

Effects of Rising Sea Levels on Coral Reef and Mangrove Distributions along the Great Barrier Reef in Australia

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Introduction

Sea levels are expected to continue rising throughout this century and beyond due to the melting of polar ice caps, as global temperatures continue to increase. Rising sea levels present challenges for both terrestrial and marine organisms. Coral reefs and mangroves, in particular, are quite vulnerable to the effects of climate change, as rising temperatures can lead to coral bleaching and elevated sea levels can potentially submerge or 'drown' reefs (light becomes too limited) and mangroves (submersion of canopy). At the same time, however, inundation of land through sea level rise can create new potential habitat for the expansion of reefs and mangroves.

Problem and Questions

This project seeks to examine the extent of coral reef and mangrove area that will be lost under projected sea levels by the years 2100 and 2500 within the Great Barrier Reef (GBR) and along the coast of Australia, as well as the area of new potential habitat that may be gained under these scenarios. Areas that are particularly under threat due to sea level change will also be identified. The following questions will be addressed:

- 1.) What is the spatial extent of coral reef area along the GBR that will be 'drowned' by the years 2100 and 2500?
- 2.) What is the spatial extent of mangrove area along the Australian coastline that will be 'drowned' by the years 2100 and 2500?
- 3.) What is the spatial extent of land area that will be below sea level by the years 2100 and 2500, and thus available for colonization by corals?
- 4.) Are there any regions of the GBR that will be more affected by rising sea levels than others?

Data Collection

1.) Data on global mangrove distributions was downloaded from:

<https://databasin.org/datasets/d214245ab4554bc1a1e7e7d9b45b9329>

The data format was a shapefile of polygons representing mangrove habitat. Data was collected with Global Land Survey (GLS) data and landsat archive, provided by the US Geological Survey.

2.) Data on coral reef distributions was downloaded from:

<https://databasin.org/datasets/b983863c0a1a41e8839383b40ade437d>

The data is based on 500 m resolution gridded data. The data format was a shapefile of polygons.

3.) Bathymetric data for the GBR was downloaded from:

<http://deepreef.org/bathymetry/65-3dgb- bathy.html>

The data format is 100 m resolution ESRI raster. Data was generated by Project 3DGBR.

4.) Elevation data for Australia was downloaded from:

http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_72760

The elevation data is from the SRTM-derived 3 Second Elevation Digital Models Version 1.0.

5.) The Australia basemap outline was downloaded from:

<http://www.gadm.org/download>

The data format is a shapefile of polygons.

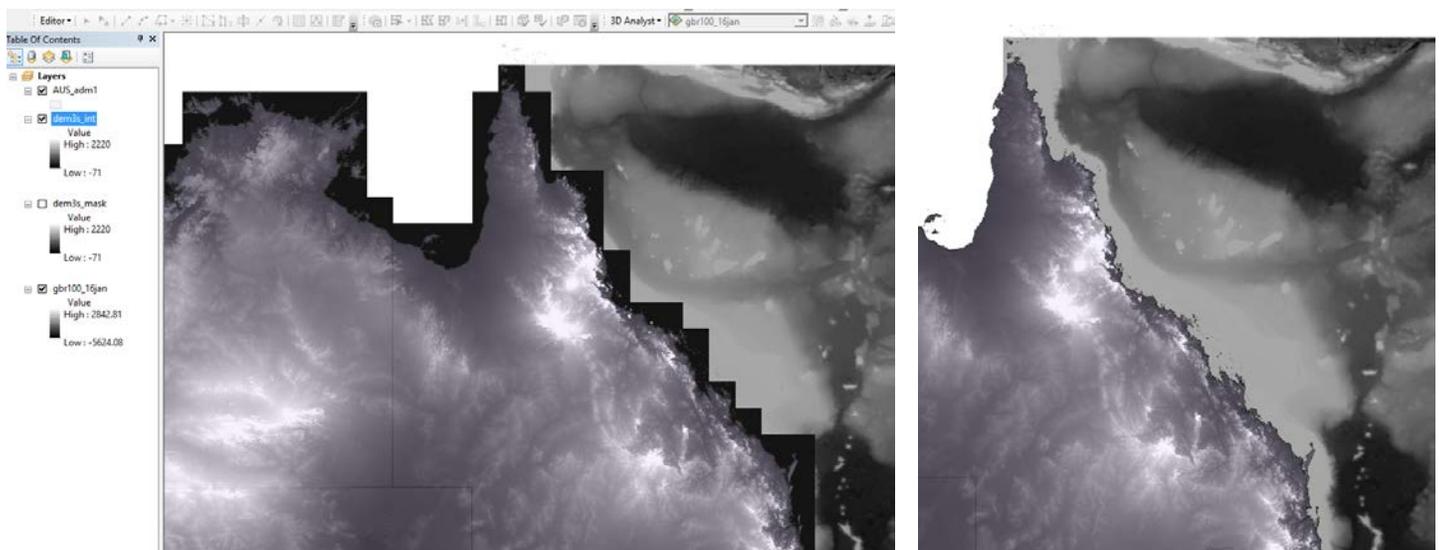
Data Preprocessing

All data could be loaded into ArcMap in the format in which it was downloaded.

