Species Richness Maps and Esri Story Maps for the biodiversity of mangrove forest for the Mangrove Action Project (MAP)

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1 – Recommend Course of Action

The Mangrove Action Project (MAP) requested species richness maps for the world's mangrove forests and Esri Story Maps for select megafanua to aid in their community based ecological mangrove restoration (CBEMR) program. This project used global data from the International Union for the Conservation of Nature (IUCN), Birds of the World (BoW), and Global Forest Watch (GFW) for species ranges for mammals, amphibians, birds, and bonefish and tarpons. With these data, coarse species richness maps were created using best practices from the fields of ecology and conservation biology. In addition to species richness maps, two Esri Story Maps were created to highlight Bengal tigers of the Sundarban Mangrove Forest and the Proboscis monkey and Bornean orangutan of the Sunda Shelf Mangroves, Borneo.

Using the deliverables from this project, it is recommended that MAP use the species richness maps as an illustrative guide to the importance of areas with mangrove forests. The Esri Story Maps should be expanded and enriched as time and data allow.

2 – Introduction

2.1 – Mangrove Action Project

The Mangrove Action Project (MAP) is a not for profit global organization that is dedicated to saving the world's mangrove forest. They have programs that both actively fight the destruction of mangroves and educate local communities to the value and importance of mangrove forests in their lives. MAP has needs for several different levels of geographical information service (GIS) analysis from maps for education to combining existing disparate data to identify areas of greatest need and threats.

This study focuses on their need of maps for their community based ecological mangrove restoration (CBEMR) program. The maps requested for the CBEMR program are mangrove specific species richness range maps and Esri Story Maps that highlight some of the megafauna that make their homes in the mangroves.

2.2 – Mangrove Forests

Mangrove forests are unique forests that are found in the relatively narrow inter-tidal zone between sea and land of the tropics and subtropics between 25°N and 30°S latitude (Valiela et al., 2001). They grow in the severe environment of high salinity, high temperatures, extreme tides, high sedimentation and muddy anaerobic soils (Giri et al., 2011). In 2000, the area of mangroves worldwide was approximately 137, 760 km^2, spanning 118 counties and territories with approximately 75% of the forests found in 15 countries (Figure 1, Table 1) (Giri et al., 2011; Valiela et al., 2001). Mangrove forests provide a wide range of ecoservices and produce numerous goods while occupying only 0.12% of the world's total land area (Polidoro et al., 2010). While the communities and ecosystems found within the mangroves rely heavily upon the unique characteristics of the forest for survival, mangrove forests are disappearing at an alarming rate. Since 1980, 20%-35% of worldwide mangrove forests have been lost with an estimated 1% - 8% lost annually (Polidoro et al., 2010).

Table 1 – Top 10 Mangrove Countries. Source Global Forest Watch 2011 and Giri et al., 2011.

Rank	Country	Mangrove Area (km^2)	% of Global Total
1	Indonesia	27,076	22.6
2	Brazil	10,589	7.1
3	Australia	9,634	7.0
4	Mexico	7,296	5.4
5	Niger	6,266	4.7
6	Malaysia	5,585	3.7
7	Myanmar	5,075	3.6
8	Papua New Guinea	4,746	3.5
9	Bangladesh	4,456	3.2
10	Cuba	4,280	3.1

