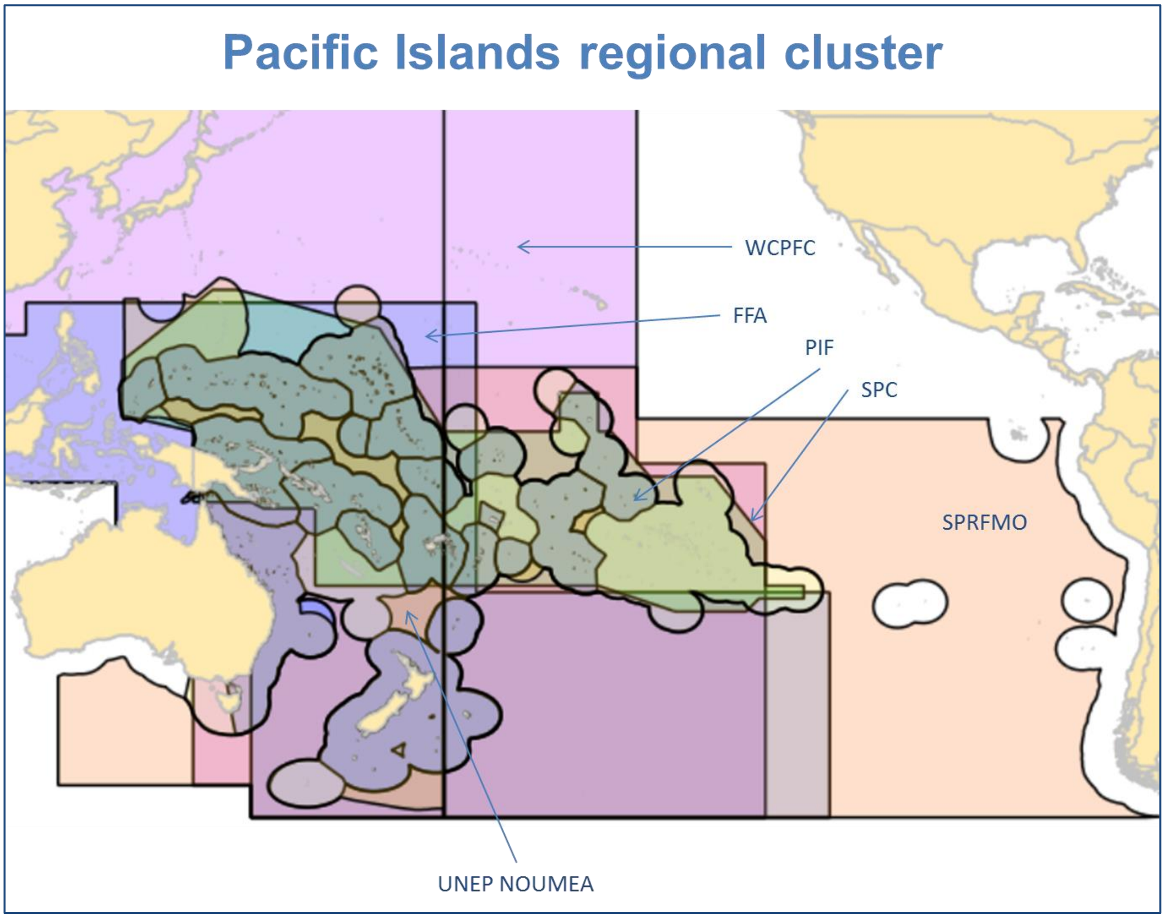
CERMES Technical Report Nº 74

Spatial analysis of ocean governance at the global level: Spatial data availability, accuracy, coordinate systems and considerations for practice

KIMBERLY BALDWIN AND ROBIN MAHON



Centre for Resource Management and Environmental Studies (CERMES)
The University of the West Indies, Cave Hill Campus, Barbados

2014

Spatial analysis of ocean governance at the global level: Spatial data availability, accuracy, coordinate systems and considerations for practice

Kimberly Baldwin and Robin Mahon

Centre for Resource Management and Environmental Studies (CERMES), University of the West Indies, Cave Hill Campus, St. Michael, Barbados, 246-417-4570, Fax 246-424-4204, baldwin.kimberly@gmail.com, rmahon@caribsurf.com, www.cavehill.uwi.edu/cermes

ACKNOWLEDGEMENTS

We would like to thank David Raleigh for his GIS input, namely the development of the 'Sea Treaty Toolbox' python script. Thanks to Dr Villy Christenson for providing Regional Seas polygons developed by the Sea Around Us Project, University of British Columbia. We also thank the many persons who provided GIS data and or maps that made this analysis possible.

Citation:

Baldwin, K. and R. Mahon. 2014. Spatial analysis of ocean governance at the global level: Spatial data availability, accuracy, coordinate systems and considerations for practice. Centre for Resource Management and Environmental Studies, The University of the West Indies, Cave Hill Campus, Barbados, CERMES Technical Report No 74: 19pp.

Contents

SUMMARY

The need for global datasets for spatial analysis of arrangements in place for the governance of the global ocean is increasing as the importance of global perspectives becomes more prominent. The use of GIS for such analyses presents a variety of challenges related primarily to the large spatial scale being addressed. This report examines several of these challenges in the context of an attempt to conduct such analyses in support of the Open Ocean component of the Global Environment Facility (GEF) Transboundary Waters Assessment Programme (TWAP). To conduct these analyses, a variety of data were assembled to spatially represent the coverage of international agreements for fisheries, pollution and biodiversity, as well as for Large Marine Ecosystems (LMEs), Exclusive Economic Zones, biogeographical features and other physical characteristics.

Much of the data needed was already available for a variety of, often poorly documented spatially, sources. In other cases the data had to be generated from coordinates and maps. Challenges included: finding appropriate global projections and re-projecting data; obtaining appropriate maps and geographic coordinates; determining the appropriate resolution to be used for the task at hand; and conducting overlay analyses for 134 ocean regimes. The approaches adopted for addressing these challenges are described to provide guidance to future efforts at global scale analyses.

1 INTRODUCTION

Global ocean governance must deal with the variety of activities occurring within explicit areas at multiple scales ranging from global to local (Bavinck et al. 2005). The need to integrate, analyse and spatially understand many types of information relating to the marine environment and the interactions among them has increased reliance on the use of geographic information systems (GIS) (FAO 2013). GIS permits the assembling of information across various scales and disciplines thereby providing an effective data management framework (Balram et al. 2004). GIS not only provides the capability to conduct spatial analysis by querying, summarising and modelling marine resource data and corresponding ocean governance frameworks but can allow for improved understanding through the visualisation of the marine environment, its uses and the interactions amongst stakeholders (Carocci et al. 2009). By improving access to an integrated information base and allowing for the development of multiple scenarios, GIS can assist knowledge-based decision-making for ocean governance (De Freitas and Tagliani 2009; Baldwin et al. 2013). Despite this, use of GIS can be constrained by the availability of, or the cost of obtaining, comprehensive and reliable data (Balram et al. 2004).

In recent times, many global datasets have become readily available from various international agencies created for diverse purposes using a multitude of methodologies (FAO 2013). Many times metadata is not or poorly documented and thus secondary GIS data must be carefully examined and standardised before use. Not surprisingly, the process of compilation and creation of GIS information from diverse sources and scales is often laborious, time-consuming and costly (Tripathi and Bhattarya 2004, Baldwin and Mahon 2014).