Methods: ArcGIS Processing

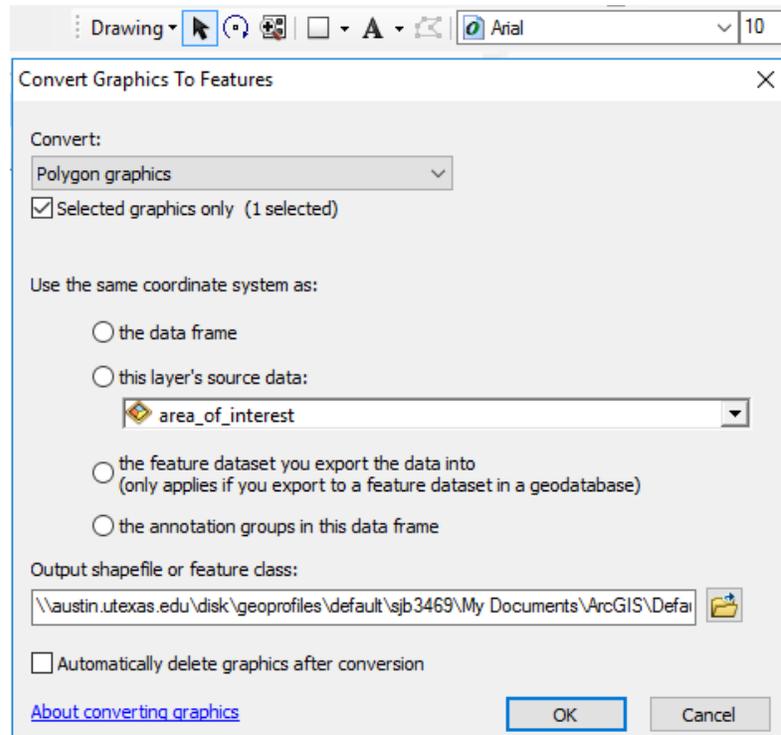
1. Download and save all data to folder on S drive or flash drive
2. Add all files to ArcMap document and examine the coordinate systems
 - a. Nearly all the files use GCS WGS 1984, except for the coral reef shapefile
3. Project the reef shapefile (currently using WGS_1984_Web_Mercator_Auxiliary_Sphere) to GCS WGS 1984
 - a. Step 1: Under Data Management tools, go to Transformations and Projections and open the **Project** tool
 - b. Step 2: Input the reef shapefile and name a new projected reef shapefile
 - c. Step 3: Select the appropriate coordinate system (GCS WGS 1984)
 - d. Step 4: Once the new file has been created, load into your ArcMap document
4. The DEM data for Australia extends beyond the boundaries of the Australia shapefile polygon and contains no data. These excess areas need to be removed.
 - a. Step 1: Turn on the spatial analyst extension under Customize, Extensions
 - b. Step 2: Open the **Extract by Mask** tool
 - c. Step 3: Input the DEM raster and set the mask to the Australia shapefile polygon
 - d. Step 4: Name an output raster, such as DEM_mask

Figure 1: Left: Before using Extract by Mask and Right: After using Extract by Mask



5. Define the area of interest as the Great Barrier Reef and surrounding Australian coastline, since many of these data files extend beyond this area
 - a. Step 1: Within the Drawing toolbar, select the rectangle and draw the area around the GBR and northernmost extent of Australia
 - b. Step 2: Select the shape, click on 'Drawing' and select **Convert Graphics to Features** and name the output shapefile feature class as Area_of_interest

Figure 2: Dialog box for Convert Graphics to Features in order to make area of interest polygon