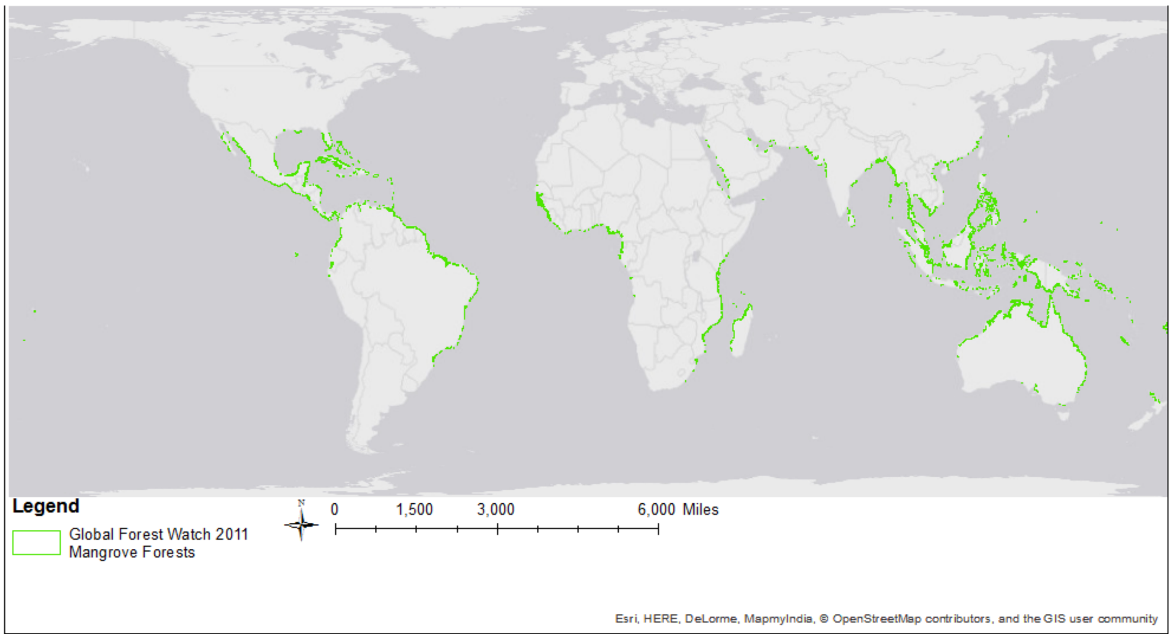

Figure 1 - Worldwide distribution of mangrove forests.

2.3 - Ecoservices

Mangrove forests are among the most productive and biologically important in the world as they provide many ecoservices and resources to coastal communities, many of them in developing countries. Among the ecoservices mangrove forests support are: flood protection, nutrient and organic matter processing, sediment control, fisheries, and renewable sources of wood (Alongi, 2008; Polidoro et al., 2010). They act as a buffer in the transition from the sea to land that provides nursery and breeding grounds for birds, mammals, amphibians, crustaceans, and fish (Alongi, 2008). The forests protect inland ecosystems from waves, tidal bores, and tsunamis and dampen coastal erosion caused by tidal activity (Alongi, 2008; Polidoro et al., 2010). In addition to physical protection, mangrove forests also provide communities with honey, tannins, mariculture crops, and salt (Valiela et al., 2001).

2.4 Species richness range maps

In the fields of ecology and conservation, examining continental-to-global patterns of species richness uses species range maps. The common way to create these maps is to overlay species range polygons with a grid and count the number of polygons per grid cell (Graham and Hijmans, 2006; Hurlbert and Jetz, 2007; Soberon and Ceballos 2001; Sangermano 2009). This method provides a coarse way to view species density patterns. When using this method, the grid cell size and projection are important design factors, as a mismatch in scale will adversely affect any attempt to examine species richness. With advanced data gathering techniques (i.e., LiDAR, satellite imagery) combined with geographical mapping software, the temptation is to use a fine spatial resolution not supported by the underlying species range polygons. This mismatch may result in an overestimation of species richness (Hurlbert and Jetz, 2007). Conversely, a coarse spatial resolution is rarely desired for a study area. Finding the compromise between resolution and accuracy is the topic of many studies (Ceballos et al., 2005; Hengl, 2006; Larsen et al., 2009; Rahbek et al., 2007; Soberón andCeballos, 2011; Stein et al., 2001) and understanding the accuracy of the scale dependence is important for the analysis of range map data (Graham and Hijmans, 2006; Hurlbert and Jetz, 2007). Hurlbert and Jetz (2007) compared range maps with species survey maps at various scales that ranged from >4° to 0.25° and found at 2° grid cell size the range maps were statistically similar to species survey maps. Hengl (2006) does not recommend a set grid size but instead encourages researchers to find resolutions that comply with the inherent resolution of the input datasets and the grid cell size should support the fixed area or volume of land being sampled. As a compromise to the spatial resolution issue, most researchers use 1° grids for range maps (Ceballos et al., 2005; Larsen et al., 2009; Rahbek et al., 2007).