Working with GIS on a global scale to develop global comparative analyses presents its own special set of problems, particularly in terms of the source, accuracy (resolution) of data needed, as well as the determination of appropriate coordinate systems to be applied. In this report we examine some of the issues encountered in conducting GIS analyses for the Transboundary Waters Assessment Programme (TWAP) Large Marine Ecosystem and Open Oceans baseline assessments (Box 1) and discuss considerations important for GIS practitioners working at global scales. In particular these relate to the use of GIS to spatially understand the relationships among and between the jurisdictions of global and regional ocean governance agreements and various physical environmental features of the global ocean.

Box 1: The Transboundary Waters Assessment Programme (TWAP)

The transboundary water systems of the world are critical for the socioeconomic development and wellbeing of the world's population, yet due to a variety of dynamic and complex human pressures the sustainability of these ecosystem services are at risk (UNEP 2011). These transboundary waters systems are the focus of the Global Environment Facility International Waters Program (GEF IW) which recognises five categories of international water systems: aquifers, lake/reservoir basins, river basins, Large Marine Ecosystems (LMEs), and open ocean (OO). Two of these categories encompass the world's ocean area; which are divided among 66 LMEs and the Open Ocean which comprises half of our planet. Thus the TWAP LME and OO assessments seek to examine the various global and regional ocean governance frameworks and the interactions of human and natural systems to better understand the links between human vulnerability and natural and anthropogenic stressors, ecosystem services and the consequences for ocean governance (UNEP 2011).

2 METHODS

2.1 Data scoping and creation

A data scoping exercise was undertaken to gather secondary information and primary data from all available sources (internet, ocean governance organisations, NGOs) that provided coverage of the global ocean. All existing spatial data and corresponding metadata were imported and examined using ArcInfo for Desktop Advanced 10.1 software.

Spatial data on the jurisdictional boundaries of ocean governance agreements' (regimes) and biophysical features were acquired or created in several ways. Many datasets were downloaded directly as shapefiles, as in the case of the exclusive economic zones (EEZs), High Seas, regional fisheries bodies and Large Marine Ecosystems (LMEs). Some data were created by substituting the shapefile for the spatial area of an agreement with a similar extent (i.e. by proxy), as in the case of the Commission of Arctic Flora and Fauna (CAFF) boundary shapefile which was assumed to be a reasonable proxy for the Arctic Council area. Likewise based on the findings of Honey and Sherman (2013), the Western Pacific Warm Pool geographic area was created by extracting the Western Pacific Warm Pool (WARM) province from the Longhurst Biogeographical Province dataset. Other data were created by converting and extracting a sub-set of data from a larger dataset, as in the case of regional seas. Some secondary data had to be converted and geoprocessed to model features of interest, such as for the continental shelf. In that case, the GEBCO Grid Display software was used to export the global elevation dataset GEBCO_08 Grid to an ASCII Grid. Using ArcGIS, the 'ASCII to Raster' Conversion tool allowed for the point data to be converted into a raster dataset. Next, the Spatial Analyst extension 'Extract by Attribute' tool was applied to extract the elevation cells (bathymetry) of the world's oceans raster ranging from (-1 to -200m). Then the 3D Analyst extension 'Raster Domain' tool was used to create a polygon footprint of the data portions of the produced raster to create a global continental shelf vector dataset.

Several ocean governance agreements did not exist in a spatial data format and therefore had to be created from secondary information. For example, in the case of the Arafura Timor Sea (ATSEA) Project area, a hard copy map of the jurisdiction of interest was geo-referenced and its boundaries were digitised. The same was done for the extended Bay of Bengal LME Project area that includes the Maldives and for the Agulhas-Somali Current LME Management Area that encompasses a large area of High Seas in the Indian Ocean. The Pacific Islands Forum (PIF) jurisdictional boundary was created by extracting the EEZs of participating countries (Australia, Cook Islands, Federated States of Micronesia, Fiji, Kiribati, Nauru, New Zealand, Niue, Palau, Papua New Guinea, Republic of Marshall Islands, Samoa, Solomon Islands, Tonga, Tuvalu, Vanuatu) and merging the selected EEZs into one area. In the case of the Protocol on Environmental Protection to The Antarctic Treaty (ATS) and the Convention for the Conservation of Antarctic Seals (CCAS), no spatial jurisdictional data existed and these areas were created based on geographic bounding coordinates generally accepted as reflecting the Southern Ocean (the entire global area south of the 60 degree parallel).

2.2 Determination of appropriate scale

A clear understanding of the scale of a GIS project is essential to determine the appropriate accuracy of data needed for analyses (FAO 2013). In our case, some of the global physical environmental features (i.e. global coastlines, bathymetry) collected were provided by various data sources and/or consisted of several levels of data accuracy (or resolution). Data were reviewed to ascertain their quality in terms of the differences in the accuracy of the various datasets available and their applicability at the global level. Initially, metadata and corresponding spatial and attribute datasets were examined using the ArcCatalog interface. The world vector shoreline (WVS) dataset, a Global Self-consistent, Hierarchical, High-resolution Geography Database (GSHHG) produced by NOAA's National Geophysical Data Center, that offers users five levels of global shoreline resolution was determined to be the most applicable for the TWAP analyses. Originally we planned to use the highest level of shoreline resolution (f) for the TWAP analyses, yet technological limitations, namely the ArcGIS 10.1 software and the computer's processing power (2.5 GHz CPU and 16 GB RAM) prevented the analyses of such high resolution data at a global scale. Therefore we proceeded to examine the differences in global ocean area resulting amongst the five resolutions of WVS datasets. To do this, all shorelines polygon data were first re-projected to a global projection that preserves area (World Cylindrical Equal Area). Next total area (km^2) was calculated for each coastline dataset (using the Calculate Geometry function) and compared to the highest resolution WVS to determine the percent difference among corresponding land and ocean areas of the world for each of the four lower resolution WVS datasets.

2.3 Data preparation and processing

Once GIS data is collected it must then be standardised before it can be effectively used for analysis. To prepare spatial data for global ocean governance analyses, all data were first organised into feature datasets or similar 'themes' comprising jurisdictional boundaries and physical environmental features, each of which contain a number of corresponding feature classes or 'layers' categorised by name, source, description and citation. Since data were collected from disparate sources and scales, all data were standardised into a common global geographic coordinate system (GCS WGS 84) if necessary (using the Project tool). Then the land areas of the world, WVS resolution (l) were clipped (using the Erase tool) from the various ocean governance framework spatial datasets to create uniform 'ocean only' data amongst the various features.

2.4 Data analysis

The application of GIS to integrate, display, query and analyse information is widely recognised as valuable for ecosystem-based analyses and decision-support of the marine environment (FAO 2013). As the TWAP recognised the need to better understand the spatial relationships among and between the jurisdictions of global and regional ocean governance regimes and various physical environmental features of the world's oceans, a number of area and overlay analyses were performed as part of the LME and OO components of the global assessment.

The following spatial analyses are presented:

- Spatial extent or total area (km^2) of global and regional ocean governance regimes
- Overlay (intersection) of the spatial extent of LME governance regimes with key physical characteristics (EEZ, High Seas, Continental Shelf)
- Calculation of overlapping or intersecting areas amongst all of the ocean governance regimes

The spatial extent (total area) of each ocean governance regime was calculated by first re-projecting each to a global projected coordinate system (PCS World Cylindrical Equal Area) known to preserve area. A field (double) was added to each regime's attribute table, geometry was calculated for area (km^2) and then statistics calculated for the total area of each feature.

