution against specific criteria. This atlas integrates data that otherwise would be scattered, heterogeneous and might be difficult to access depending on its source, hampering its contribution to biodiversity conservation (Flemons et al. 2007, Map of Life 2020).

Web mapping has advantages, when constructing a web map using zero or low code. Other research studies using web maps have also opted for the same method of using ArcGIS Online with technological tools, that can be used to create a GIS web map requiring less technical knowledge, given that programming and writing code are complex. These maps, which were designed with spatial data about environment, habitat and species occurrence and compiled from the largest biodiversity datasets in their respective fields, are intrinsically complementary and can provide stakeholders with options for obtaining accurate data, and facilitate successful decision-making processes, as well as the ability of scientific communities to develop geospatial tools to support biodiversity conservation. (NIES, JBIF, 2015; Lin et al., 2018; Asaad et al., 2019; Kansas Biological Survey, 2020).

We have compiled and integrated data on marine invertebrates in mangroves, seagrasses, corals through the coastal zones of MOZ and STP. These maps were incorporated into a web platform to assemble an interactive map, MARINBIODIV Atlas, on the occurrence, and distribution of marine invertebrates across different habitats in MOZ and STP, to disseminate and share the obtained information with the scientific community, conservation managers, policymakers and the general public. Replication of this type of approach in other regions is important, as biodiversity loss continues and limited resources are available to preserve and protect biodiversity (Janicki et al. 2016, Asaad et al. 2019).

The spatial data on marine invertebrates through different habitats along the coasts of MOZ and STP, provided in this study contribute to the United Nations (UN) sustainable development goals (SDGs), namely SDG #14: “Life below water” referring to marine and coastal biodiversity, its conservation and sustainable use for human society's sustainable growth (United Nations Development Programme 2019a). This information is also relevant, as it can be related to the natural and gastronomic resources, and food security in these two countries, adding on to SDG # 2: "No hunger”, aimed at ending hunger by achieving food security and improving nutrition worldwide (United Nations Development Programme 2019b), because marine invertebrates are a vital component of the diet and livelihoods of MOZ and STP local populations. In addition, by being freely accessible, this data and digital resources can be further used to develop new research projects, to create teaching or dissemination tools, to write books, articles and brochures for outreach, among other work programmes.

Conclusions

The importance of this study lies in its ability to provide clear baseline biodiversity data, that can be applied to model species distributions and estimate the size of species range in mangroves, seagrasses and corals along the coasts of Mozambique and São Tomé and Príncipe, to predict their risk of extinction and to hopefully advance biodiversity conservation strategies.

Due to an overflowing and constant increase of data available online, computer science techniques, such as the ones used in this work, are essential for their analysis and critical to extract knowledge for the field of biological sciences (Torres et al. 2006). By leading toward a smoother integration of biodiversity data with international standards, relating to biodiversity data from various sources, the approach used throughout this work may have broader applications for the scientific community, politicians, conservation managers, various stakeholders, and the general public to view and use.

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Author contributions

H. Niza: Methodology, Software, Validation, Investigation, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization. **M. Bento:** Methodology, Validation, Investigation, Data Curation, Writing - Review & Editing, Visualization. **L.F. Lopes:** Conceptualization, Supervision, Writing - Original Draft, Writing - Review & Editing, Visualization, Project administration. **A. Cartaxana:** Investigation, Supervision, Writing - Review & Editing, Visualization. **A.M. Correia:** Conceptualization, Supervision, Writing - Original Draft, Writing - Review & Editing, Visualization, Project administration.

References

- Anderson J (2009) Report. Southern oceans education and development (SOED) Project9.
- Asaad I, Lundquist CJ, Erdmann MV, Costello MJ (2019) An interactive atlas for marine biodiversity conservation in the Coral Triangle. Earth System Science Data 11: 163-174. https://doi.org/10.5194/essd-11-163-2019
- Bunting P, Rosenqvist A, Lucas R, Rebelo LM, Hilarides L, Thomas N, Hardy A, Itoh T, Shimada M, Finlayson CM (2018) The global mangrove watch—A new 2010 globalbaseline of mangrove extent. Remote Sensing 10: 1669. https://doi.org/10.3390/rs10101669
- Cartaxana A, Correia AM, Carvalho D, Lopes L (2014) O papel das coleções de história natural no estudo e conservação de invertebrados. Ecologi@ 7: 15-21.