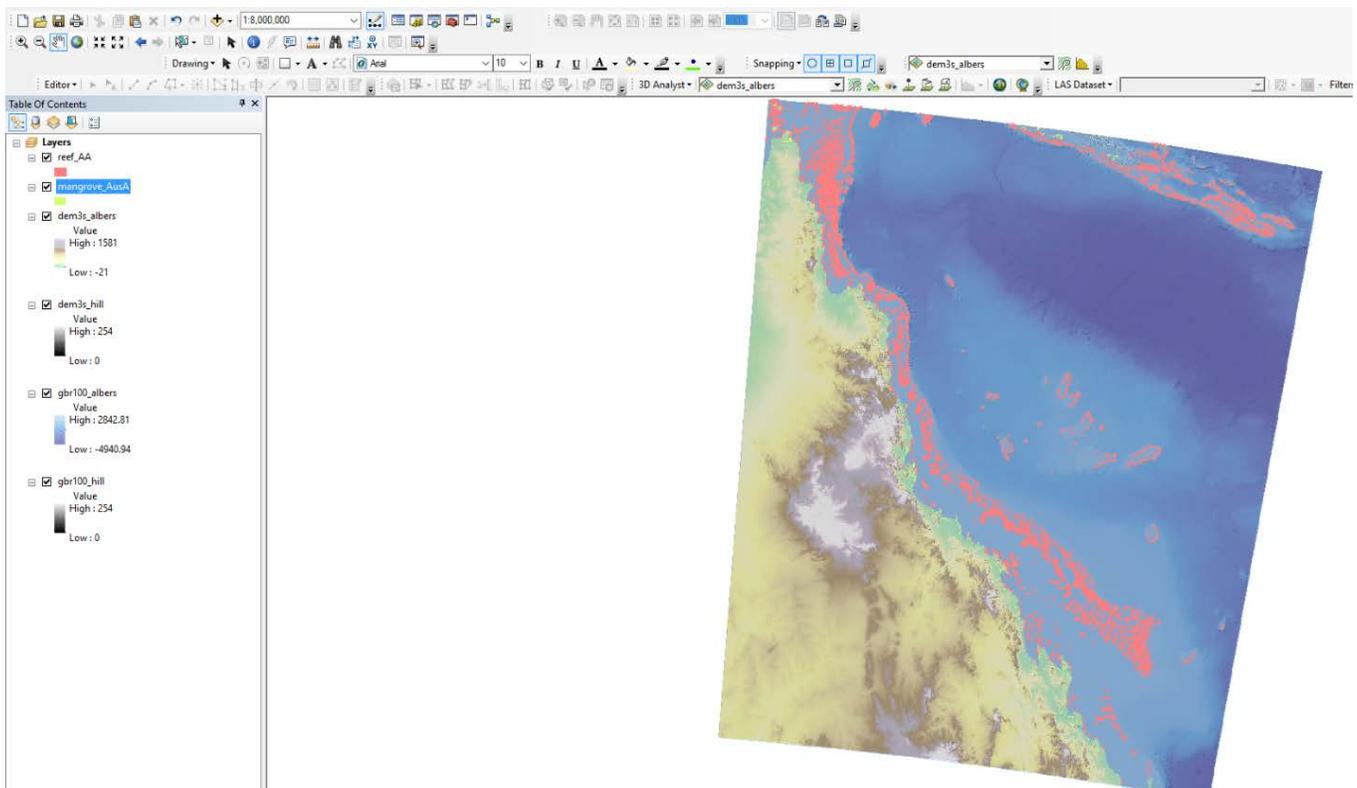
- c. Step 3: Search for the **Clip tool (Data Management)** to clip the DEM raster based on the spatial extent of the new area of interest polygon
- d. Step 4: Input the DEM data and set the output extent as Area_of_interest and click OK
- e. Step 5: Examine the new clipped raster, and repeat for the bathymetric data
- f. Step 6: In order to clip the reef, mangrove, and Australian basemap shapefiles, open up the Clip tool (Analysis) tool
- g. Step 7: Input the feature class of interest (reef, mangrove, basemap, or population) and set Clip Features to the Area of interest shapefile. Repeat for all feature classes.

Figure 3: Clip tool showing input and clipping feature



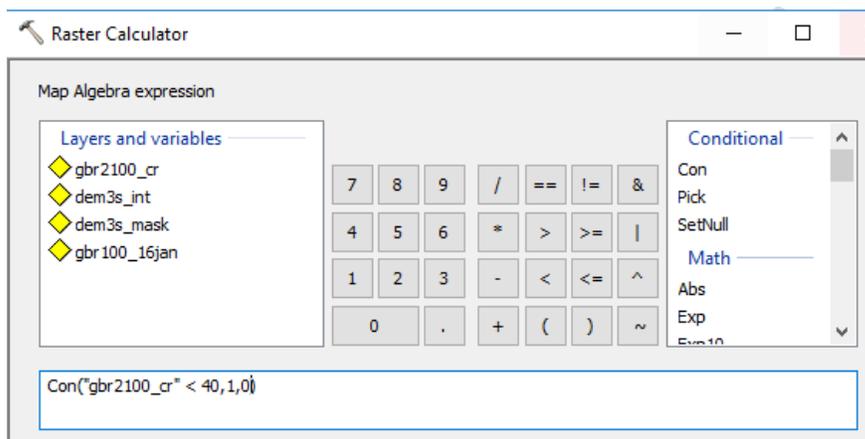
6. In order to determine the spatial extent of sea level rise, all the files need to be in a projected coordinate system in real world units, such as meters. Because the GBR encompasses two MGA zones within Australia, the projected coordinate system GDA 1994 Australia Albers is a good option.
 - a. Step 1: For the shapefiles (mangrove and coral reef), open the **Project tool** within Data Management tools. Input the shapefile of interest and output file name, and select GDA 1994 Australia Albers for the projected coordinate system.
 - b. Step 2: For the raster datasets (bathymetry and elevation), open the **Project Raster** tool. Follow the same procedure as in Step 1.
7. To make the map more visually appealing, change the symbology of the mangrove and coral reef polygons, such that mangroves are green and coral reefs are coral colored.
 - a. Step 1: Right click the layer of interest in the table of contents and select the symbology tab. Change the colors as indicated.
8. Create a hillshade for the bathymetric and elevation data.
 - a. Step 1: Open the **hillshade** tool (spatial analyst) and set the input and output rasters.
 - b. Step 2: Put the hillshade raster under the original raster in the TOC, and make the original raster 50% transparent and colored.
 - c. The current map should look like that pictured below.