Overlay analysis of the spatial extent of overlap of LMEs with key physical characteristics (i.e. EEZ, High Seas, continental shelf) was performed using the 'Intersect' tool of the Overlay toolbox. The Intersect tool computes a geometric intersection of the input features in which portions of the input features which overlap are written to an output feature class. For example, an intersection of LMEs and EEZs resulted in a new feature (LME_EEZ_Intersect). This resulting feature was then re-projected to the projected coordinate system (PCS

World Cylindrical Equal Area) and corresponding area (km^2) was recalculated for overlapping feature as described previously for total area.

Although calculating area and overlay analyses are relatively straightforward GIS procedures, the TWAP LME and OO assessment included a total of 134 regional and global ocean governance regimes. Hence to calculate total area of intersecting areas amongst the various ocean regimes, requiring a comparison of the spatial extent of each regime to every other, would therefore result in a total of 17,956 separate analyses. Thus a GIS analysis model, or a predefined sequence of analysis steps, was built to automate this process. A custom GIS analysis model 'Sea Treaty Toolbox' was built as a python script for use with the ArcGIS 10.1 software (Raleigh 2013). The input datasets for the Sea Treaty Toolbox include both the 'Regime' and global coastline 'WVS' shapefiles.

The 'Sea treaty toolbox' GIS analysis sequence is as follows:

- Regime and Coastline datasets were checked for errors (spatial topology) and all errors were repaired
- A copy of Regime data was created for editing called 'scratchRegime' geodatabase
- All terrestrial parts of the Regime data were removed (clipped) using the Coastline data to create ocean-only Regime polygons and 'scratchRegime' geodatabase was updated with ocean-only Regime polygons
- Ocean-only Regimes were projected from a Geographic Coordinate System (WGS 84) to a Projected Coordinate System (World Cylindrical Equal Area) and 'scratchRegime' was updated with the projected ocean-only Regime polygons
- Using the Get Area (GEODESIC) method, a pairwise comparison of the spatial extent of each Regime to one another was performed and only the areas of overlap for intersecting Regimes were calculated
- The results of the analysis were outputted as a .CSV matrix (134 rows x 134 columns).

All GIS analyses results were converted to MS Excel worksheets using the ArcMap export table function. Lastly the sources of information and data collected and created including methodologies for data conversion, creation, geoprocessing and analysis applied were documented and corresponding metadata were produced using ArcCatalog.

3 RESULTS AND DISCUSSION

3.1 Data scoping and creation

Collecting data and populating the geodatabase was an iterative process initially taking several months, but continued throughout the remainder of the project (additional 6 months). A total of 23 datasets were collected, of which 11 were subsequently used in the TWAP OO analyses (Table 1). A challenge in the review of existing data was a limited amount of metadata. Much time was therefore spent communicating with the data creators when possible to determine the accuracy, scale and methods that were applied to each dataset.

A total of 132 ocean regime features were compiled: 66 LMEs, 4 LME variants, 38 Regional Fisheries Bodies (RFBs), 15 Regional Seas (RS), 9 Other (Appendix I). The LMEs, RFBs and RS features were all downloaded directly as shapefiles from their corresponding governance organisations (Table 1). All RFBs and 66 LMEs provided were used in the analysis. Due to contention in some of the LME boundaries, an additional four LME jurisdictional areas were added to the analysis: (1) the LME Agulhas Current and LME Somali Current combined; (2) the Agulhas-Somali Management Area; (3) the Arafura Timor Sea project area; and (4) the Bay of Bengal LME extended area (that includes the Maldives). On the other hand, only 15 of the 41 Regional Seas polygons (developed by the Sea Around Us Project, University of British Columbia) were relevant to the TWAP ocean governance assessment of the world's oceans and therefore selected for inclusion. Several data gaps were found and thus several regime features were produced. Data were created from either geoprocessing secondary data (continental shelf, PIF), substituting similar jurisdictional boundaries from secondary GIS data (Arctic) or using known geographic coordinates (ATS, CCAS) (Table 2). These five datasets were classified as 'General' regimes in the analyses.

Table 1. List of feature datasets comprising physical environmental features and jurisdictional boundaries, each of which contain a number of corresponding features categorised by source, description and citation.

Feature dataset	Feature	Source	Description	Citation
Physical environ-mental features	General Bathymetric Chart of the Oceans (GEBCO_08 Grid)	https://www.bodc.ac.uk/data/online_delivery/gebco/	The GEBCO_08 Grid is a 30 arc-second grid of global elevations; it is a continuous terrain model for ocean and land.	General Bathymetric Chart of the Oceans (GEBCO), British Oceanographic Data Centre (2010). GEBCO_08 Grid.
	Continential Shelf (0-200 m)	Created from GEBCO_08 Grid	Continental Shelf: Bathymetry ranging from -1 to -200 meters in depth extracted from GEBCO_08 Grid.	GEBCO_08 Grid (2010).
	International Hydrographic Organization (IHO) Sea Areas	http://geonode.iwlearn.org/data/geonode:World_Seas	This dataset represents the boundaries of the major oceans and seas of the world. The source for the boundaries is the publication 'Limits of Oceans & Seas, Special Publication No. 23' published by the IHO in 1953.	VLIZ (2005). International Hydrographic Organization (IHO) Sea Areas.
	World Vector Shorelines	http://www.ngdc.noaa.gov/mgg/shorelines/gshhs.html	The GSHHG (2013) version 2.2.2 is a high-resolution geography data set, amalgamated from two databases in the public domain: World Vector Shorelines (WVS) and CIA World Data Bank II (WDBII) created by NOAA. NOAA shoreline data, the data goes from low resolution (c) to high resolution (f) using the follow lettering scheme (c, l, i, h, f).	Wessel, P., and W. H. F. Smith (1996), A global, self-consistent, hierarchical, high-resolution shoreline database, J. Geophys. Res., 101(B4), 8741–8743.
Jurisdict-ional and ecosystem boundaries	Exclusive Economic Zones (EEZs)	http://www.marineregions.org/downloads.php	Version 7 - November 2012. This dataset represents Exclusive Economic Zones (EEZ) of the world.	VLIZ (2014). Maritime Boundaries Geodatabase, version 7.

