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An interactive atlas for marine biodiversity conservation in the Coral Triangle

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Abstract. An online atlas of the Coral Triangle region of the Indo-Pacific biogeographic realm was developed. This online atlas consists of the three interlinked parts: (1) Biodiversity Features; (2) Areas of Importance for Biodiversity Conservation; (3) recommended priorities for Marine Protected Area (MPA) Network Expansion (http://www.marine.auckland.ac.nz/CTMAPS). The first map, Biodiversity Features, provides comprehensive data on the region's marine protected areas and biodiversity features, threats, and environmental characteristics. The second provides spatial information on areas of high biodiversity conservation values, while the third map shows priority areas for expanding the current Coral Triangle MPA network. This atlas provides the most comprehensive biodiversity datasets that have been assembled for the region. The datasets were retrieved and generated systematically from various open-access sources. To engage a wider audience and to raise participation in biodiversity conservation, the maps were designed as an interactive and online atlas. This atlas presents representative information to promote a better understanding of the key marine and coastal biodiversity characteristics of the region and enables the application of marine biodiversity informatics to support marine ecosystem-based management in the Coral Triangle region.

1 Introduction

The advancement of internet technology has led to the development of marine biodiversity informatics, namely information technologies that are employed to support the management of data and information on marine biodiversity (Bisby, 2000; Heidorn, 2011; Parr and Thessen, 2018). They enable people to freely access primary and secondary data over online systems, promote integration of data across datasets, and facilitate collaboration between parties (Costello and Vanden Berghe, 2006). Publicly available biodiversity information is important for engaging the public and policymakers in the addressing of global issues that threaten ecosystem services and functions such as biodiversity loss, climate change, habitat destruction, and overfishing (Costello, 2009). Integration of data across disciplines is increasingly imperative, as biodiversity research requires interactions with other related fields (e.g., genomics, oceanography, climatology, evolution) to foster better analyses and interpretations (Reichman et al., 2011; Costello et al., 2013).

There has been massive improvement in online biodiversity databases covering species names (e.g., WoRMS; Horton et al., 2016), species occurrence records (e.g., GBIF; GBIF, 2018), OBIS; OBIS, 2015), species ranges (e.g., Map of Life: Jetz et al., 2012, AquaMaps; Kaschner et al., 2016), species protection status (e.g., IUCN Redlist; UNEP-WCMC, 2015), biodiversity and fisheries-related data (e.g., Sea Around Us; Pauly and Zeller, 2015), and taxa specific information (e.g., FishBase; Froese and Pauly, 2016, AlgaeBase; Guiry and Guiry, 2018, and sea turtles; Kot et al., 2015) that are managed, curated, and supported by international projects and initiatives. However, the culture of data publishing is still a concern (Costello et al., 2013). Less than 1 % of ecological data is accessible after publication (Reichman et al., 2011) and more than 57 % of the papers in environmental biology publications examined in a 2011 review had not released their data (Alsheikh-Ali et al., 2011).

Biodiversity informatics is expected to grow exponentially. Software, infrastructure, and management tools to store, publish, and share biodiversity data, particularly over the internet and World Wide Web, have been improved significantly in recent years (Michener, 2015). Such development is supported by the availability of metadata standards to facilitate description of datasets and data records (e.g., Ecological metadata language (EML); Michener et al., 1997); Darwin core; GBIF, 2010), widely assessed repositories for depositing ecologically relevant data (e.g., Dryad; http://datadryad.org/; Figshare; https://figshare.com/; KNB; https://knb.ecoinformatics.org/) and a variety of open-source data management tools (e.g., MySQL, R, and Kepler).