3 - Design & Methods

3.1 Design for Species Richness Maps

The most common datasets used, for non-avian species, for species range maps is the International Union for the Conservation of Nature (IUCN) Red List and Birds of the World (BoW) for avian species. These dataset provides species range polygons in Esri shapefiles that are based on expert knowledge of species range extent. The ranges can include inferred or projected sites of present occurrence and inevitably includes omissions due to lack of data (IUCN, 2016). The dataset are distributed unprojected in GCS_WGS_1984.

This study uses the 2011 mangrove forest Esri shapefile from Global Forest Watch (GFW) for the mangrove forest areas. This dataset is also distributed unproject in GCS_WGS_1984. The scale of these mangrove polygons is fine compared to the coarse, global scale of the IUCN data. The compromise between the coarse and fine nature of the datasets was to use a coordinate reference system that was spheroid, equal area with reduced area distortion in equatorial regions. The system selected was Behrmann World. This is a cylindrical equal-area projection with the standard parallels between 30°N and 30°S, thereby distorting the areas of interest the least. The grid used to calculate density as well as mean area was a 100 km x 100 km fishnet grid.

3.2 Design for Esri Story Maps

Esri Story Maps are a platform designed to share information/stories/photos/data in an engaging manner. The Story Maps for this project were designed in the Story Map Series using the Side Accordion layout. The stories combine facts, photos, and web maps about the selected megafauna of Royal Bengal tigers in the Sundarban Mangrove Forest and the Proboscis monkey and Bornean orangutan of the Sunda Shelf Mangroves.

3.3 Methods for Species Richness Maps

The original method for creating the species richness maps was to clip the IUCN global datasets to the GFW 2011 mangrove dataset. This was not feasible to due to the scale differences between the datasets, in terms of data represented and in terms of records and complex geometry within the datasets (e.g. Mangrove dataset n = 1,386,714, Mammals dataset n = 42,165). Therefore, the clip method was abandoned.

The methods used to create the species richness maps from the IUCN and BoW global datasets and used the Spatial Join method in ArcMap. The steps are outlined below.

Step 1 – The datasets from the IUCN, BoW, and GFW were in the geographic coordinate system GCS_WGS_1984. These sets were projected to Behrmann (World). A fishnet grid was created at the 100 km x 100 km scale.

Step 2 - The full IUCN dataset (for mammals, amphibians, and bonefish and tarpons) and BoW database were opened in ArcMap and in the 'Properties' the 'Define Query' was set to 'PRESENCE' = 1 or 'PRESENCE'=2. These are the values for polygons where the species is Extant or Probably Extant. The Probably Extant value has been discontinued due to ambiguity; however it existed in the spatial data.

Step 3 – The 100 km x 100 km fishnet was spatially joined with each dataset. This was done using the ArcToolbox -> Analysis Tools -> Overly -> Spatial Join tool. The text fields from the datasets were removed and a new field "MeanRange" was created.

To count how many polygons were in each degree cell, the field "Presence" was set to a merge rule of 'Count'. A new field name "MeanRange" was created as a double with precision 6 and range 20. It was linked to the IUCN/BoW dataset.shape_Area through the 'Add Input Field' right click menu option. Once the field was linked, the merge rule was set to "Mean". Once the spatial join was complete, a new field called 'Mangroves' was added to the new dataset.

Step 4 – Select the polygons that intersect with the Global Forest Watch (GFW) 2011 mangrove dataset. The new spatially joined dataset was the 'Target' and the GFW 2011 mangroves were the source for the 'Selection by Location' function. Once the selection was complete, the records that were selected had the 'Mangrove' field populated with 'mangrove cell'.

Step 5 – The new joined shapefile was then spatially joined with a Country shapefile to get the name of the countries. The 'Target' was the IUCN/GFW shapefile and the 'Join Feature' was the country shapefile.

Step 6 – To create the species richness maps, under 'Properties' of the newly created file the 'Define Query' was set to 'Mangrove' <> '' to select the mangrove cells. The 'Symbology' was set to 'Quantities' -> 'Graduated colors'. The Field Value was 'count' or 'presence'. The classification was five classes modified from 'Natural Breaks (Jenks)'. Based on the number breaks and data distribution from 'Natural Breaks', the classification was modified to an ease-of –reading pattern (e.g. Natural Breaks of 0-71, 72 – 114, 115 – 156 was modified to 0-50, 51-100, 101 – 150).