- Celliers L, Ntombela C (2015) Urbanization, coastal development and vulnerability, and catchments. In: UNEP, WIOMSA (Eds) Regional State of Coast Report: Western Indian Ocean. https://doi.org/10.18356/cd2f1dd6-en
- Chapman AD (2015) Principles and methods of data cleaning: primary species and species-occurrence data. Report for the Global Biodiversity Information Facility, Copenhagen. URL: http://www.gbif.org/document/80528
- Cristofori EI, Balbo S, Camaro W, Pasquali P, Boccardo P, Demarchi A (2015) Flood risk web-mapping for decision makers: A service proposal based on satellite-derived precipitation analysis and geonode. IEEE International Geoscience and Remote Sensing Symposium1389-1392. https://doi.org/10.1109/IGARSS.2015.7326036
- Cristofori EI, Facello A, Demarchi A, Camaro W, Fascendini M, Villanucci A (2017) A geographic information system as support to the healthcare services of nomadic community, the filtu woreda case study. In: Leal Filho W, Belay S, Kalangu J, Menas W, Munishi P, Musiyiwa K (Eds) Climate Change Adaptation in Africa. Climate Change Management. Springer https://doi.org/10.1007/978-3-319-49520-0_6
- Darwin Core maintenance group (2014) Biodiversity information standards: Darwin Core. Zenodo. https://doi.org/10.5281/zenodo.592792
- Demarchi A, Facello A, Cristofori EI (2017) Visualize and communicate extreme weather risk to improve urban resilience in Malawi. In: Tiepolo M, Pezzoli A, Tarchiani V (Eds) Renewing local planning to face climate change in the tropics. Green Energy and Technology. Springer, 18 pp. https://doi.org/10.1007/978-3-319-59096-7_7
- Edwards JL (2004) Research and societal benefits of the Global Biodiversity Information Facility. BioScience 54: 485-486. https://doi.org/10.1641/0006-3568(2004)054[0486:RASBOT]2.0.CO;2
- ESRI (1990) Definition of geographical information system. Environmental Systems Research Institute
- Flemons P, Guralnick R, Krieger J, Ranipeta A, Neufeld D (2007) A web-based GIS tool for exploring the world's biodiversity: The global biodiversity information facility mapping and analysis portal application (GBIF-MAPA). Ecological Informatics 2: 49-60.
- GeoLocate Developer Resources (2019) https://www.geo-locate.org/developers/default.html/
- Giri C, Ochieng E, Tieszen LL, Zhu Z, Singh A, Loveland T, Masek J, Duke N (2011) Status and distribution of mangrove forests of the world using earth observation satellite data. Global Ecology and Biogeography 20: 154-159. https://doi.org/10.1111/j.1466-8238.2010.00584.x
- Guralnick R, Hill A (2009) Biodiversity informatics: Automated approaches for documenting global biodiversity patterns and processes. Bioinformatics 25: 421-428. https://doi.org/10.1093/bioinformatics/btn659
- Hortal J, Bello F, Diniz-Filho JA, Lewinsohn TM, Lobo J, Ladle RJ (2015) Seven shortfalls that beset large-scale knowledge of biodiversity. Annual Review of Ecology, Evolution, and Systematics 46: 523-549. https://doi.org/10.1146/annurev-ecolsys-112414-054400
- Janicki J, Narula N, Ziegler M, Gunard B, Economo EP (2016) Visualizing and interacting with large-volume biodiversity data using clientserver web-mapping applications: The design and implementation of antmaps.org. Ecological Informatics 32: 185-193. https://doi.org/10.1016/j.ecoinf.2016.02.006