	High Seas	http://www.fao.org/geonetwork/srv/en/main.home?uuid=cc7dbf20-1b8b-11dd-8bbb-0017f293bd28	For high-seas vs. EEZ, FAO relies on the EEZ dataset provided by the VLIZ and extrapolated the attached file which also includes the FAO Major Areas. Otherwise to be derived by extracting EEZs from oceans	FAO. © 2008-2013. Regional Fisheries Bodies Maps. In: FAO Fisheries and Aquaculture Department [online]. Rome. Updated 22 February 2013.
	Large Marine Ecosystems (LMEs)	http://www.lme.noaa.gov/	This dataset represents the 66 Large Marine Ecosystems of the world. 2013.	NOAA (2013). US Large Marine Ecosystem Program.
	Longhurst biogeographical provinces	http://www.marineregions.org/	This dataset represents a partition of the world oceans into provinces as defined by Longhurst (1995, 1998, 2006), and are based on the prevailing role of physical forcing as a regulator of phytoplankton distribution.	Longhurst Biogeographical Provinces. Version 4 (2010).
	Regional Fishery Bodies (RFB)	http://www.fao.org/geonetwork/srv/en/main.home?uuid=cc7dbf20-1b8b-11dd-8bbb-0017f293bd28	The Regional Fishery Bodies are about 40 established Fishery Bodies (FAO and non-FAO RFBs) that cover the world's marine and inland regions.	FAO. © 2008-2013. Regional Fisheries Bodies Maps. In: FAO Fisheries and Aquaculture Department [online]. Rome. Updated 22 February 2013.
	Regional Fisheries Management Organizations (RFMOs)	http://www.fao.org/geonetwork?uuid=cc7dbf20-1b8b-11dd-8bbb-0017f293bd28	Citation: FAO. 2008-2013. Regional Fisheries Bodies Maps. In: FAO Fisheries and Aquaculture Department [online]. Rome. Updated 22 February 2013. [Cited (day month year)]. www.fao.org/figis/geoserver/factsheets/rfb.html	FAO. © 2008-2013. Regional Fisheries Bodies Maps. In: FAO Fisheries and Aquaculture Department [online]. Rome. Updated 22 February 2013.
	Regional Seas	UNEP Regional Seas Program	This dataset represents UNEP's 41 Regional Seas Programs.	Sea Around Us Project (2013).

Table 2. List of 'General' regimes listed by name, acronym and geoprocessing performed.

Regime name	Acronym	Geoprocessing
Arctic Region (no convention)	ARCTIC	Created by proxy (Commission of Arctic Flora and Fauna boundary)
Pacific Warm Pool	WARM	Created by proxy (Longhurst Biogeographical Province 'WARM')
Pacific Islands Forum	PIF	Created by merging the EEZs of participating countries
Protocol on Environmental Protection to The Antarctic Treaty	ATS	Created using coordinates (area south of 60 degrees south)
Convention for the Conservation of Antarctic Seals	CCAS	Created using coordinates (area south of 60 degrees south)

3.2 Determination of appropriate scale

Based on the visual inspection of the accuracy of spatial features of well-known areas (i.e. islands in the Caribbean) the various resolutions of the WVS seemed significant (e.g. entire small islands not represented in some of the lower resolution datasets, Figure 1), hence we initially planned on using one of the highest resolution WVS shorelines (f or h) for the regime overlay analysis. Yet due to technological limitations (both of the ArcGIS software and our computer's processing power) we were not able to conduct the regime overlay analysis with such high resolution data. However upon calculating total area for each the various resolutions of the WVS data, the maximum difference amongst the total land area on a global scale was less than 1% (Table 3). Likewise corresponding differences in total ocean area for each of the various WVS datasets was less than 2% on a global scale. Additional comparisons between the WVS (h) and (l) resolutions and corresponding ocean areas at smaller regional scales (regimes) were shown to result in even smaller differences, averaging a 0.1% among a subset of six selected regimes (EAFC, APFIC, CECAF, Cartagena, Nairobi, Barcelona) (Table 4). Therefore the WVS resolution (l) dataset was chosen for use in the TWAP analysis, as it was considered to be a suitable compromise between our technological limitations (computer processing power) and accuracy required working at a global scale.

Table 3. Table of the calculated total area of land, as well as corresponding percent difference in land and ocean areas based a comparison of each level to the highest resolution level (f) of the WVS dataset.

Resolution level	WVS dataset	Total area (km^2) land	Percent (%) difference land area	Percent (%) difference ocean area
Highest	f	149,059,700.5	0	0
	h	149,047,181.2	0.008	0.020
	i	149,001,295.1	0.039	0.095
	l	148,781,510.0	0.187	0.453
Lowest	c	147,949,867.5	0.750	1.815

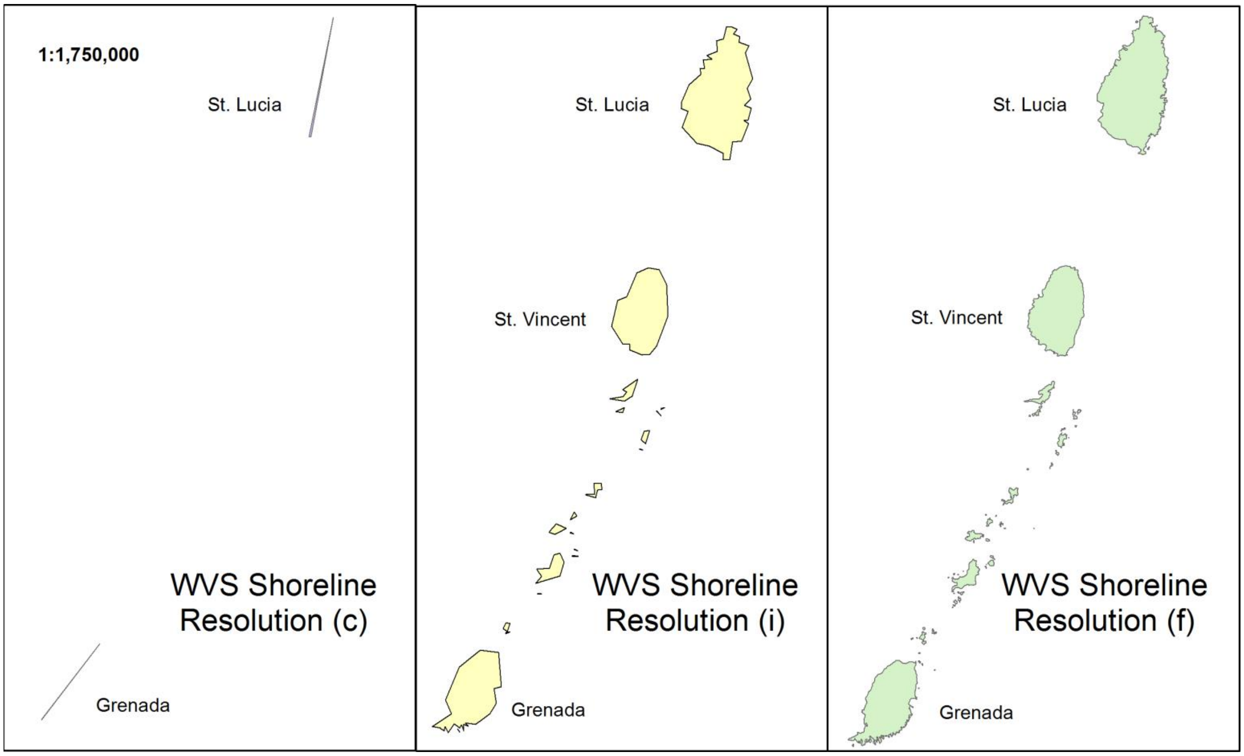


Figure 1. Map of selected Eastern Caribbean countries to show the accuracy between the various levels of shoreline resolution provided by the WVS dataset.

Table 4. Comparison of total ocean areas and corresponding percent difference derived between the WVS (h) and (l) resolution datasets among a subset of six selected regimes.