Figure 4: ArcMap screenshot of coral reef and mangrove areas; elevation raster and bathymetry raster with hillshading



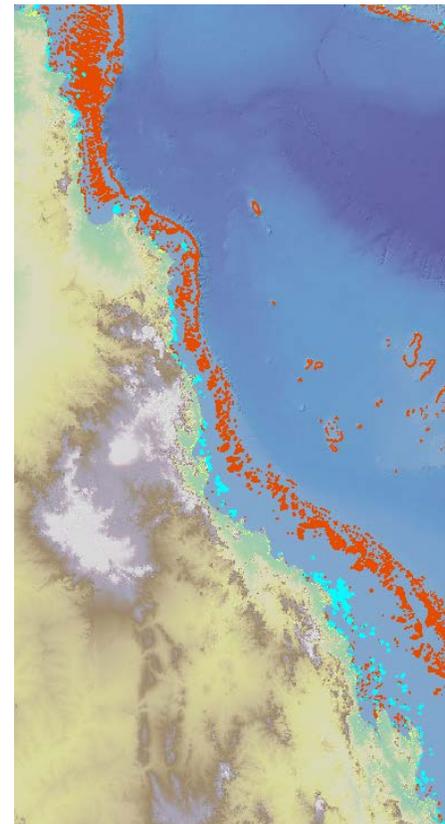
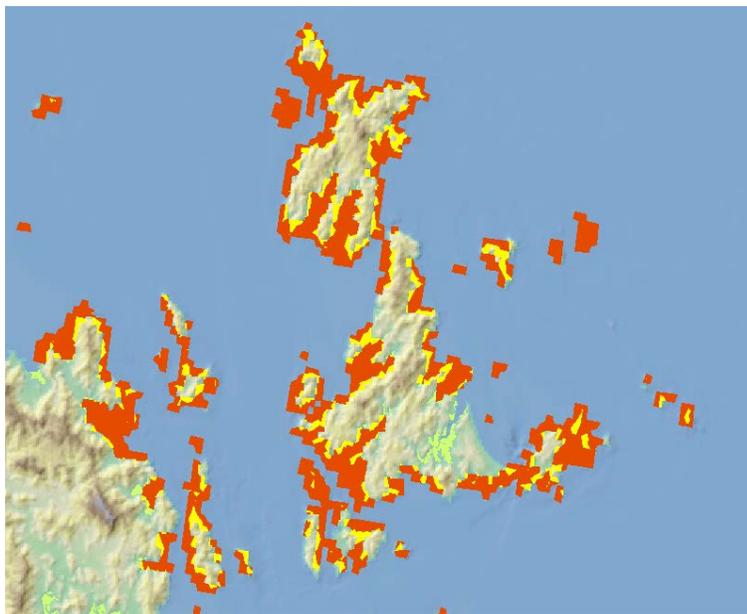
9. Determine the total extant area of coral reef along the GBR and mangrove area
 - a. Step 1: For the coral reef data, right click on the layer of interest, and select Open Attribute Table
 - b. Step 2: Under table options, select Add Field... and select type as float
 - c. Step 3: Right click on the new field in the attribute table and select **Calculate Geometry**
 - d. Step 4: Set the property to Area and units as square kilometers
 - e. Step 5: The mangrove data already has the area calculated for each polygon. To get the total area, open the attribute table, selected AREA_KM2, right click and select Statistics. The sum will be provided in the output.
 - f. Output: The total coral reef area is **40,099 km²**, and the total mangrove area is **3,203 km²**.
10. Determine the total current coral reef habitat that will be lost through sea level rise (i.e. drowning) based on estimates for the years **2100 (1 meter)** and **2500 (15 meters)**. Show the visual extent of reef area lost.
 - a. Step 1: For the coral reef data, add 1 meter to the bathymetry raster using the **raster calculator** tool under spatial analyst, and name the new raster with Name_2100. Do the same for the projected sea level rise for the year 2500 (15 m).
 - b. Step 2: Extract the new bathymetric rasters using the coral reef polygons as a mask. The tool to do this is **Extract by Mask**. Do the same for the original bathymetric raster to compare the results.
 - c. Step 3: The most prolific shallow water tropical corals grow best at depths above 40 meters. To determine the potential area of reef lost due to sea rise, select only the raster cells (from those that have been extracted from the reef polygons) which are above a depth of 40 meters. Again, use the **raster calculator**, but set up a conditional statement to classify cells as either above (1) or below (0) 40 m. The following statement can be used `Con("gbr2100_CR" < 40, 1, 0)`. (**Do this for both the original and year 2100 and year 2500 bathymetric rasters to compare the total area above/below 40 m at present and in the future.)