Geographic information systems (GIS) provide a tool to explore spatial relationships within and between data (Wright et al., 2016; Hamylton, 2017), and there is a growing trend of internet-based GIS (i.e., GIS designed for operating online over the World Wide Web) (Morets, 2017). The application of internet GIS through online atlases (the process of designing, generating, and delivering maps on the internet) provides a number of advantages over traditional desktop-based GIS (Neumann, 2008). Web-based maps can deliver up to date data, can be generated using a low-cost software and hardware infrastructure, and facilitate inexpensive map distributions. In addition, online atlases enables the integration of different data sources and collaborative mapping (e.g., Google Maps, Openstreet Maps; Neumann, 2008; Fu and Sun, 2010; Clarke, 2014). These geo-based websites applications are supported by Open GIS infrastructure that allow users in the world to access and operate GIS and to facilitate the exchange of spatial data and information (Sui, 2014). In the biodiversity conservation discipline, online atlases offer greater accessibility and allow for user-driven interaction (Peterson, 2018). Furthermore, the advancement of smartphone applications (apps) that are linked to mobile web-based maps provides an avenue to involve broader audiences in the natural sciences and a convenient tool for scientists to disseminate their research (Teacher et al., 2013; Marchante et al., 2017). Online atlases exist for several coastal regions, including Ireland's Marine Atlas (https://atlas.marine.ie/), the Oregon Coastal Atlas (https://www.coastalatlas.net/), and the European Atlas of the Seas (Barale et al., 2015). These coastal web-atlases serve a variety of functions, including being data repositories, and allow users to explore and overlay different data with geospatial analysis tools. Therefore, Wright et al. (2011) define the coastal online atlas as "a collection of maps with supplementary tables, illustrations, and information which systematically illustrate the coast".

To take advantage of the potential of online atlases, here we developed an application for the Coral Triangle (CT) region of the Indo-Pacific realm, a marine area situated between the Indian Ocean and Pacific Ocean and a global focus for marine biodiversity conservation due to its superlative species richness and endemicity. This region is considered to contain the world's highest number of shallow-water reef-building coral species (Veron et al., 2009), reef fishes (Allen, 2008), mangrove biodiversity (Polidoro et al., 2010; Walton et al., 2014), mushroom corals (Hoeksema, 2007), and razor clams (Saeedi et al., 2016), with areas of high biodiversity importance clustered along the southern part of the Philippines, the northeastern part of Malaysian Sabah, the central to eastern part of Indonesia, the eastern part of Papua New Guinea, and the Solomon Islands (Asaad et al., 2018a). Although considerable biodiversity and natural resources data have been collected for the region by scientists and conservation programmes, the data have been scattered and difficult to access. While our prioritization of locations for marine protected areas (MPAs) (Asaad et al., 2018a, b) was successfully collating data of biodiversity features, threats, and environmental variables, this did not make it easily viewable to the public. In addition, a previous online atlas of the CT was developed to support coral reef management and provided biophysical and MPA data from the region (Cros et al., 2014), but was more limited in data on species ranges (e.g., threatened species, endemic species). Thus, updated, more systematic and comprehensive "biodiversity informatics" datasets are required to showcase all of the available data in the region.

This online atlas aims to support the objective of the CTI-CFF initiative (the Coral Triangle Initiative on Coral Reefs, Fisheries, and Food Security). The CTI-CFF initiative is a multilateral partnership of six countries (Indonesia, Malaysia, Papua New Guinea, the Philippines, Solomon Islands, and Timor-Leste) working collaboratively to conserve and sustainably manage their coastal and marine resources (CTI-CFF, 2009). One of the objectives of the Coral Triangle Initiative is to establish and effectively manage MPAs within the region, including a region-wide Coral Triangle MPA system (CTMPAS) (CTI-CFF, 2009). The CTMPAS is a system of MPAs within the CT which includes a range of MPA types and MPA network. This system comprises MPAs that form local ecological and/or governance networks that are nested within larger-scale social networks (CTI-CFF, 2013). Thus, the collections of geospatial data collated in this online GIS database support the development of MPAs and management of marine resources in the region by giving access to policymakers, scientists, and the general public to the most comprehensive, up-to-date and integrated spatial information available for the Coral Triangle.

2 Methods (Web map design)

This atlas was developed to interactively display geo-referenced biodiversity information on the Coral Triangle (CT): (1) Biodiversity Features; (2) Areas of Importance for

Biodiversity Conservation; and (3) priority areas for Marine Protected Area (MPA) Network Expansion.

To generate the atlas, related datasets were retrieved from the Coral Triangle database collected in the previous chapters (Asaad et al., 2018a, b). These datasets were collated and developed from various sources (Table 1). For consistency, all the datasets were clipped to the CT region following the implementation boundary of the Coral Triangle Initiative (CTI-CFF, 2009) with bounding geographic coordinates of 23° N to 16° S and 90 to 175° E. All of the data preparations were performed using ArcGIS Desktop 10.5 (ESRI, 2016) and ArcGIS Pro. 2.0 (ESRI, 2017).