- Kansas Biological Survey (2020) https://biosurvey.ku.edu/kars/kansas-natural-resource-planner
- Lin C, Huang X, Ji L (2018) MapBio: Mapping biodiversity of China. Biodiversity Information Science and Standards 2: e26075 https://doi.org/10.3897/biss.2.26075
- Maldonado C, Molina CI, Zizka A, Persson C, Taylor CM, Albán J, Chilquillo E, Rønsted N, Antonelli A (2015) Estimating species diversity and distribution in the era of Big Data: To what extent can we trust public databases? Global Ecology and Biogeography 24: 973-984. https://doi.org/10.1111/geb.12326
- Map of Life (2020) http://www.mol.org/
- Mosquito Alert (2020) http://www.mosquitoalert.com
- NAS - Nonindigenous Aquatic Species (2020) https://nas.er.usgs.gov/viewer/omap.aspx?SpeciesID=95
- NIES, JBIF (2015) Biodiversity Web Mapping System (BioWM). http://www.nies.go.jp/biowm/
- Paula J, Silva R (1998) Review of the specialist study on the potential impacts of a proposed iron and steel production plant on the marine flora and fauna of the Bay of Maputo, Document II - Tentative economic assessment of fisheries in Maputo Bay and of the expected impact of a proposed iron & steel plant in Matola. Study commissioned by GIBB Africa (Pty) Ltd for the Environmental Impact Assessment of the Maputo Iron and Steel Project MISP.
- Rocha LA, Aleixo A, Allen G, et al. (2014) Specimen collection: An essential tool. Science 344: 814-815. https://doi.org/10.1126/science.344.6186.814
- Spalding M, Kainuma M, Collins L, Mangroves WA (2010) A collaborative project of ITTO, ISME, FAO, UNEP-WCMC, UNESCO-MAB, UNU- INWEH and TNC. 310. Earthscan
- Sui D (2014) Opportunities and impediments for open GIS. T. GIS 18: 1-24. https://doi.org/10.1111/tgis.12075
- Torres RS, Medeiros CM, Calves MA, Fox E (2006) A digital library framework for biodiversity information system. International Journal on Digital Libraries 6: 3-27. https://doi.org/10.1007/s00799-005-0124-1
- UNEP-WCMC, FT S (2017) Global distribution of seagrasses. Version 6. UN Environment World Conservation Monitoring Centre.
- UNEP-WCMC, WorldFish Centre, WRI, TNC (2018) Global distribution of coral reefs compiled from multiple sources including the Millennium Coral Reef Mapping Project. 4. UNEP World Conservation Monitoring Centre.
- United Nations Development Programme (2019a) Sustainable development goals – Goal 14: Life below water. https://www.un.org/sustainabledevelopment/oceans/
- United Nations Development Programme (2019b) Sustainable development goals – Goal 2: Zero hunger. https://www.un.org/sustainabledevelopment/hunger/
- Veenendaal B, Brovelli MA, Li S (2017) Review of web mapping: Eras, trends and directions. ISPRS International Journal of Geo-Information 6: 317. https://doi.org/10.3390/ijgi6100317
- Vicente E, Bandeira S (2014) Socio-economic aspects of gastropod and bivalve harvest from seagrass beds – comparison between urban (disturbed) and rural (undisturbed) areas, Case Study_15.3. In: Bandeira S, Paula J (Eds) Maputo Bay. WIOMSA, 6 pp.
- Vincent K, Roth RE, Moore SA, Huang Q, Lally N, Sack CM, Nost E, Rosenfeld H (2018) Improving spatial decision making using interactive maps: An empirical study on

interface complexity and decision complexity in the North American hazardous waste trade. Environment and Planning B: Urban Analytics and City Science 18 https://doi.org/10.1177/2399808318764122

- Wahid MT, Sharif AR, Napis S, Ahmad N (2016) Spatio-temporal biodiversity data model using object relational modeling approach. IJCSNS International Journal of Computer Science and Network Security 6: 10.
- Worboys M, Duckham M (2004) GIS: A computing perspective. CRC Press, 448 pp. https://doi.org/10.4324/9780203481554
- WoRMS Editorial Board (Ed.) (2019) World Register of Marine Species. http://www.marinespecies.org
- Wright DJ (2016) Cloudy with a chance of fish: ArcGIS for server and cloud-based fisheries oceanography applications. In: Vance T, Sontag S, Wilson K (Eds) Ocean Solutions, Earth Solutions. 2nd Edition. Esri Press

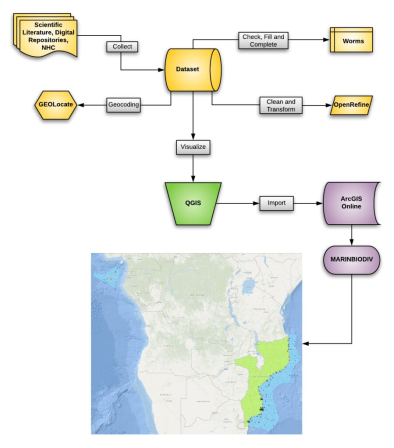

Figure 1.