	Ocean Area (km2)		
Regime	**WVS resolution (h)**	**WVS resolution (l)**	**Percent difference**
NEAFC	13,532,763.1	13,564,383.7	0.23
APFIC	13,414,278.6	13,450,798.4	0.27
CECAF	14,072,179.7	14,076,060.5	0.03
Cartagena	6,620,460.7	6,627,033.8	0.10
Nairobi	6,264,665.1	6,268,673.9	0.06
Barcelona	2,512,691.6	2,510,148.9	-0.10

3.3 Data preparation and processing

All spatial features used in the TWAP LME and OO analyses were standardised into a common coordinate system (GCS WGS 84; PCS World Cylindrical Equal Area) and clipped with the WVS shoreline resolution (l) to create uniform global ocean features. There was only one pre-existing global dataset (e.g. LMEs), in which the coastline features already were erased, comprising ocean-only features, in the source data. The utilisation of disparate coastlines would therefore result in slightly different total ocean areas calculated independently from the LME source data as compared to the LME ocean areas created from the 'Sea Treaty Toolbox' geoprocessed using the WVS resolution (l) dataset (Table 5). This discrepancy warranted further investigation to determine the effect on the accuracy of the subsequent TWAP analyses. Therefore six LMEs (Sea of Okhotsk, Gulf of Alaska, Canary

Current, Caribbean Sea, Bay of Bengal, Patagonian Shelf) were selected to examine the differences that would result in derived ocean areas based on the utilisation of different coastlines. An overall difference of 2.7% globally was found to result between the two LME ocean areas (e.g. LMEs source data and LMEs created using the Sea treaty toolbox). This difference was found to be substantially lower when examined at the regional LME scale (ranging between 0.5% to 1.2% of total area amongst the six selected LMEs) (Table 6).

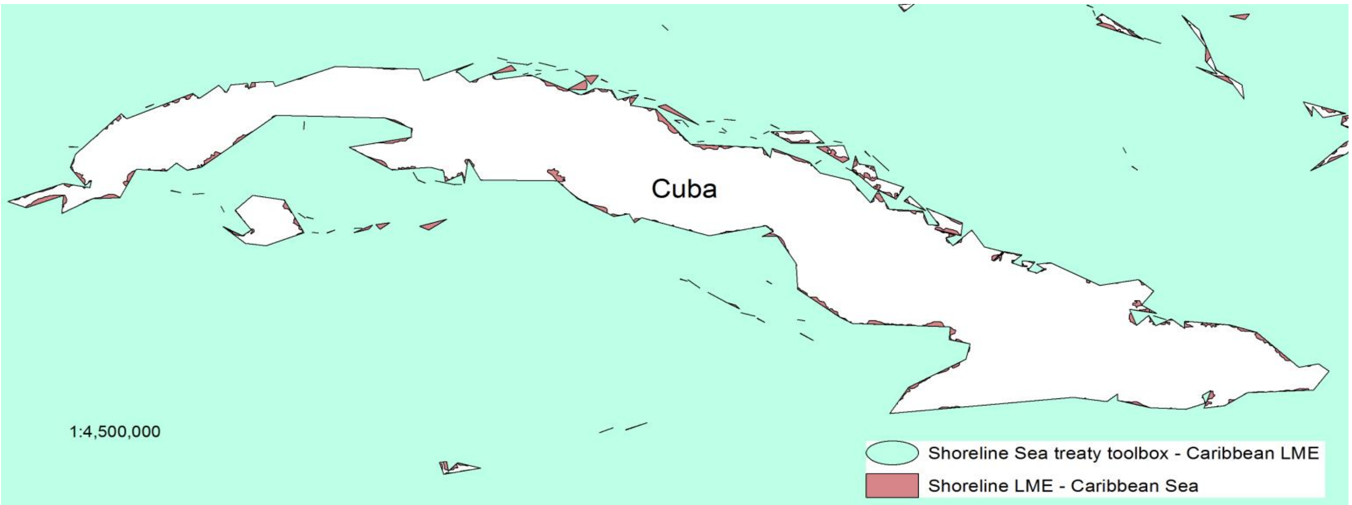


Figure 2. Map of Cuba showing the difference in the two coastlines; the LME source data and those created from the 'Sea treaty toolbox' geoprocessed using the WVS resolution (l) dataset.

Table 5. Comparison of the total ocean area (km2) and percent difference in area of six randomly selected LMEs derived from both the LME source data and the Sea Treaty Toolbox.

LME	Ocean Area (km^2)		% Difference
	LME Data	Sea Treaty Toolbox	
Sea of Okhotsk	1,564,323.9	1,556,480.4	0.50
Gulf of Alaska	1,481,492.8	1,463,823.5	1.21
Canary Current	1,122,976.8	1,118,001.2	0.45
Caribbean Sea	3,263,022.6	3,246,025. 1	0.52
Bay of Bengal	3,664,822.4	3,647,970.9	0.46
Patagonian Shelf	1,170,656.5	1,164,264.4	0.55

Table 6. Comparison of LME areas from source data with those derived from using the Sea Treaty Toolbox)

	Ocean Area (km^2)		
LME	LME Data	SeaTreaty Toolbox	% Difference
Sea of Okhotsk	1,564,323.877	1,556,480.440	0.50
Gulf of Alaska	1,481,492.849	1,463,823.463	1.21
Canary Current	1,122,976.764	1,118,001.220	0.45
Caribbean Sea	3,263,022.565	3,246,025.091	0.52
Bay of Bengal	3,664,822.355	3,647,970.912	0.46
Patagonian Shelf	1,170,656.461	1,164,264.444	0.55

3.4 Data analysis

Geoprocessing tools can allow for the integration of data layers to help explore patterns that occur between and among ocean governance frameworks as well as the relationships between the physical environmental features. Here we provide a subset of our results, although supplementary information was produced and is included as part of the larger TWAP LME and OO assessments (Mahon et al. in press; Fanning et al. in press).

Using standard geoprocessing tools, total area (km^2) was calculated for each of LMEs (based on the source LMEs dataset) and corresponding intersections amongst the various physical environmental features (Table 7).

Table 7 Total area (km^2) for each LME and intersecting EEZ, High Seas and Continental Shelf features.

LME No	LME Name	Total LME area (km^2)	High Seas area (km^2)	Percent High Seas	Continental Shelf Area (km^2)	Percent Shelf
1	East Bering Sea	1,279,388	126,477	9.9	575,071	44.9
2	Gulf of Alaska	1,481,493	228,858	15.4	282,963	19.1
3	California Current	2,215,065	669,623	30.2	103,126	4.7
4	Gulf of California	222,332	-	-	68,416	30.8
5	Gulf of Mexico	1,533,006	35,568	2.3	552,619	36.0
6	Southeast U.S. Continental Shelf	301,676	-	-	126,665	42.0
7	Northeast U.S. Continental Shelf	321,974	390	0.1	266,591	82.8
8	Scotian Shelf	284,843	-	-	216,551	76.0
9	Labrador – Newfoundland	908,785	102,738	11.3	486,071	53.5
10	Insular Pacific-Hawaiian	980,517	-	-	16,793	1.7
11	Pacific Central-American Coastal	1,983,489	13,536	0.7	191,578	9.7
12	Caribbean Sea	3,263,023	-	-	477,664	14.6
13	Humboldt Current	2,557,713	251,551	9.8	246,397	9.6
14	Patagonian Shelf	1,170,656	21,929	1.9	998,908	85.3
15	South Brazil Shelf	566,862	607	0.1	276,434	48.8
16	East Brazil Shelf	1,075,022	1,224	0.1	161,484	15.0
17	North Brazil Shelf	1,053,656	41,891	4.0	452,040	42.9
18	Canadian Eastern Arctic - West Greenland	1,385,104	-	-	358,917	25.9
19	Greenland Sea	1,212,972	91,813	7.6	145,618	12.0
20	Barents Sea	2,003,064	65,445	3.3	896,664	44.8
21	Norwegian Sea	1,055,881	224,851	21.3	45,128	4.3
22	North Sea	695,749	-	-	577,577	83.0
23	Baltic Sea	396,358	-	-	370,667	93.5
24	Celtic-Biscay Shelf	762,631	24,580	3.2	514,809	67.5
25	Iberian Coastal	304,350	-	-	51,347	16.9
26	Mediterranean Sea	2,530,147	-	-	482,983	19.1
27	Canary Current	1,122,977	2,700	0.2	186,780	16.6
28	Guinea Current	1,918,962	201,158	10.5	272,637	14.2
29	Benguela Current	1,458,724	144,387	9.9	191,902	13.2
30	Agulhas Current	2,626,583	122,076	4.6	296,261	11.3