Figure 5: Example of raster calculator conditional statement



- d. Convert the raster to a polygon in order to calculate area. (*I got numbers that were incorrect if I tried to calculate area based on just the number of raster cells and cell size for some reason). Use the **Raster to Polygon** tool to do this.
- e. Open the attribute table and choose Select by Attribute to choose entries that are classified as 0 (below 40m) or 1 (above 40m).
- f. Step 4: Calculate the area of the polygons above and below 40m before and after 1 m of sea rise by selecting Statistics.
 - i. Before sea rise: 39,713 km² above 40 m and **152 km² below 40 m**.
 - ii. After 1m sea rise: 39,709 km² above 40 m and **156 km² below 40m**.
- g. Step 5: Calculate the area of the raster cells above and below 40 m after 15 m of sea rise
 - i. After 15 m of sea rise: 39,621 km² above 40 m and **243 km² below 40 m**.
 - ii. Observation: most of the 'drowned' reef habitat is located inshore or near land, whereas offshore reefs are shallower.

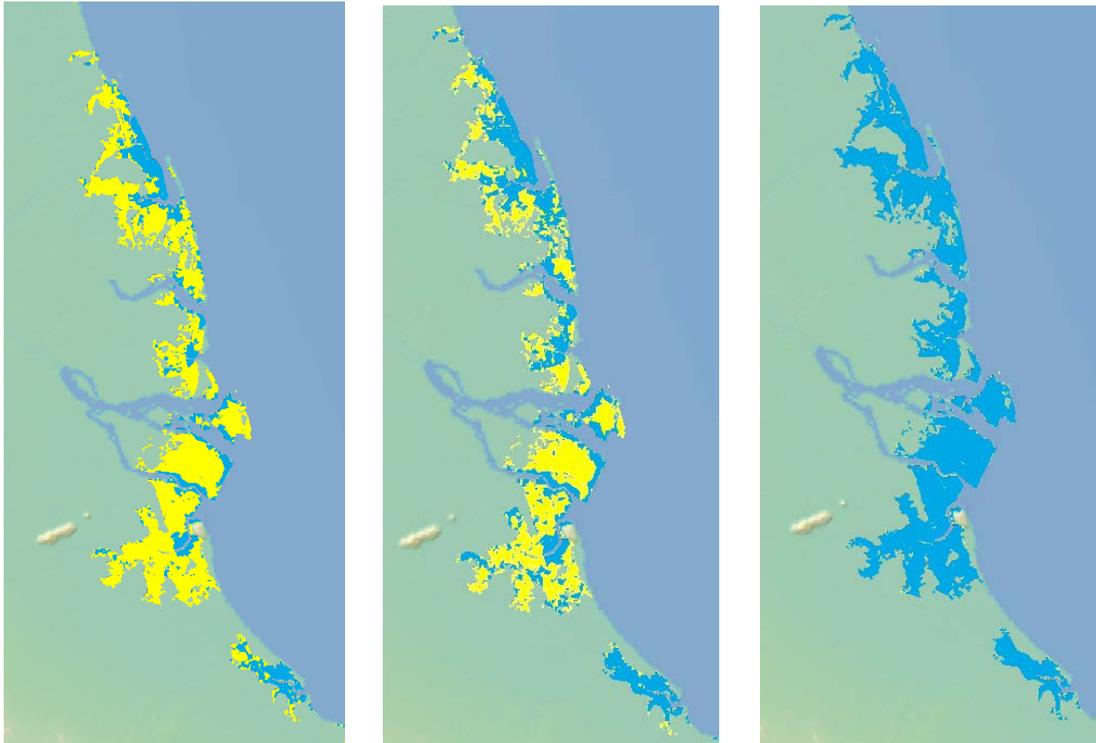
Figure 6: Left: Reef areas above 40 m are indicated in red and below in yellow for the year 2500. Right: Reef areas below 40 m are indicated in blue and above 40 m are indicated in red for sea level rise projections for the year 2500.



11. Calculate the area of mangrove that will be underwater after 1 m and 15 m of sea level rise. Show a visual of mangrove area underwater.
 - a. Step 1: Use the **Extract by Mask** tool to retain raster cells that overlap with the mangrove polygons.

- b. Step 2: Subtract either 1 m from the new elevation raster using the **raster calculator**. Repeat for 15 m.
- c. Step 3: Set up a conditional statement to generate a binary raster, where 0 indicates below sea level and 1 indicates above sea level. This statement should look something like: `con("dem3s_2100">0, 1, 0)`
- d. Step 4: convert the raster to a polygon as outlined above, and determine the area above and below sea level.
 - i. Before sea rise: 1506 km² above sea level and **975 km² below sea level**.
 - ii. After 1 m sea rise: 1236 km² above sea level and **1245 km² below sea level**.
 - iii. After 15 m sea rise: 9.49 km² above sea level and **2471 km² below sea level**.