The ArcGIS Pro 2.0 was used to deliver and share all of the maps to web feature layers in ArcGIS Online, and design three digital maps using the ArcGIS Online template. Here, a similar template was used for each map to allow map comparisons. These digital maps used a website as an interface and can be accessed from any computer or other electronic device that is connected to the internet using a standard browser (e.g., Internet Explorer, Google Chrome, or Safari). The maps were hosted by ArcGIS Online in a cloud service provided by the Amazon EC2 (Elastic Compute Cloud).

Each atlas consists of different feature layers:

- The map of "biodiversity features" is comprised of 10 feature layers, including (a) seven layers of biodiversity features (biogenic habitat, species richness-ranges, species richness-occurrence, species of conservation concern, species of restricted range, important areas for sea turtles and habitat rugosity; (b) two types of threat (anthropogenic and climate change); and (c) a composite of 16 environmental variables (Table 1).

- The map of "areas of importance for biodiversity conservation" is comprised of two feature layers: (a) regional biodiversity hotspots; and (b) sites of biodiversity importance (Table 1).

- The map of "priority areas for marine protected area network expansion" consists of nine feature layers: (a) three layers highlighting recommended priority areas for expansion of the Coral Triangle MPA network under scenarios of regional expansion to encompass 10 %, 20 %, and 30 % of CT marine area within the network; and (b) six layers showing priority areas for expansion of individual CT country MPA networks for Indonesia, Malaysia, the Philippines, Papua New Guinea, Solomon Islands and Timor-Leste. Each layer of the national priority areas is comprised of three scenarios of MPA expansion (10 %, 20 %, 30 %) (Table 1).

- Three base layers are included for each web map: existing marine protected areas, national exclusive economic zones (EEZs) and country boundaries (Table 1).

To access the maps, a gallery-like web front page was developed with a hyperlink to each digital map. To allow users to explore a wide variety of functions offered by the maps, 15 types of widgets (a control element in a graphical user interface) were embedded (e.g., Home button, Layer list, Select, Draw; see Table 2). A documentation website was developed to define the map's objectives, datasets, classifications, and original citations of the sources.

3 Results

The atlas of the Coral Triangle is an online GIS database, and can be assessed through a web front-page (http://www.marine.auckland.ac.nz/CTMAPS; Fig. 1). These geospatial datasets were built on three interlinked themes: (a) Biodiversity Features (http://marine.auckland.ac.nz/CT_Biodiversity; Fig. 2), which provides comprehensive data on the region's marine protected areas, biodiversity features, threats, and environmental characteristics; (b) Areas of Importance for Biodiversity Conservation (http://www.marine.auckland.ac.nz/CT_Priority), which provides spatial distributions of areas of high biodiversity conservation value; and (c) priority areas for Coral Triangle Marine Protected Area (MPA) Network Expansion (http://www.marine.auckland.ac.nz/CT_MPA), which provides spatial information of priority areas for potential expansion of the existing MPA network. Relevant information on the maps can be accessed through an accompanying documentation website (https://sites.google.com/view/coral-triangle-digital-map).

4 Data availability

The "Data availability" is covered in the results section.

5 Discussion

The atlas of the Coral Triangle showcases all of the currently available marine biodiversity conservation data for the Coral Triangle region. They are derived from the most comprehensive biodiversity conservation datasets for the region, featuring spatial information for the region based on their habitat and species-specific attributes, vulnerabilities to threats, and environmental characteristics. The maps also include a set of data to indicate areas of importance for biodiversity conservation, existing MPAs, and priority areas of the designation of new MPAs or MPA expansion in the Coral Triangle, showing priorities for biodiversity conservation at both regional and national scales.

Collating and comparing datasets from different sources presented a number of challenges. To have a consistent format and spatial attributes, all datasets were converted into a vector format (i.e., lines or polygon shape) and standardized geographic projections. To reduce data discrepancy, the biodiversity feature datasets were classified using equal interval classes based on their biodiversity values. The datasets were then grouped into themes (biodiversity features, areas

Table 1. Coral Triangle datasets specifications.