LME No	LME Name	Total LME area (km^2)	High Seas area (km^2)	Percent High Seas	Continental Shelf Area (km^2)	Percent Shelf
31	Somali Coastal Current	840,343	5,194	0.6	55,203	6.6
32	Arabian Sea	3,932,201	1,227,351	31.2	660,864	16.8
33	Red Sea	460,924	-	-	185,791	40.3
34	Bay of Bengal	3,664,822	932,899	25.5	625,182	17.1
35	Gulf of Thailand	387,517	-	-	381,345	98.4
36	South China Sea	3,164,769	14,129	0.4	1,467,394	46.4
37	Sulu-Celebes Sea	1,013,560	-	-	192,735	19.0
38	Indonesian Sea	2,266,995	-	-	770,570	34.0
39	North Australian Shelf	779,892	-	-	765,322	98.1
40	Northeast Australian Shelf	1,281,700	-	-	293,993	22.9
41	East Central Australian Shelf	652,837	26	0.0	63,057	9.7
42	Southeast Australian Shelf	1,193,820	155	0.0	211,757	17.7
43	South West Australian Shelf	1,016,576	60	0.0	288,153	28.3
44	West Central Australian Shelf	580,405	-	-	105,591	18.2
45	Northwest Australian Shelf	911,716	-	-	356,821	39.1
46	New Zealand Shelf	968,706	93,800	9.7	208,613	21.5
47	East China Sea	779,633	-	-	553,460	71.0
48	Yellow Sea	440,502	-	-	427,803	97.1
49	Kuroshio Current	1,321,400	30,490	2.3	88,092	6.7
50	Sea of Japan	988,671	-	-	193,194	19.5
51	Oyashio Current	534,360	11,202	2.1	48,962	9.2
52	Sea of Okhotsk	1,564,324	43,194	2.8	587,084	37.5
53	West Bering Sea	759,753	4,353	0.6	107,885	14.2
54	Northern Bering - Chukchi Seas	1,333,997	283,921	21.3	1,009,815	75.7
55	Beaufort Sea	1,092,196	130,959	12.0	376,115	34.4
56	East Siberian Sea	630,040	47,451	7.5	552,824	87.7
57	Laptev Sea	893,318	39	0.0	771,202	86.3
58	Kara Sea	993,659	-	-	728,385	73.3
59	Iceland Shelf and Sea	476,481	-	-	106,701	22.4
60	Faroe Plateau	104,442	-	-	25,536	24.5
61	Antarctica	4,373,433	51,777	1.2	244,028	5.6
62	Black Sea	462,825	-	-	143,723	31.1
63	Hudson Bay Complex	1,251,254	-	-	1,068,597	85.4
64	Central Arctic	3,341,716	2,343,603	70.1	-	-
65	Aleutian Islands	218,755	-	-	32,601	14.9
66	Canadian High Arctic - North Greenland	599,443	-	-	180,382	30.1

The creation of a GIS analysis model (Sea Treaty Toolbox) to automate the large overlay analyses to calculate total intersecting area between the 134 ocean regime features allowed for spatial analysis that would not have been possible within a short timeframe. The Sea Treaty Toolbox analysis using the WVS resolution (l) data took over 27 hours to complete using a relatively fast computer processor (16 GB RAM). Attempts made to use the next highest level of WVS resolution (i) data were unsuccessful after running for over 9 days and crashing due to a lack of internal memory (350 GB hard drive) that the ArcGIS software required to run the Sea Treaty Analysis Toolbox. Despite technical limitations encountered, differences in simple calculations of total land and ocean areas among the various WVS resolution datasets were found to be insignificant on a global scale. Thus our decision to use WVS resolution (l) resulted in an additional error of approximately 0.5% in the determination of our global ocean areas provided in the TWAP OO and LME analyses. Here we provide a subset of six regimes (LME East China Sea; LME Southeast Australian Shelf; RFB ICCAT; RFB PICES; GENERAL PIF; RS OSPAR) resulting from the regime matrix results (Table 8).

Table 8. Subset matrix for six randomly selected regimes showing the total area (million km^2) of jurisdictional boundary overlap.

	LME E China Sea	LME SE Australian Shelf	RFBICCAT	RFBPICES	GENPIF	RSOSPAR
LME E China Sea	772,310	0	0	345,285	0	0
LME SE Australian Shelf	0	1,188,382	0	0	523,070	0
RFB ICCAT	0	0	97,386,843	0	0	13,473,146
RFB PICES	345,285	0	0	26,832,716	0	0
GEN PIF	0	523,070	0	0	26,104,377	0
RS OSPAR	0	0	13,473,146	0	0	13,492,990

4 LESSONS LEARNED AND CONSIDERATIONS FOR PRACTICE

Several key lessons were learned in the TWAP LME and OO assessments provide considerations for GIS practitioners working at regional and global scales. To effectively manage complex, interdependent systems, it is essential to have access to diverse information (e.g., environmental, economic, political) over various geographic regions and at various scales (Butler et al. 2008). The collection and processing of data is recognised to be the most important, time-consuming and costly component to successful GIS analysis (Carroci et al. 2009). With the advent of information technologies and the internet, existing secondary GIS data are now widely available from many different data sources, in a variety of scales and formats (FAO 2013). Primary and secondary GIS data typically require a substantial investment in time for processing into a format suitable for use. Moreover, producing high resolution data is particularly laborious and the cost increases exponentially with scale (FAO 2013). Despite the various data quality standards applied and metadata developed in the creation of secondary GIS data, the importance of ensuring open access to GIS data produced should not be underestimated (Butler et al. 2008). The benefits of proxy data and using GIS to integrate various datasets are paramount to conducting meaningful global analyses.

Clearly, determining the geographic scale, coordinate systems to be applied and corresponding considerations regarding data quality required is critical from the outset to develop appropriate GIS analyses. Data quality is largely scale-dependent and different resolutions (or accuracy) of data are required for mapping at different scales. For example, the accuracy needed at a global scale is substantially less than the accuracy required for working at regional or national scales. In the case of the global TWAP analyses, the determination of an appropriate coastline resolution was largely dependent on the estimation of total error that would be introduced to the various ocean areas created from the various WVS datasets. Despite the discrepancies seen in geometry of the five resolution levels of WVS data, upon the calculation of the resulting total land and ocean area these disparities were found to be insignificant at a global scale. Thus we chose a coastline resolution that minimised resulting error while working within the technological limitations of both the hardware (computer processor) and software (ArcGIS) components at hand.