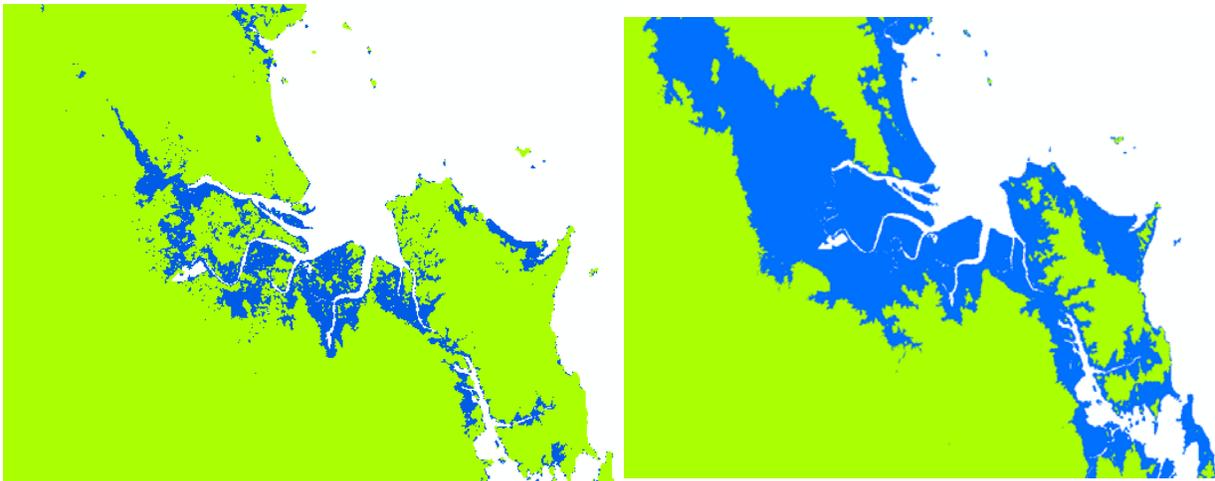
Figure 7: From left to right: Section of the Australian coast showing Present, 2100, and 2500 projected mangrove areas underwater (blue) or above sea level (yellow).



- 12.** Calculate the area of land that will be underwater after 1 m and 15 m of sea level rise. The area underwater represents new potential reef habitat.
- a. Step 1: Subtract 1m from the elevation raster using the **raster calculator**. Repeat for 15 m.

- b. Step 2: Set up a conditional statement to generate a binary raster, where 0 indicates below sea level and 1 indicates above sea level. This statement should look something like: `con("dem3s_curr">0, 1, 0)`
- c. Step 3: convert the raster to a polygon as outlined above, and determine the area above and below sea level.
 - i. After 1 m sea rise: 784,946 km² above sea level and **2,577 km² below sea level**.
 - ii. After 15 m sea rise: 768,097 km² above sea level and **19,426 km² below sea level**.

Figure 8: Portion of the Australian coast near the south. Green indicates land above sea level and blue indicates land below sea level after 1 m of sea level rise (left) or 15 m of sea level rise (right).



- 13.** Generate three maps showing current and projected (2100 and 2500) mangrove, and coral distributions, with areas above and below the limits for growth distinguished with different colors.