	Data layer	Feature	Type, spatial resolution, class	Descriptions	Sources
Base Layers					
a.	Coral Triangle boundary	Generated from the Coral Triangle Initiative implementation boundary	Polygon	The boundary covers the full exclusive economic zones (EEZs) of Indonesia, Malaysia, Papua New Guinea, the Philippines, Solomon Islands, and Timor-Leste, and includes the EEZs of two additional nations: Brunei Darussalam and Singapore.	VLIZ (2014)
b.	Country boundary	Internal boundary of Coral Triangle countries	Polyline	The EEZs and internal boundaries are indicative only, and a dispute over boundaries exists.	VLIZ (2014)
c.	Marine protected areas (MPAs) coverage	Coverage of 678 units of MPA	Polygon	The layers' attribute table provides detailed information following its native sources (WDPA, CTAtlas) (e.g., information about name, local name, designation type, IUCN category, coverage; IUCN and UNEP-WCMC, 2016; Cros et al., 2014) with amendment and adjustment from local sources (Indonesian database). To allow simple indexing, a new CT MPAs ID format (MPA_ID) is introduced. The new ID consists of 10 digits (C IC XXXX yyy): – C = Country; 1 = Indonesia, 2 = Malaysia, 3 = Philippines, 4 = Papua New Guinea, 5 = Solomon Islands, and 6 = Timor-Leste – IC = IUCN MPAs category; strict nature reserve (1a = 11, 1b = 12), national park (20), habitat and species management Areas (40), protected landscape/seascape (50), and managed resource protected areas (60) – XXXX = establishment year (e.g., 1980) – yyy = Number; ordered based on their establishment year	IUCN and UNEP-WCMC (2016), Cros et al. (2014), MoF-MoMAF (2010), MoMAF (2016)
Biodiversity features					
a.	Biogenic Habitat	Refers to the habitats that are created by plants and animals. Spatial distribution of coral reef, seagrass, and mangroves.	Grid square cells; 5 km; 3 classes	Calculated based on the number of biogenic habitat present in each cell. Cell values ranged 1–3.	UNEP-WCMC et al. (2010), Giri et al. (2011a, b), UNEP-WCMC and Short (2005)
b.	Species richness – ranges	A modeled geographic distribution of 10 672 species ranges.	Grid square cells; 50 km; 10 classes	Calculated based on the number predicted species in each cell. The number of predicted species per cell ranged 0–5509.	Kaschner et al. (2016)
c.	Species richness – occurrence	The occurrence records of 19 251 species.	Grid square cells; 50 km; 10 classes	Based on the index of expected species richness of ES_{50} (estimated species in random 50 samples).	OBIS (2015)
d.	Species of conservation concern	The occurrence records of 834 species of conservation concern (Bony fish, anthozoans, elasmobranchs, mammals, and mollusks).	Grid square cells; 50 km; 10 classes	Based on the index of expected species richness of ES_{35} (estimated species in random 50 samples).	OBIS (2015), Froese and Pauly (2016), IUCN (2015), UNEP-WCMC (2015)
e.	Species of restricted-range	The distribution of 373 restricted-range reef fish species.	Grid square cells; 5 km; 10 classes	Calculated based on the number of of species present in each cell. Cell values ranged 1–101.	Allen (2008), Allen and Erdmann (2013).

Table 1. Continued.

	Data layer	Feature	Type, spatial resolution, class	Descriptions	Sources
f.	Important areas for sea turtle	Nesting sites and migratory route of six species (2055 records).	Grid square cells; 5 km; 3 classes	The richness calculated based on the number of sea turtle species present in each cell (i.e., 1, 2, 3).	MoF-MoMAF (2010), OBIS (2015)
g.	Habitat rugosity	A vector ruggedness measure (VRM) of benthic terrain, generated from bathymetric data.	Grid square cells; 50 km; 10 classes	The VRM index ranged from 0.1 (areas with low terrain variations) to 0.9 (areas with high terrain variations).	Basher et al. (2014), Wright et al. (2012)
h.	Anthropogenic pressure (AP)	Spatial distribution of AP on marine environments.	Grid square cells; 5 km; 10 classes	The cumulative impact of 19 different types of anthropogenic stressors. The AP value ranged 0–15.4, indicating areas from low to high human-induced pressure.	Halpern et al. (2008, 2015a, b)
i.	Climate change pressure	Spatial distribution of sea surface thermal stress level (the average of degree heating weeks, DHW) from 2006 to 2099.	Grid square cells; 5 km; 10 classes	The projected thermal stress index ranged 5.6–20.2, indicating areas from low to high vulnerability to climate change.	Van Hooidonk et al. (2016)
j.	Environmental Variables	Spatial distribution of environmental variables (physical, biochemical, and nutrients).	Point; 50 km; 10 classes	Composite point features of 16 environmental variables, i.e., depth, slope, land distance, temperature, surface current, salinity, wind speed, tide, primary productivity, photosynthetically active radiation (PAR), chlorophyll *a*, pH, dissolved oxygen, nitrate, silicate, and calcite.	Basher et al. (2014)
Areas of Importance for Biodiversity Conservation					
a.	Regional biodiversity hotspots	Clusters of areas of biodiversity importance.	Grid square cells; 55 km; three classes of hotspots (high, medium, and low) and one class was not significant	Developed based on the multi-criteria analysis to five ecological criteria (sensitive habitat, species richness, the presence of species of conservation concern, the occurrence of restricted-range species, areas of importance for particular life history stages). Analyzed based on the spatial patterns of data using the hotspots analysis tool in ArcGIS. The analysis clustered the cells from hotspot (high-score cells) to coldspots (low-score cells).	Asaad et al. (2018a)
b.	Sites of biodiversity importance	Distribution of sites of areas of biodiversity importance.	Grid square cells; 55 km; five classes (high, medium-high, medium, medium-low, and low)	Developed based on the similar ecological criteria to those used in the biodiversity hotspots region analysis. While the hotspots analysis identified clustered areas of biodiversity importance. The site-based analysis identifies specific sites of highest biodiversity importance by analyzing the biodiversity score of each cell. The higher the score, the higher their biodiversity importance.	Asaad et al. (2018a)