Workflow of the study depicting the main steps used to construct the interactive web map: 1) data collection in yellow, 2) data representation in green and 3) data dissemination in purple (created using the Lucidchart web-based application).

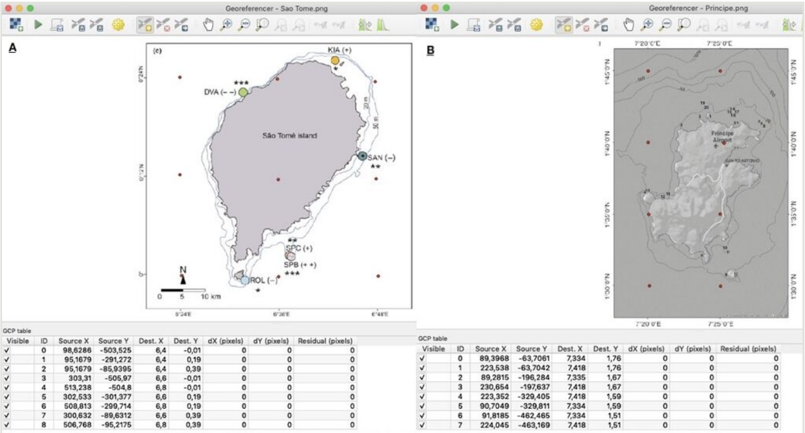

Figure 2.

Using the QGIS Georeferencer interface, two raster data sets from the literature are used to identify Mangrove habitats: **A** the coloured circles and **B** the numbers. Red dots indicate raster Ground Control Points.

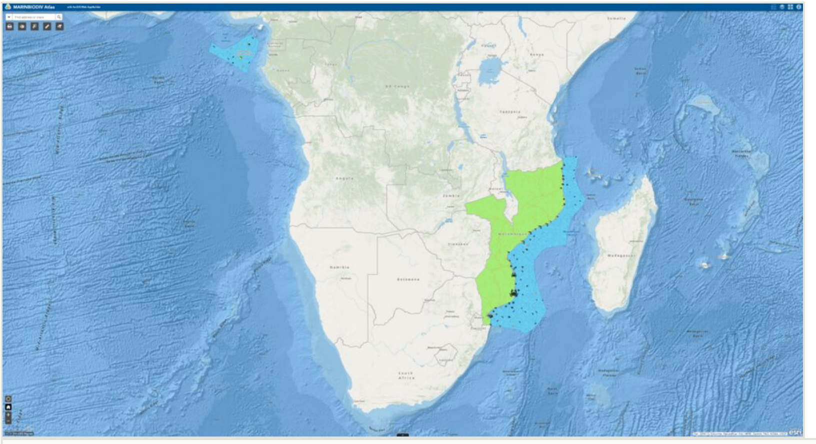

Figure 3.

The default scale/zoom of the MARINBIODIV Atlas.

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○ **Icon**	○ **Layer**	○ **Description**
Base layers		
	MOZ area	Mozambique territory area with reference system WGS84.
	MOZ EEZ	Mozambique Maritime Boundaries and Exclusive Economic Zones (200NM).
	STP area	São Tomé and Príncipe territory area with reference system WGS84.
	STP EEZ	São Tomé and Príncipe Maritime Boundaries and Exclusive Economic Zones (200NM).
Habitat layers		
	Coral polygon-data	Global distribution of coral reefs in tropical and subtropical regions, composed of one set of polygon occurrence data, with temporal range from 1954 to 2018 and reference system WGS 1984.
	Coral point-data	Point occurrence data of observation details of coral bleaching around the world, on coral reef monitoring site locations from major reef monitoring programs and on marine protected locations with coral reefs areas, with temporal range since early 2002.
	Mangrove polygon-data	Global distribution of mangroves, composed of various sets of polygon occurrence data, with temporal range mainly from 1996 to 2016 and reference system WGS 1984.
	Mangrove point-data	Point occurrence data of description details of mangrove sites.
	Seagrass polygon-data	Global distribution of seagrasses, composed of one set of polygon occurrence data, with temporal range from 1934 to 2015 and reference system WGS 1984.
	Seagrass point-data	Point occurrence data of description details of seagrass sites.