Figure 9: Map of current coral reef and mangrove distribution along the GBR

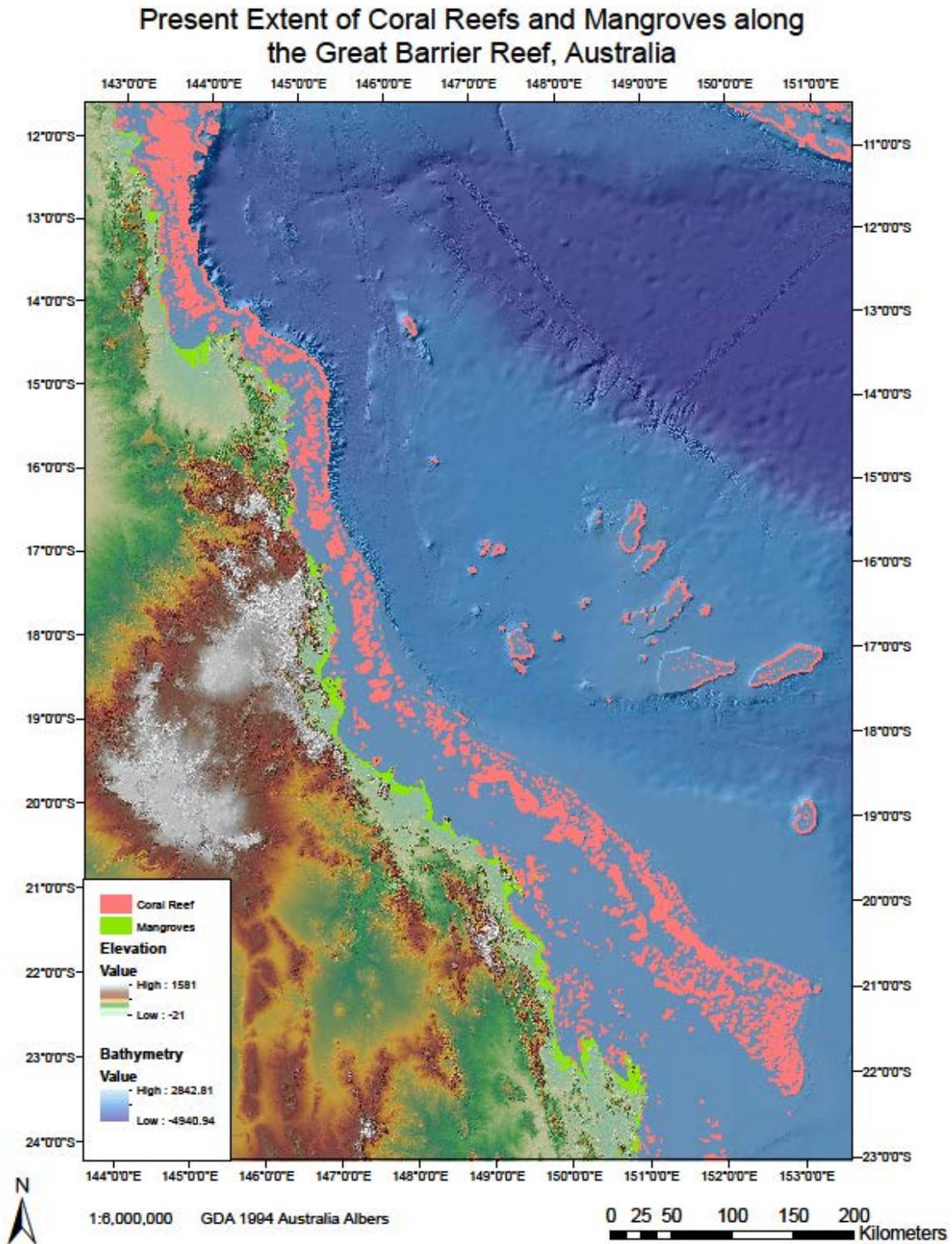


Figure 10: Map of the projected coral reef and mangrove distribution along the GBR by 2100