of important for biodiversity conservation, and priority areas for MPA network expansion). Each theme consists of sub-themes, to promote simple indexing, retrieving, and data management. Here, this study showed that for conducting a biodiversity conservation programme, biodiversity data are indeed available, yet they are frequently scattered and not always easily accessed. Using an approach such as the one we describe here, these widely scattered datasets can be integrated and amalgamated to perform such complex tasks as biodiversity prioritization analysis (Asaad et al., 2018a, b).

Table 1. Continued.

	Data layer	Feature	Type, spatial resolution, class	Descriptions	Sources
Marine Protected Area (MPA) Network Expansion					
a.	Regional priority areas	Spatial distribution of regional priority areas with three expansion scenario layers: 10 %, 20 %, and 30 %.	Grid square cells; 0.5 km	Prioritization analyses were performed using Zonation tools to analyze the proportions of the CT region placed into an MPA network (e.g., expansion of the MPA network from existing coverage to 10 %, 20 %, and 30 % of the exclusive economic zone (EEZ) area). The prioritization scenarios were based on seven sets of biodiversity features (biogenic habitat, habitat rugosity, species richness, distribution of threatened and endemic species, areas important for sea turtle); two types of threat (anthropogenic and climate change induced pressure); and the coverage of the existing MPA network. Regional analyses were performed for the full CT EEZ region.	Asaad et al. (2018b)
b.	National Priority Areas	Spatial distribution of national priority areas with six layers of scenarios representing national MPA network expansion for Indonesia, Malaysia, the Philippines, Papua New Guinea, Solomon Islands and Timor-Leste.	Grid square cells; 0.5 km	Developed based on the same approach as the regional priority areas. National analyses were performed individually on each CT country's national EEZ. Each layer consisted of three scenarios of MPA expansion (10 %, 20 %, 30 %)	Asaad et al. (2018b)