Figure 4.

MARINBIODIV Atlas layers list.

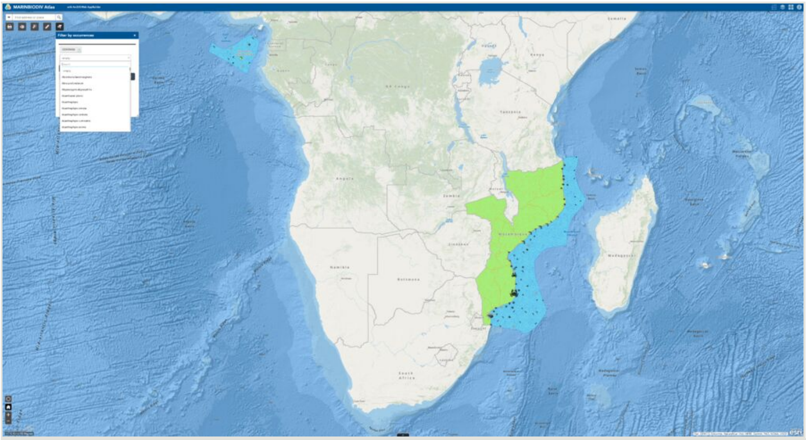

Figure 5.

Representation of the filter by occurrences widget on the map.

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○ **Icon**	○ **Widget**	○ **Description**
Header Controller widgets		
	About	Provides general information about the project.
	Basemap Gallery	Presents a gallery of base maps and allows users to select one from the gallery as the base map for the app.
	Layer List	Provides a list of operational layers and their symbols and allows users to turn individual layers on and off.
	Legend	Displays labels and symbols for layers in the map.
On-screen widgets		
	Draw	Allows users to draw simple graphics and text on the map, as well as adding line distance or polygon area to the feature as text.
	Group Filter	Allows users to apply a filter on the map based on species occurrences.
	Measurement	Allows users to measure the area of a polygon or length of a line or find the coordinates of a point. Measurements can be displayed in multiple units.
	Print	Connects the web app with a printing service to allow the current map to print. Allows users to choose the map layout, format, scale, size and printing quality.
	Select	Enables users to interactively select features on the map and take actions on the selected features.
Off-panel widgets		
	Attribute Table	Displays a tabular view of operational layers' attributes. It displays at the bottom of the web app and can be opened, resized, or closed.
	Coordinate	Displays x and y coordinate decimal values on the map. Shows the coordinates in the WGS 1984 Mercator Auxiliary Sphere (WKID 3857) projection.
	Home Button	Zooms the map to the initial map extent.
	My Location	Allows the network to detect users' physical location and zoom the map to it.
	Overview	Displays the current extent of the map within the context of a larger area and updates whenever the map's extent changes.
	Scalebar	Displays on the map a scale bar in metric units.
	Search	Enables users to find locations or search features on the map.
	Zoom Slider	Provides interactive zoom controls in the map display.

Figure 6.

MARINBIODIV Atlas widgets list.

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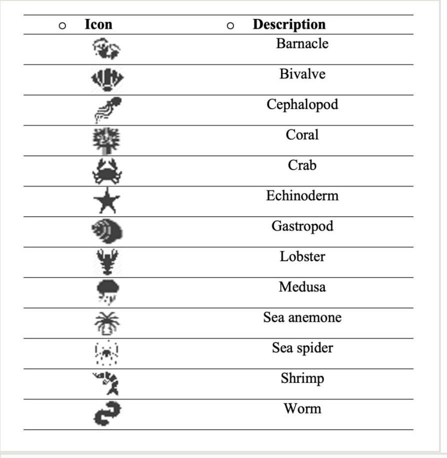

○ Icon	○ Description
	Barnacle
	Bivalve
	Cephalopod
	Coral
	Crab
	Echinoderm
	Gastropod
	Lobster
	Medusa
	Sea anemone
	Sea spider
	Shrimp
	Worm

Figure 7.