An interesting lesson, not immediately apparent at the outset of this project, was that most of the existing data for regimes relevant to global ocean did not have coastlines (or the land) pre-cut from the data. As previously mentioned, the LMEs dataset was the only one that comprised ocean-only data. Despite initially appearing to be a benefit, this pre-cutting of the coastline actually increased the amount of error in our global analysis and the comparison of total area calculations based on the two different analyses applied. These differences were found to be small on a global scale but accuracy on a smaller scale could have serious implications. It therefore is recommended that practitioners creating global GIS ocean data for distribution do not pre-cut coastlines so the appropriate resolution can be determined and used based on the scale of the analysis to be applied.

Similarly, attention in regards to coordinate systems applied to global GIS data is warranted. It is important to remember that GIS is merely a three-dimensional (3D) mathematical model of the earth's surface, where the Geographic Coordinate System, also known as the Global Reference System, is used to identify point locations anywhere on the earth's surface. Yet it is difficult to make accurate measurements in spherical coordinates, and thus geographic data must be projected into planar coordinate system. To convert global 3D data to a projected two-dimensional coordinate system some amount of error must be introduced. A suitable map projection, a method for converting the earth's 3D surface to a map's two-dimensional surface, is therefore scale dependent. Moreover, the suitability of a particular map projection will differ depending on the need to calculate shape, area, distance, or direction from coordinates. In this study nearly all secondary global GIS data downloaded was projected in a geographic coordinate system (GCS WGS 84), yet area calculations require that data is projected to a Cartesian coordinate system or map projection that preserves area. It is therefore recommended that global GIS data is produced and shared using a global geographic coordinate system so that end-users can choose an appropriate map projection suited to the analysis at hand.

Lastly the importance of producing metadata must be highlighted. The process of creating and maintaining metadata is often overlooked, yet documenting how GIS data were created (e.g. source, processing and citation for information) is of upmost importance for the sharing and usability of data. Basic quality assurance and metadata standards should be observed for effective utilisation of GIS data particularly on a global scale. Although there are several metadata standards available, we recommend the following minimum requirements: title, data model, coordinate system, scale, accuracy, data creation methodology (geoprocessing applied), data source, citation, data limitations, date created, data creator and contact information. If the GIS project involves the production of several datasets and/or analyses a corresponding technical report should be produced and referenced accordingly in the associated metadata.

Working with GIS at a global scale requires additional insight into the various GIS system components. The global TWAP LME and OO GIS analyses presented a new context as compared to national or regional GIS analysis particularly in terms of data collection, coordinate systems, standardisation, creation and metadata. The importance of these core GIS components at various scales of analysis will persist despite on-going technological advances.

5 REFERENCES

Armitage, D., R. Plummer, F. Berkes, R. Arthur, A. Charles, I. Davidson-Hunt, N. Doubleday et al.. 2008. Adaptive co-management for social-ecological complexity. *Frontiers of Ecology and the Environment* (6): DOI 10.1890/070089.

Baldwin, K., R. Mahon and P. McConney. 2013. Participatory GIS for strengthening transboundary marine governance in SIDS. *Natural Resources Forum* 37 (4): 257-268.

Baldwin, K. and R. Mahon. 2014. A geospatial framework to support marine spatial planning and management for the transboundary Grenadine Islands. *Electronic Journal of Information Systems for Developing Countries* 63(7).

Balram, S., S. Dragicevic and T. Meredith. 2004. A collaborative GIS method for integrating local and technical knowledge in establishing biodiversity conservation priorities. *Biodiversity and Conservation* 13:1195-1208.

Bavinck, M., R. Chuenpagdee, M. Diallo, P. Van der Heijden, J. Kooiman, R. Mahon and S.Williams. 2005. *Interactive Fisheries Governance*. Delft, Netherlands: Eburon Publishers.

Butler, M., P. Boudreau, C. LeBlanc and K. Baldwin. 2009. Spatial data infrastructures in support of ecosystem based management and ecosystem approach to fisheries in the Caribbean. In *Towards marine ecosystem-based management in the Wider Caribbean*, ed. L. Fanning, R. Mahon and P. McConney. Amsterdam: Amsterdam University Press.

Carocci, F., G. Bianchi, P. Eastwood and G. Meaden. 2009. "Geographic Information Systems to Support the Ecosystem Approach to Fisheries: Status, Opportunities and Challenges." FAO Fisheries and Aquaculture Technical Paper No. 532. Rome: Italy.

De Freitas D. and P. Tagliani. 2009. The use of GIS for the integration of traditional and scientific knowledge in supporting artisanal fisheries management in southern Brazil. *Journal of Environmental Management* 90 (2009): 2071-2080.

Fanning, L., R. Mahon, K. Baldwin and S. Douglas. In press. "Transboundary Waters Assessment Programme (TWAP) Assessment of Governance Arrangements for the Ocean: Vol 1 – Transboundary Large Marine Ecoystems." IOC Technical Series 115.

FAO (Food and Agriculture Organisation). 2013. "Advances in Geographic Information Systems and Remote Sensing for Fisheries and Aquaculture." FAO Fisheries and Aquaculture Technical Paper No. 552. FAO, Paris, Italy.

Honey, K. and K. Sherman. 2013. The Western Pacific Warm Pool Assessment Approach for the Transboundary Waters Assessment. Background Brief. April, 2013. NOAA Large Marine Ecosystem Program, Narragansett, RI, USA.

Mahon, R., L. Fanning, K. M. Gjerde, O. Young, M. Reid, S. Douglas. In press. "Transboundary Waters Assessment Programme (TWAP) Assessment of Governance Arrangements for the Ocean: Vol 2 – Ocean Areas Beyond National Jurisdiction." IOC Technical Series 115.

Raleigh, D. 2013. Sea treaty toolbox analysis: Python script for ArcGIS version 10.1.

Tripathi N. and S. Bhattarya. 2004. Integrating indigenous knowledge and GIS for participatory natural resource management: State-of-the-practice. *The Electronic Journal on Information Systems in Developing Countries* 17 (3): 1-13.

UNEP (United Nations Environmental Program). 2011. Jeftic, L., P. Glennie, L. Talaue-McManus and J. A. Thornton (eds.). "Methodology for the GEF Transboundary Waters Assessment Programme. Volume 1. Methodology for the Assessment of Transboundary Aquifers, Lake Basins, River Basins, Large Marine Ecosystems, and the Open Ocean." UNEP. 60 pp.