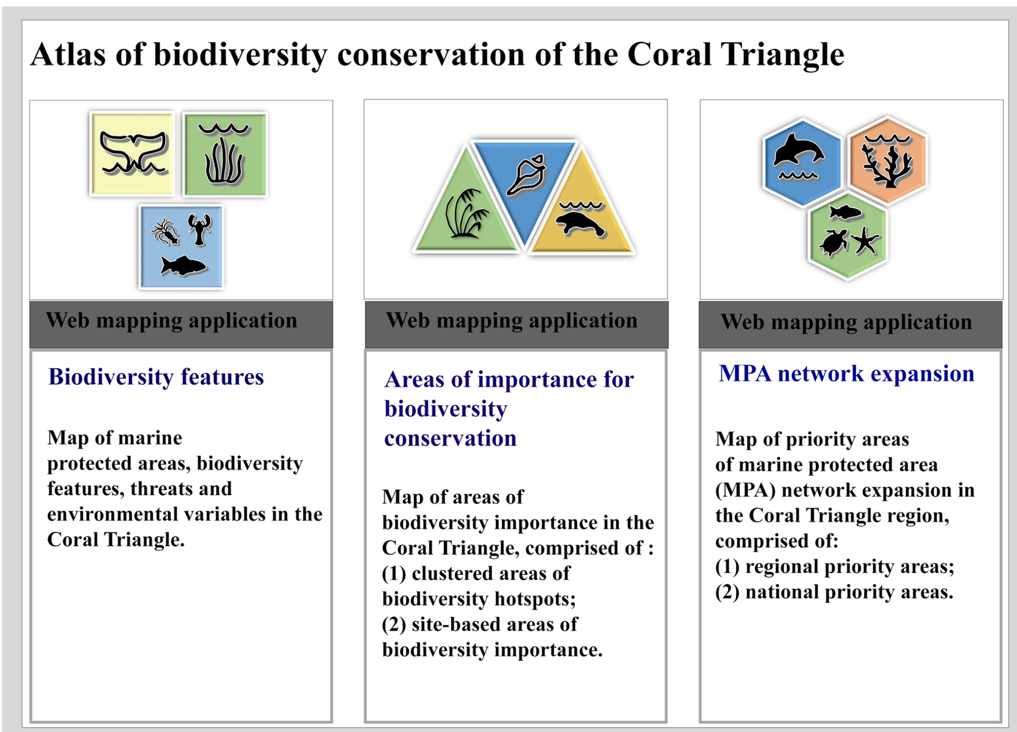

Figure 1. Coral Triangle web-mapping application front-page. This gallery-like interface provides a hyperlink to access each of the maps of the Coral Triangle Atlas.

Table 2. Widgets provided for the Coral Triangle Atlas.

Icon	Widget	Functions
Controller widgets (header panels)		
	About	Displays general information about the apps, including purposes, data layers, and links to the documentation files.
	Basemap gallery	Provides a gallery of base maps and allows users to select their preference.
	Layer list	Presents a list of layers in the map and allows users to interactively choose layers that need to be activated.
		Each layer has a checkbox and allows users to change the order of the layers in the map.
	Legend	Displays a legend of active layers showing in the map.
Placeholder widgets (on-screen panel)		
	Swipe	Displays thumbnail views of different layers on top of the map to enable a quick comparison of the content of different layers. Here we used the spyglass view model.
	Draw	Enables users to create and draw graphics (sketches) on the map. There are 11 feature creation tools (point, line, polyline, freehand, triangle, rectangle, circle, ellipse, polygon, freehand polygon, and text). It also displays measurements of the drawn features (lengths, areas, and perimeters).
	Measurement	Provides tools to measure areas (polygons), to calculate distance (line), and to show geographic coordinates (point). Each measurement can be displayed in a variety of measurement units (i.e., metric and imperial system).
	Print	Enables printing of the map. This widget allows users to choose the map layout (and format e.g., pdf, jpg, gif) and an advanced option to select map scale, size, and printing quality.
	Select	Provides interactive tools to select features and perform tasks on the selected features. There are four options to draw a selection: select by rectangle, polygon, circle, and line. The selected features actions can be explored through the following functions. – Display tasks: zoom to- , pan to- and flash. – Export: to CSV files, to feature collections, and to GeoJSON (export to a features.geojson file). – Statistics: display simple statistics of the selected features (sum, max, min, average, standard deviation). – Save to My Content: save selected features to My Content page in ArcGIS Online or ArcGIS Enterprises. – Create layer: enables to create layer for a single or selected feature. – View in attribute table: previews the attribute table of the selected features.
Off-panel widgets		
	Home button	Displays the initial extent of the map. The bounding coordinates of the map are from 23° N to 16° S and 90 to 175° E.
	Attribute table	Shows a tabular view of operational layers' attributes. Located at the bottom of the map, and can be configured to display selected features, zoom to and filter the table based on the map extent.
	Coordinate	Displays coordinates of the map (x and y values). Shows the coordinates in the WGS 1984 Mercator Auxiliary Sphere (WKID 3857) projection. Located in the lower-left corner of the map.
	Scale bar	Shows a scale bar of the map. Updated dynamically based on map's scale. Located in the lower-left corner of the map.
	My location	Displays the physical location and zooms the map to the users location.
	Zoom slider	Provides an interactive zoom for the map display.