The attribute table from all result sets was exported to Excel. In Excel the species count was plotted against the species range mean area for each 100 km x 100 km grid square.

3.4 Methods for Esri Story Map Webmaps

The Story Maps were designed rather as a platform to highlight specific megafanuna than a showcase for a map. From the provided text and photo links from MAP, the layout and web map were designed to capture the viewer's attention and draw the viewer through the story to highlight the specific mangrove forests. The web maps created used subsets of the mangrove species richness data. The Royal Bengal tiger Story Map has a web map that shows the historic range and present tiger range. The IUCN data is not divided into the subspecies of panther tigris tigris. To illustrate the present range using the IUCN data, range maps from the websites of World Wildlife Fund, Wikipedia, and Tiger Population were compared and matching polygons were selected from the IUCN mammal dataset. The web map for the Proboscis monkey and Bornean orangutan was created by clipping the mammal species richness data for Boreno.

4 – Results

The IUCN mammals, amphibian, and bonefish and tarpon dataset for 'PRESENT' = 1 or 2 results are Table 2 – 4. The BoW dataset (Table 5) was not divided the same as the IUCN and therefore does not have the unique species numbers. These are the values from the IUCN/BoW datasets to understand the number of records and unique species represented in this study. Figures 2 – 6 show the species count plotted against the species range. These values are a count of polygons per 100 km x 100 km grid cell (n = 51,156). Figures 2 –5 plot both mangrove cell-specific and non-mangrove cell species together and Figure 6 plots the mangrove cell-specific species together (the bird data is excluded to scale in species range). The resultant maps highlighting the mangrove species richness are in Appendix A.

Table 2: IUCN Red List 2016 Mammals dataset

IUCN Red List 2016 Code	Records	Unique Mammals
Critically Endangered 'CR'	515	191
Endangered 'EN'	2,002	478
Vulnerable 'VU'	5,054	509
Near Threatened 'NT'	1,935	323
Least Concern 'LC'	29,966	3,109
Data Deficient 'DD'	1,601	772
Totals	**41,073**	**5,382**

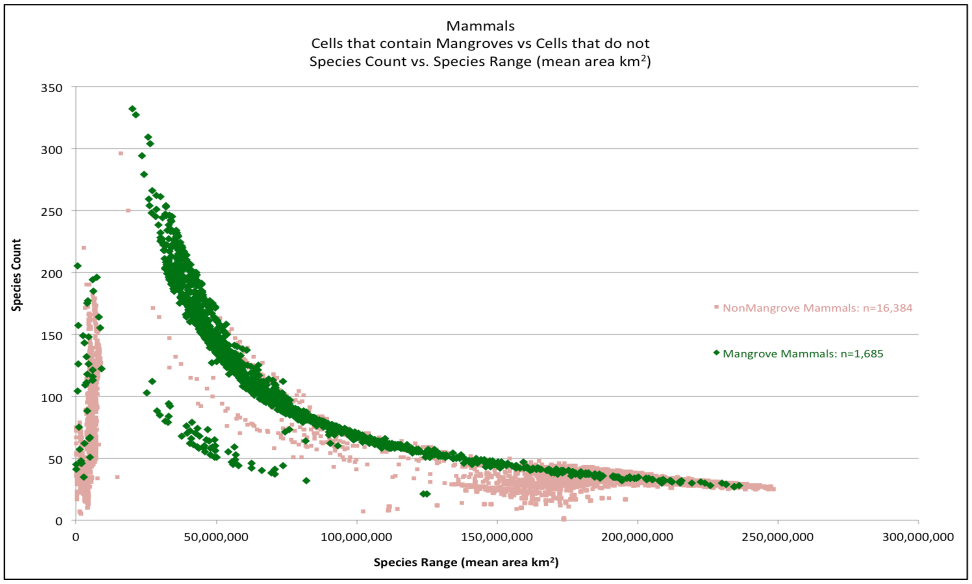

Figure 2 - The mammal species count vs species range for cells that contain mangrove forests vs. cells that do not