6 APPENDIX 1: REGIMES USED IN THE ANALYSES

Type	Name	Full name
LME	Agulhas Current	Same
LME	Aleutian Islands	Same
LME	Antarctica	Same
LME	Arabian Sea	Same
LME	Baltic Sea	Same
LME	Barents Sea	Same
LME	Bay of Bengal	Same
LME	Beaufort Sea	Same
LME	Benguela Current	Same
LME	Black Sea	Same
LME	California Current	Same
LME	Canadian Eastern Arctic - West Greenland	Same
LME	Canadian High Arctic - North Greenland	Same
LME	Canary Current	Same
LME	Caribbean Sea	Same
LME	Celtic-Biscay Shelf	Same
LME	Central Arctic	Same
LME	East Bering Sea	Same
LME	East Brazil Shelf	Same
LME	East Central Australian Shelf	Same
LME	East China Sea	Same
LME	East Siberian Sea	Same
LME	Faroe Plateau	Same
LME	Greenland Sea	Same
LME	Guinea Current	Same
LME	Gulf of Alaska	Same
LME	Gulf of California	Same

LME	Gulf of Mexico	Same
LME	Gulf of Thailand	Same
LME	Hudson Bay Complex	Same
LME	Humboldt Current	Same
LME	Iberian Coastal	Same
LME	Iceland Shelf and Sea	Same
LME	Indonesian Sea	Same
LME	Insular Pacific-Hawaiian	Same
LME	Kara Sea	Same
LME	Kuroshio Current	Same
LME	Labrador - Newfoundland	Same
LME	Laptev Sea	Same
LME	Mediterranean Sea	Same
LME	New Zealand Shelf	Same
LME	North Australian Shelf	Same
LME	North Brazil Shelf	Same
LME	North Sea	Same
LME	Northeast Australian Shelf	Same
LME	Northeast U.S. Continental Shelf	Same
LME	Northern Bering - Chukchi Seas	Same
LME	Northwest Australian Shelf	Same
LME	Norwegian Sea	Same
LME	Oyashio Current	Same
LME	Pacific Central-American Coastal	Same
LME	Patagonian Shelf	Same
LME	Red Sea	Same
LME	Scotian Shelf	Same
LME	Sea of Japan	Same
LME	Sea of Okhotsk	Same
LME	Somali Coastal Current	Same
LME	South Brazil Shelf	Same

LME	South China Sea	Same
LME	South West Australian Shelf	Same
LME	Southeast Australian Shelf	Same
LME	Southeast U.S. Continental Shelf	Same
LME	Sulu-Celebes Sea	Same
LME	West Bering Sea	Same
LME	West Central Australian Shelf	Same
LME	Yellow Sea	Same
LME	Agulhas - Somali Current	Combined Agulhas - Somali Current LMEs
LME	Agulhas - Somali Current MA	Agulhas - Somali Current extended management area
LME	ATSEA	Arafura Timor Seas Project Area
LME	Bay of Bengal extended	Bay of Bengal extended area to include the Maldives
RFB	APFIC	Asia Pacific Fisheries Commission
RFB	BOBP-IGO	Bay of Bengal Programme Inter-Governmental Organization
RFB	CCAMLR	Commission on the Conservation of Antarctic Marine Living Resources
RFB	CCBSP	The Convention on the Conservation and Management of the Pollock Resources in the Central Bering Sea
RFB	CCSBT	Commission for the Conservation of Southern Bluefin Tuna
RFB	CECAF	Fishery Committee for the Eastern Central Atlantic
RFB	COMHAFAT	Conference Ministerial sur la Cooperacion Etats Africain Riverain Ocean Atlantique
RFB	COREP	Regional Fisheries Committee for the Gulf of Guinea
RFB	CPPS	Permanent Commission for the South Pacific
RFB	CRFM	Caribbean Regional Fisheries Mechanism
RFB	CTMFM	Joint Technical Commission for the Argentina/Uruguay Maritime Boundary
RFB	FCWC	Fishery Committee of the West Central Gilf of Guinea
RFB	FFA	Forum Fisheries Agency
RFB	GFCM	General Fisheries Commission for the Mediterranean.
RFB	IATTC	InterAmericanTropical Tuna Commission
RFB	ICCAT	International Commission for The conservation of Atlantic Tunas
RFB	ICES	International Council for the Exploration of the Sea
RFB	IOTC	Indian Ocean Tuna Commission

RFB	IPHC	International Pacific Halibut Commission
RFB	NAFO	Northwest Atlantic Fisheries Organization
RFB	NAMMCO	North Atlantic Marine Mammal Commission
RFB	NASCO	North Atlantic Salmon Conservation Organization
RFB	NEAFC	North East Atlantic Fisheries Commission
RFB	NPAFC	North Pacific Anadromous Fish Commission
RFB	OLDEPESCA	Latin American Organization for Fisheries Development
RFB	OSPESCA	Organización del Sector Pesquero y Acuícola del Istmo Centroamericano
RFB	PICES	The North Pacific Marine Science Organization
RFB	PSC	Pacific Salmon Commission
RFB	RECOFI	Regional Commission for Fisheries
RFB	SEAFDEC	Southeast Asian Fisheries Development Center
RFB	SEAFO	South East Atlantic Fisheries Organisation
RFB	SIOFA	South Indian Ocean Fisheries Agreement
RFB	SPC	Secretariat of the Pacific Community
RFB	SPRFMO	South Pacific Regional Fisheries Management Organization
RFB	SRFC	Subregional Fisheries Commission
RFB	SWIOFC	Southwest Indian Ocean Fisheries Commission.
RFB	WCPFC	Western and Central Pacific Fisheries Commission.
RFB	WECAFC	Western Central Atlantic Fisheries Commission.
OTH	Arctic	Arctic Council
OTH	ASCOBANS	Agreement on the Conservation of Small Cetaceans in the Baltic, North East Atlantic, Irish and North Seas
OTH	ATS	Antarctic Treaty System and Protocol
OTH	Bonn Agreement	Agreement for cooperation in dealing with pollution of the North Sea by oil and other harmful substances
OTH	CCAS	Commission for the Conservation of Antarctic Seals
OTH	Dugong MOU	Memorandum of Understanding on the Conservation and Management of Dugongs and their Habitats throughout their Range
OTH	EU	European Union Common Fisheries Policy and Maritime area
OTH	PIF	Pacific Islands Forum

OTH	WARM	Pacific Warm Pool
RS	Abidjan Convention and protocols	Abidjan Convention for Co-operation in the protection and Development of the Marine and Coastal Environment of the West and Central African Region
RS	Antigua Convention and protocols	The Convention for Cooperation in the Protection and Sustainable Development of the Marine and Coastal Environment of the Northeast Pacific
RS	Barcelona Convention and protocols	The Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean
RS	Bucharest Convention and protocols	Convention on the Protection of the Black Sea against Pollution (three protocols)
RS	Cartagena Convention and protocols	Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region
RS	COBSEA	Coordinating Body on the Seas of East Asia
RS	Helsinki Convention	Convention on the Protection of the Marine Environment of the Baltic Sea Area
RS	Jeddah Convention and protocols	Regional Convention for the Conservation of the Red Sea and Gulf of Aden Environment
RS	Kuwait Convention and protocols	Regional Convention for Cooperation on the Protection of the Marine Environment from Pollution
RS	Lima Convention and protocols	Convention for the Protection of the Marine Environment and Coastal Areas of the South-East Pacific
RS	Nairobi Convention and protocols	Nairobi Convention for the Protection, Management and Development of the Marine and Coastal Environment of the West Indian Ocean
RS	Noumea Convention and protocols	Convention for the Protection of the Natural Resources and Environment of the South Pacific
RS	NOWPAP	Action Plan for the Protection, Management and Development of the Marine and Coastal Environment of the Northwest Pacific Region
RS	OSPAR Convention	Convention for the Protection of the Marine Environment of the North-East Atlantic
RS	SACEP	South Asian Cooperative Environment Programme