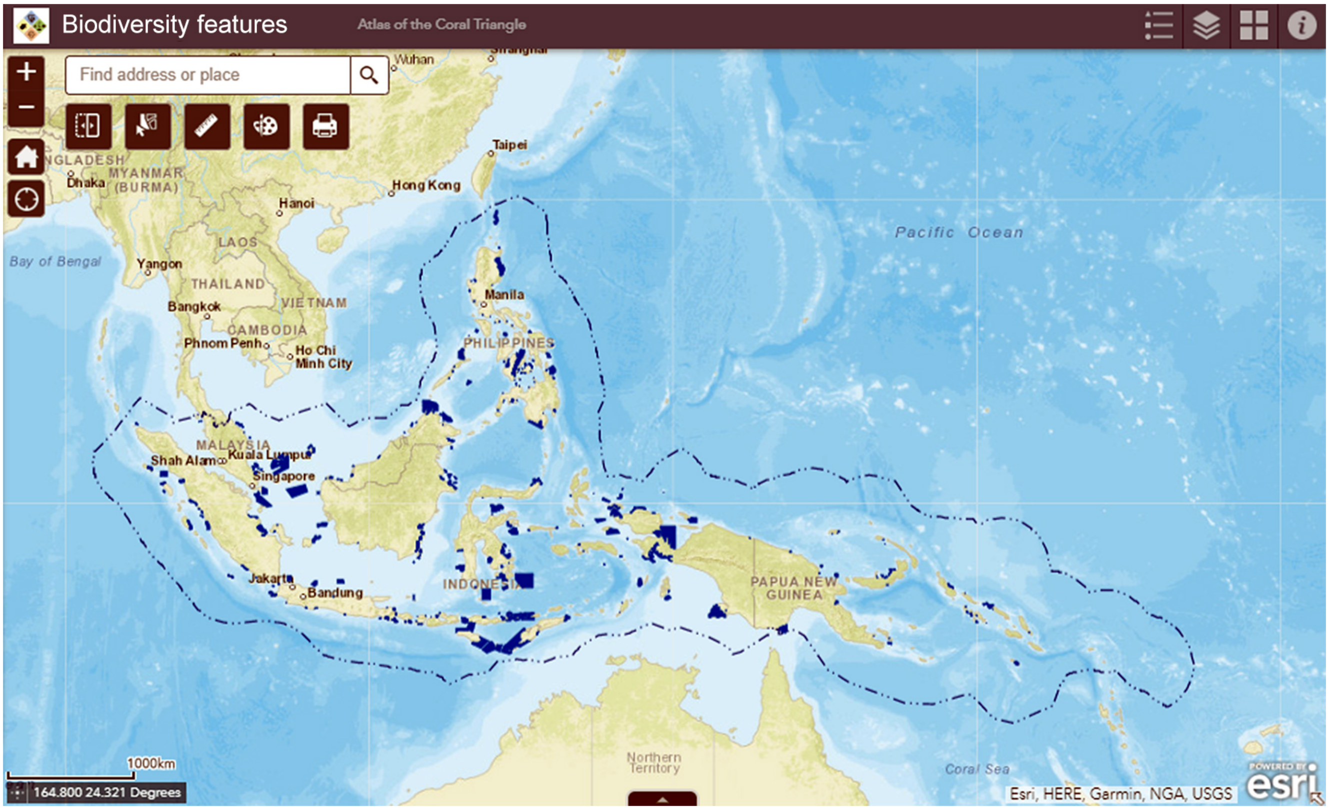

Figure 2. The interface of the Atlas of the Biodiversity Conservation of the Coral Triangle. The Coral Triangle countries' EEZs (blue-dashed line) and distribution of marine protected areas (blue) are indicated.

This study developed an interactive web application that featured maps and geospatial contents using a configurable template provided by ArcGIS Online. This approach reduces the complexity of code writing, website programming, and other technical knowledge needed to create a web map. We opted to use accessible and less technical tools, to show that even with limited skills in internet GIS and web development, scientific communities have an opportunity to develop geospatial tools to support biodiversity conservation. Replication of this type of approach in the other regions is important as there is a continuing trend of biodiversity loss and limited resources are available to protect all of the important biodiversity.

This atlas was designed to enable an efficient decision-making process and to engage a wider stakeholder audience. To support these objectives, all of the datasets were featured in a format that can be overlaid and visualized directly using a standard web browser. This web browser platform facilitates interactive access and examination of the data without the need for expensive GIS software. The spatial information in each dataset can be extracted through (a) intuitively hovering the mouse over and selecting a feature; (b) using "select" widgets and exporting the selected features to preferred data formats; and (c) reproducing the maps in suitable graphic formats using "print" widgets. The "select" widgets provide a range of export formats, ranging from a generic "comma-separated values (CSV)" file that stores tabular data in plain text, to a "Geo JavaScript Object Notation (GeoJSON)" file, an open standard format designed for representing simple geographical features, along with their non-spatial attributes. The "print" widgets provide an option to reproduce maps in a variety of formats such as pdf, jpeg, and gif, which facilitate inclusion in presentations or embedding of maps in reports. To enable and encourage data explorations, the "select" widgets were supplied with functions to conduct simple statistical analysis (e.g., sum, average, maximum, minimum, and standard deviation of selected data).