MARINBIODIV Atlas species occurrences legend.

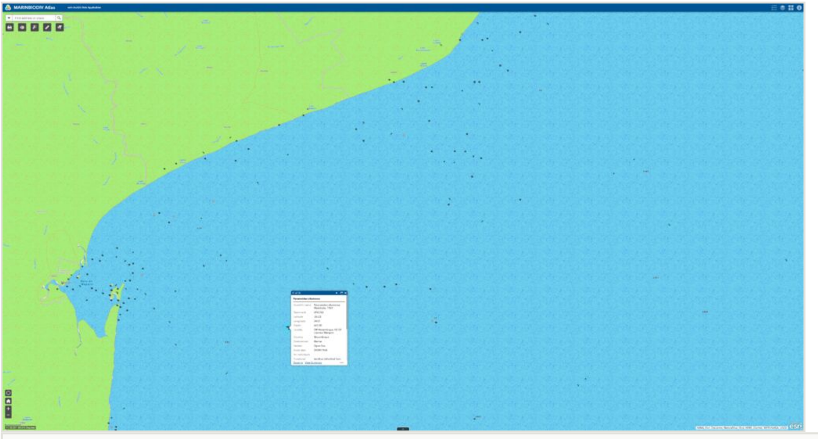

Figure 8.

Zoom in on the Mozambique portion of the web map to show the various symbols based on the specimen's typology and the information box.

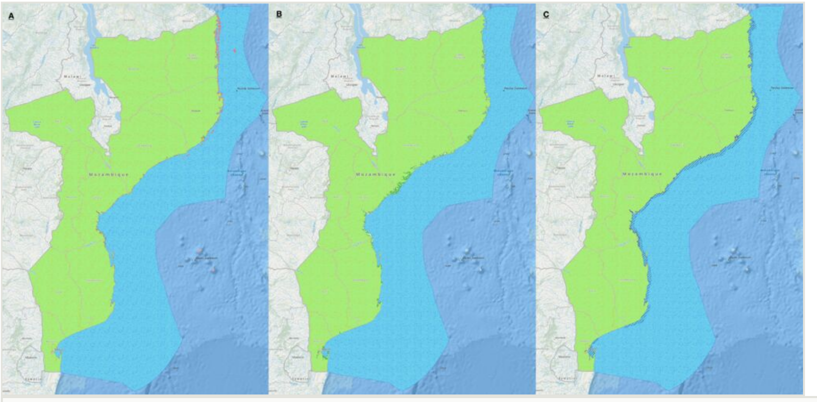

Figure 9.

Types of habitats present along the coast of Mozambique that are represented in the MARINBIODIV Atlas as polygon-data **A** corals **B** mangroves and **C** seagrasses.

Figure 10.

Types of habitats present along the coast of São Tomé and Príncipe are depicted as point-data in the Web Map: corals in red, mangroves in green, and seagrasses in blue.

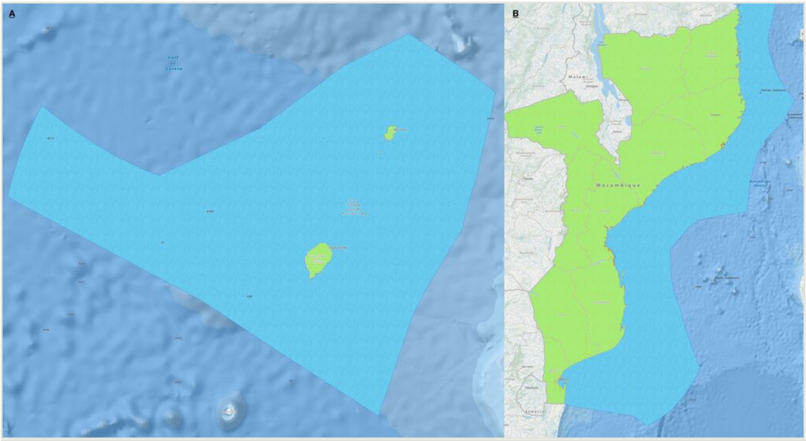

Figure 11.

Represantation of the borders of **A** São Tomé and Príncipe and **B** Mozambique.