Table 3: IUCN Red List 2016 Amphibian dataset

IUCN Red List 2016 Code	Records	Unique Amphibians
Critically Endangered 'CR'	711	515
Endangered 'EN'	1,502	806
Vulnerable 'VU'	1,487	652
Near Threatened 'NT'	1,109	398
Least Concern 'LC'	12,456	2,420
Data Deficient 'DD'	2,134	1,523
Totals	**19,399**	**5,799**

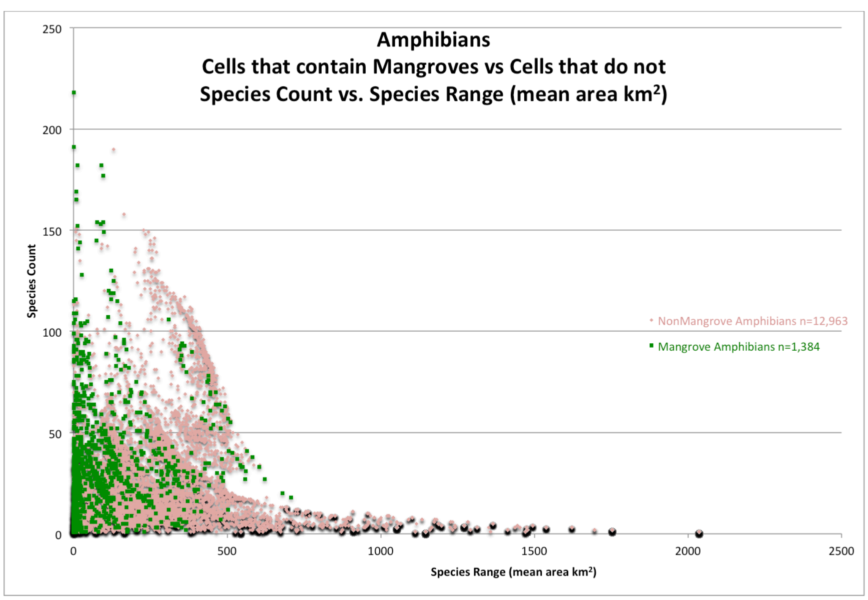

Figure 3 - The amphibian species count vs species range for cells that contain mangrove forests vs. cells that do not.

Table 4: IUCN Red List 2016 Bonefish and Tarpons dataset

IUCN Red List 2016 Code	Records	Unique Fish
Critically Endangered 'CR'	0	0
Endangered 'EN'	0	0
Vulnerable 'VU'	2	2
Near Threatened 'NT'	1	1
Least Concern 'LC'	3	3
Data Deficient 'DD'	12	12
Totals	**18**	**18**

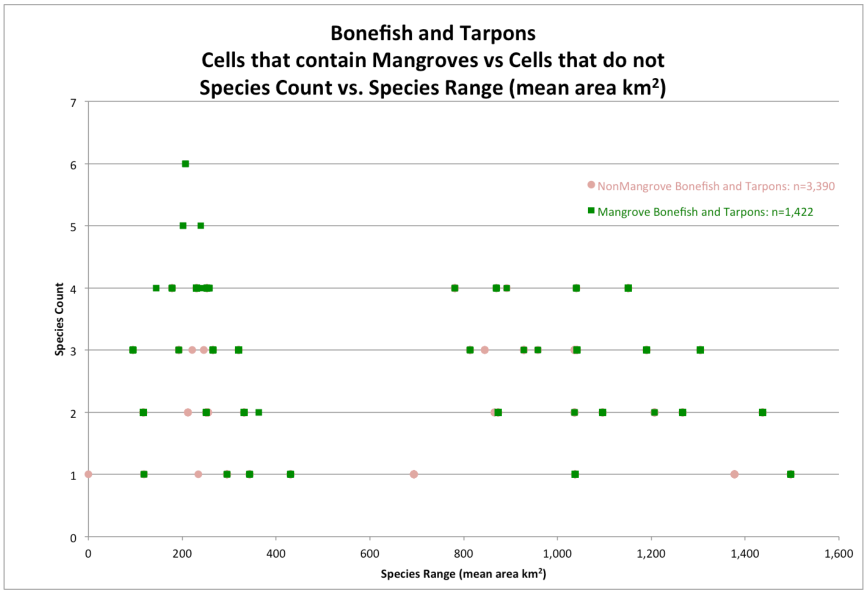

Figure 4 - The bonefish and tarpon species count vs species range for cells that contain mangrove forests vs. cells that do not