This atlas could be linked to the previous Coral Triangle Atlas developed by Cros et al. (2014) that is currently managed by the Coral Triangle Initiative Secretariat. These atlases are complementary in design and applications and may provide options to stakeholders to retrieve reliable Coral Triangle data. Here, our atlas provides a supplement and enriches the previous atlas by providing access to explore areas of biodiversity importance within the coral Triangle and a set of priority areas to designate new MPA within the region. We integrated ecological and biological datasets following standard ecological criteria to identify areas for biodiversity conservation (Asaad et al., 2016). Our "Biodiversity Features" datasets are comprised of biogenic habitat, species richnessoccurrences, species richness-ranges, species of conservation concern, restricted range species, areas important for life history stage of species, and habitat rugosity. The datasets are ready to use and are applicable for identifying priority areas for biodiversity conservation. In addition, this atlas included datasets of threats, comprised of present anthropogenic and projected climate change induced pressures. Knowledge of threat level provides key information for developing alternative marine spatial planning and management strategies, e.g., enforcement, habitat restoration, and mitigation (Green et al., 2009; McLeod et al., 2010; Maynard et al., 2015). Furthermore, this atlas also provided data for 16 environmental variables (including physical, chemical, and oceanographic variables). As such, this atlas offers an opportunity to explore the relationship between biologically diverse areas and underlying physical and chemical parameters, as well as the relationship with potential pressure factors.

In this atlas, the biogenic habitat distribution map was retrieved from three types of coastal habitat (coral reefs, seagrass, and mangroves) that may generate a bias towards coastal regions. A detailed habitat map and a defined list of habitat types are needed to fully evaluate the ecological and biological significance of the marine area. In addition, this atlas focuses on the biodiversity features within the economic exclusive zones (EEZs) of the Coral Triangle countries. There are vast resources found outside the EEZ including some of the most productive ecosystems (e.g., seamounts, hydrothermal vents), rare and unique species, and migratory routes of endangered marine species. Thus, biodiversity data of areas beyond national jurisdictions potentially complement the EEZ data to improve and develop a comprehensive biodiversity conservation programme in the region.

There are opportunities to improve and advance the geospatial functionality of this Coral Triangle atlas. An envisioned future version of this atlas is a dynamic online database which provides tools to add, upload and store new biodiversity data (e.g., species occurrence data). The growing trend of citizen science opens an opportunity to collect and integrate potentially massive amounts of data to fill gaps in the biodiversity data records. In addition, the availability of options for running online spatial analysis tasks such as identifying priority areas or delineating protected reserves in a defined geographic area or for a specific dataset may offer an opportunity to further enhance the performance of this atlas.

This atlas may be used by initiatives such as IODE–ICAN (International Coastal Atlas Network), the Global Health Ocean Index (http://www.oceanhealthindex.org/), the GEO-Marine Biodiversity Observation Network (https://boninabox.geobon.org/), UNEP-WCMC Network (http://data.unep-wcmc.org/), and others network related to the UN SDG Goal 14 and the upcoming UN Decade of Ocean Science. This type of atlas fills a regional gap in data within such global initiatives and provides more detailed information that can be used to develop a region-based biodiversity conservation strategy.

The collections of geospatial data collated on this online GIS database are aimed to give access to policymakers, scientific communities, and the general public full access to the most comprehensive, up-to-date, and integrated spatial information available for the Coral Triangle. This atlas presents representative information to promote a better understanding of important areas for biodiversity conservation and the application of marine biodiversity informatics to support conservation prioritization in the Coral Triangle region.

Author contributions. IA conceived the research ideas, designed the methodology, developed the web GIS applications, and wrote the manuscript. CJL gave advice and guidance in the study design, interpretation of the research, and reviewed the manuscript for scientific rigor and readability. MVE gave advice and guidance in the study design, interpretation of the research, and reviewed the manuscript for scientific rigor and readability. MJC gave advice and guidance in the study design, interpretation of the research, and reviewed the manuscript for scientific rigor and readability.

Competing interests. The authors declare that they have no conflict of interest.

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