Table 5: Birds of the World All Species dataset

IUCN Red List 2016 Code	Records
Critically Endangered 'CR'	199
Endangered 'EN'	417
Vulnerable 'VU'	741
Near Threatened 'NT'	971
Least Concern 'LC'	7,872
Data Deficient 'DD'	61
Totals	**10,261**

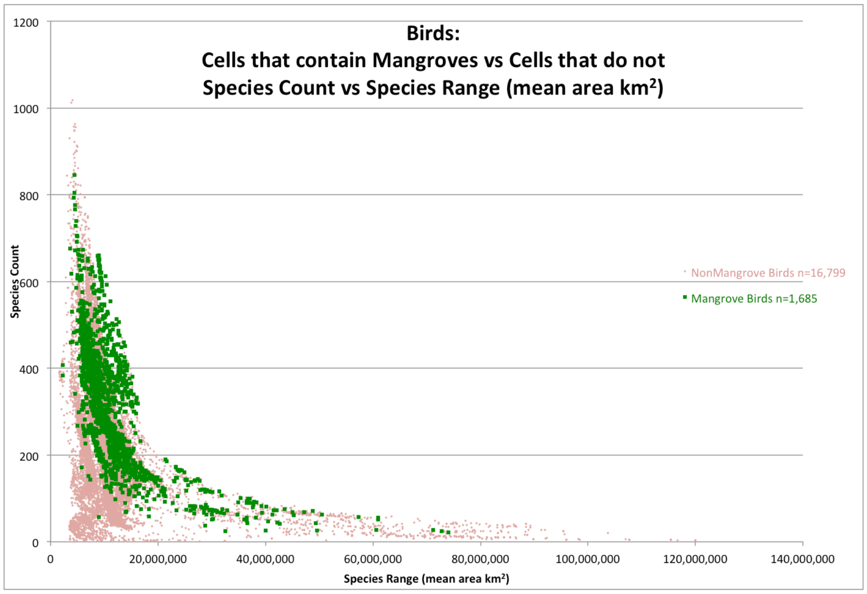

Figure 5 – The bird species count vs species range for cells that contain mangrove forests vs. cells that do not.

While the method of clipping the full species datasets with the GFW mangrove datasets was abandoned, four codes within the full mammal dataset were clipped and Table 6 shows the results of unique species whose range is within the boundaries of the mangrove forests.

Table 6: Number of unique mammal ranges that are within the GFW 2011 Mangrove area

Critically Endangered 'Cr'	Endangered 'EN'	Vulnerable 'VU'	Near Threatened 'NT'
65 out of 191	177 out of 478	308 out of 509	200 out of 323

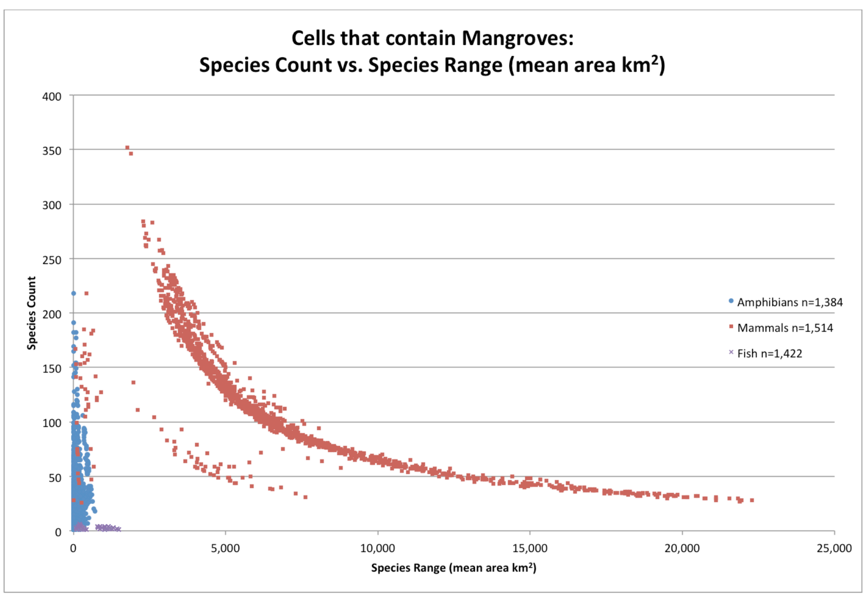

Figure 6 - Species count vs species range for only the cells that contain mangrove forests.

The mammals, amphibians, and bird datasets present interesting patterns when the species count vs. species range mean area is plotted. The bonefish and tarpon dataset is the smallest with the least species variation and least habitat range. It is not unexpected that the pattern is simplistic. None of the numerical values from this study have been statistically evaluated. The patterns show a high species count per species range in the grid cells that also contain mangrove forests. It is outside the scope of this study to interpret the spatial distribution patterns.

The results of the Esri Story Map are located in Appendix B.

5 – Discussion

Species richness maps are often used to identify hotspots and areas of conservation concern and planning. When using global data to investigate small areas, caution needs to be exercised. Modern computer programs can allow for the overstretching of data scales that researchers must be cautious to avoid. The mangroves of the world occupy a very small area (examples in Table 1) compared to the currently available species range polygons. The spatial resolution of the mangroves data is much finer than the detail of the IUCN Red List and BoW data (Figure 7)

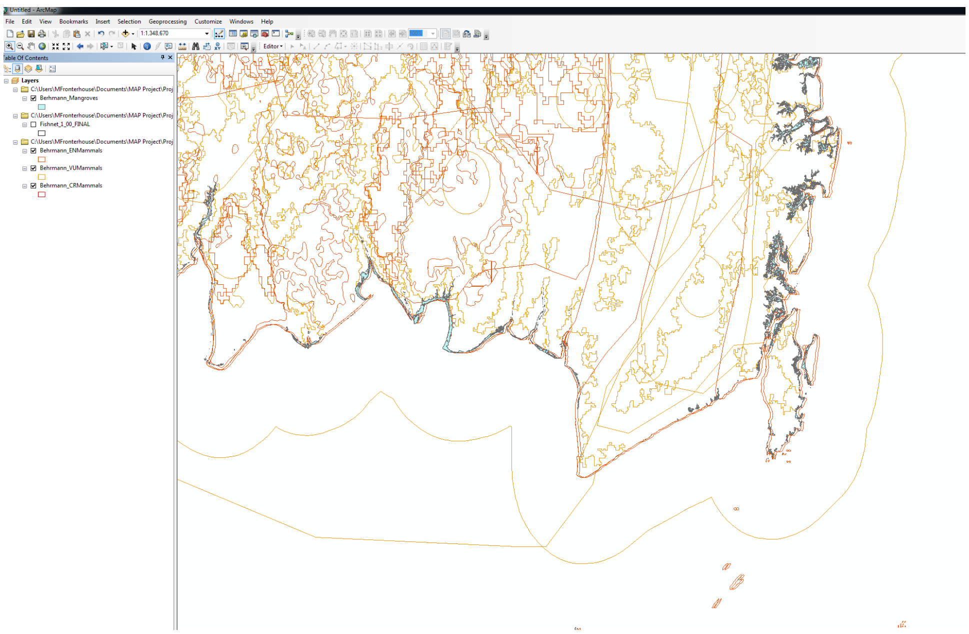

Figure 7 – Comparison of scale and detail between the IUCN Red List 2016 and GFW 2011 data. View of southeastern coast of Borneo. IUCN Red List data is from divided shapefiles based on 'Code'.

This mismatch prohibits the creation of mangrove specific species richness maps. The finest scale that is appropriate for any study between these two datasets is the 100 km x 100 km (or 1-degree) grid cell size (Figure 8).

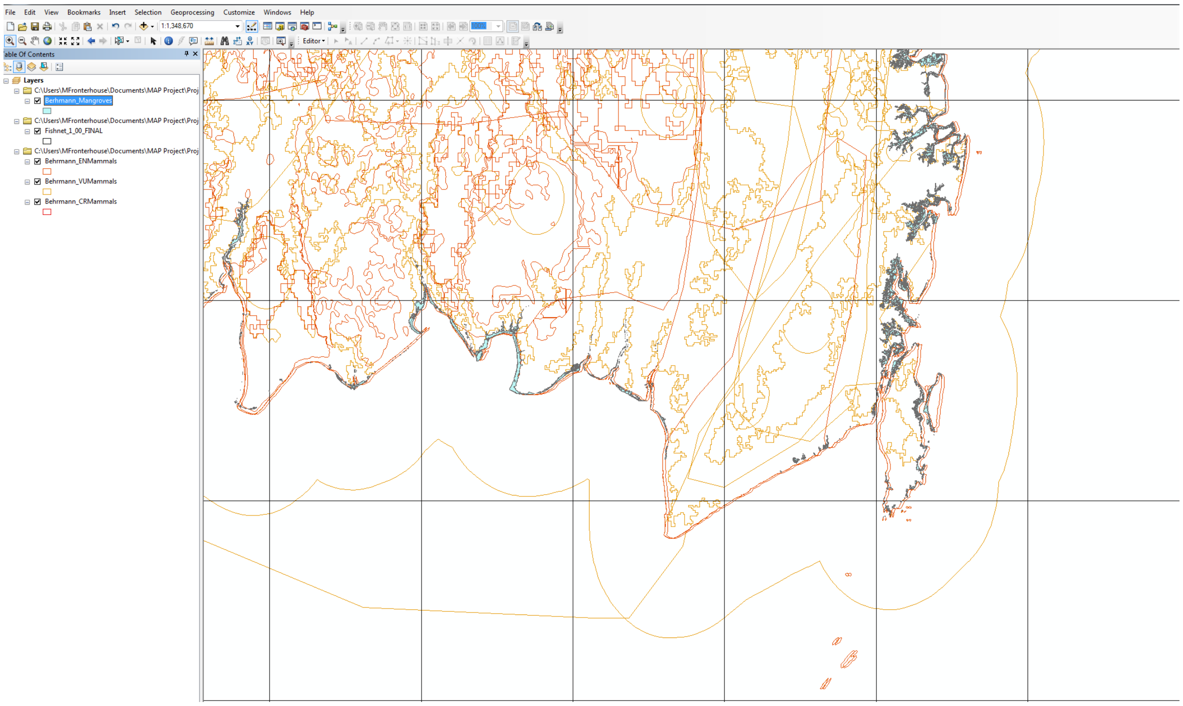

Figure 8 - Finest, reasonable scale for all datasets to be used together. View of southeastern coast of Borneo. . IUCN Red List data is from divided shapefiles based on 'Code'.

The resultant maps (Appendix A) produced from these datasets provide an important visual representation of the species richness of areas that contain mangrove forests. The species count vs. species range plots may also show insightful patterns. Both highlight the vast biodiversity that is supported in small areas and the need to preserve and conserve these areas for the health and well being of all.

6 – Business Case and Implementation Plan

To further the analysis that is started in this project, the IUCN datasets that highlight mangrove forests should be combined and compared to more refined range maps and species studies. Following a method similar to the species distribution model used by Sangermano (2009) for birds of South American, the data used for the mangrove dataset can be refined and more accurate range data can be explored. This study did not exam the numerical results through any statistically analysis or presence-absence matrices such as Soberón and Ceballos (2011). Without further refining of the underlying range polygons, it is advised the Mangrove Action Project use the maps generated through this exercise for guidance and illustrative purposes only in their CBEMR program.

To move the Species Richness Maps from static files to Esri ArcOnline, the species-specific shapefiles will need to be reduced in size and features by splitting along 'id_no' or a similar unique value. The total storage allotted for Esri ArcOnline for all applications is 2GB and the site will only upload shapefiles with less than 1,000 features.

The Esri Story Maps that have been created under the MAP Esri ArcOnline account. They can be easily expanded as new information is gathered.

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