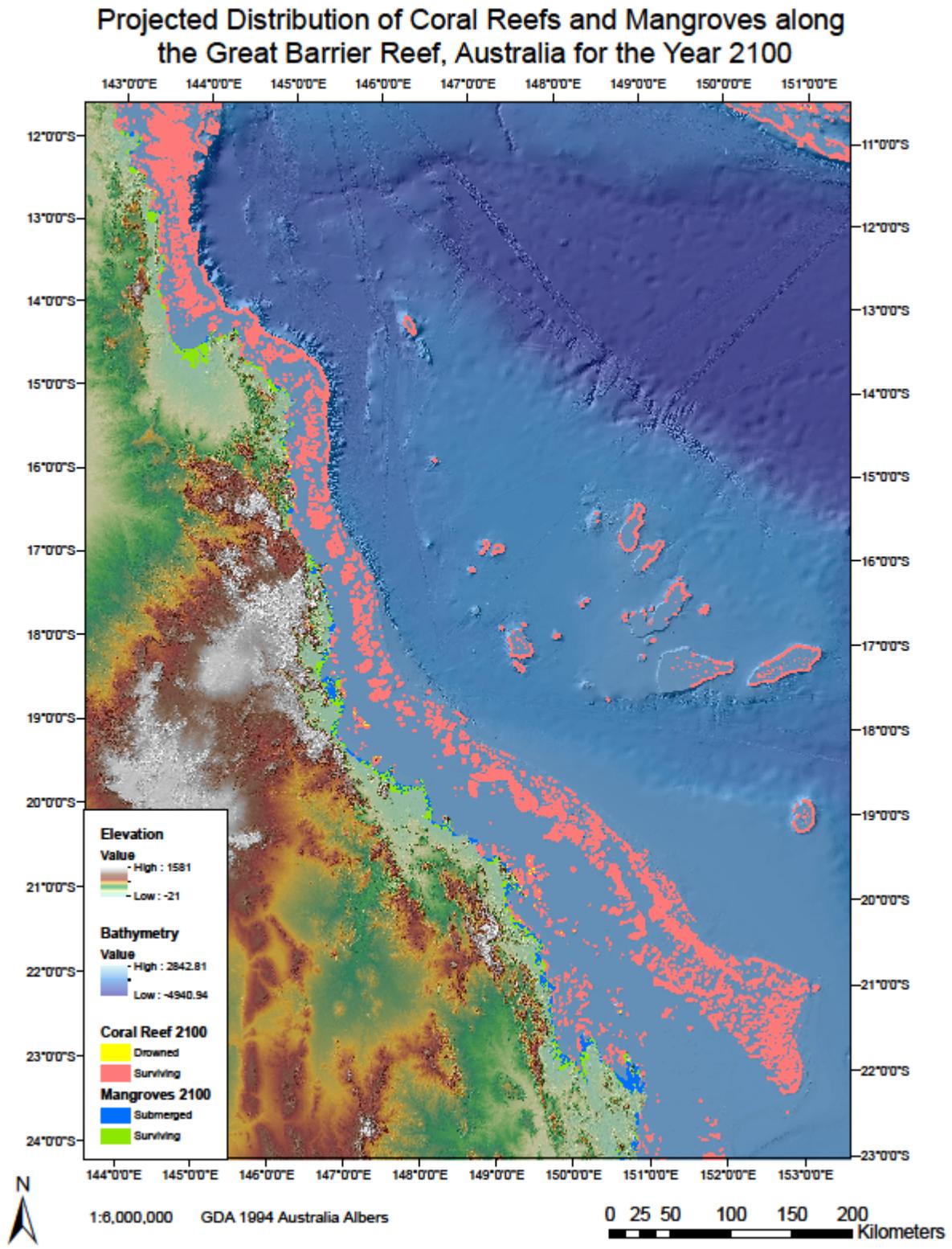


Figure 11: Map of the projected coral reef and mangrove distribution along the GBR by 2500

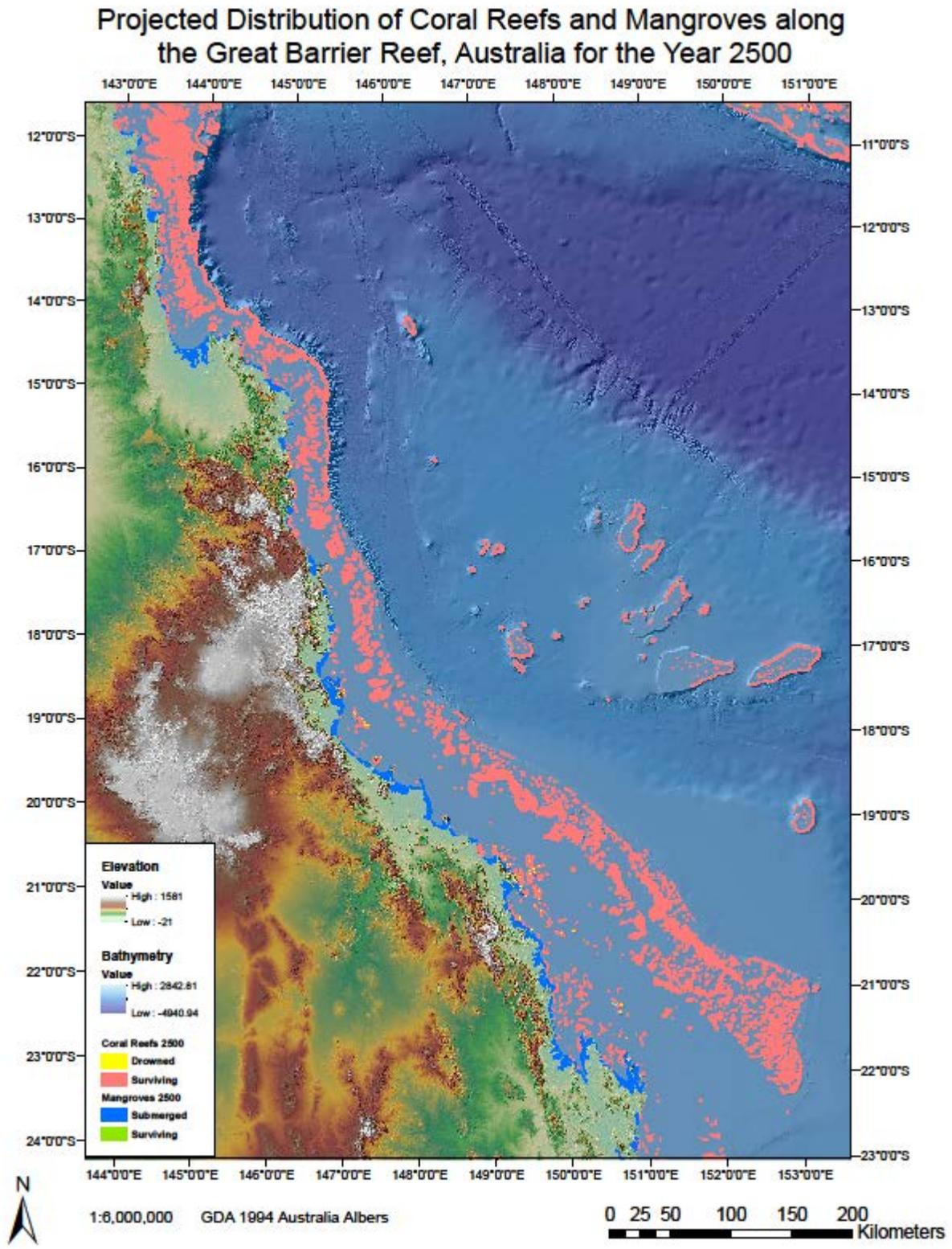


Figure 12: Map of the projected land area along the southern Australian coast by 2100

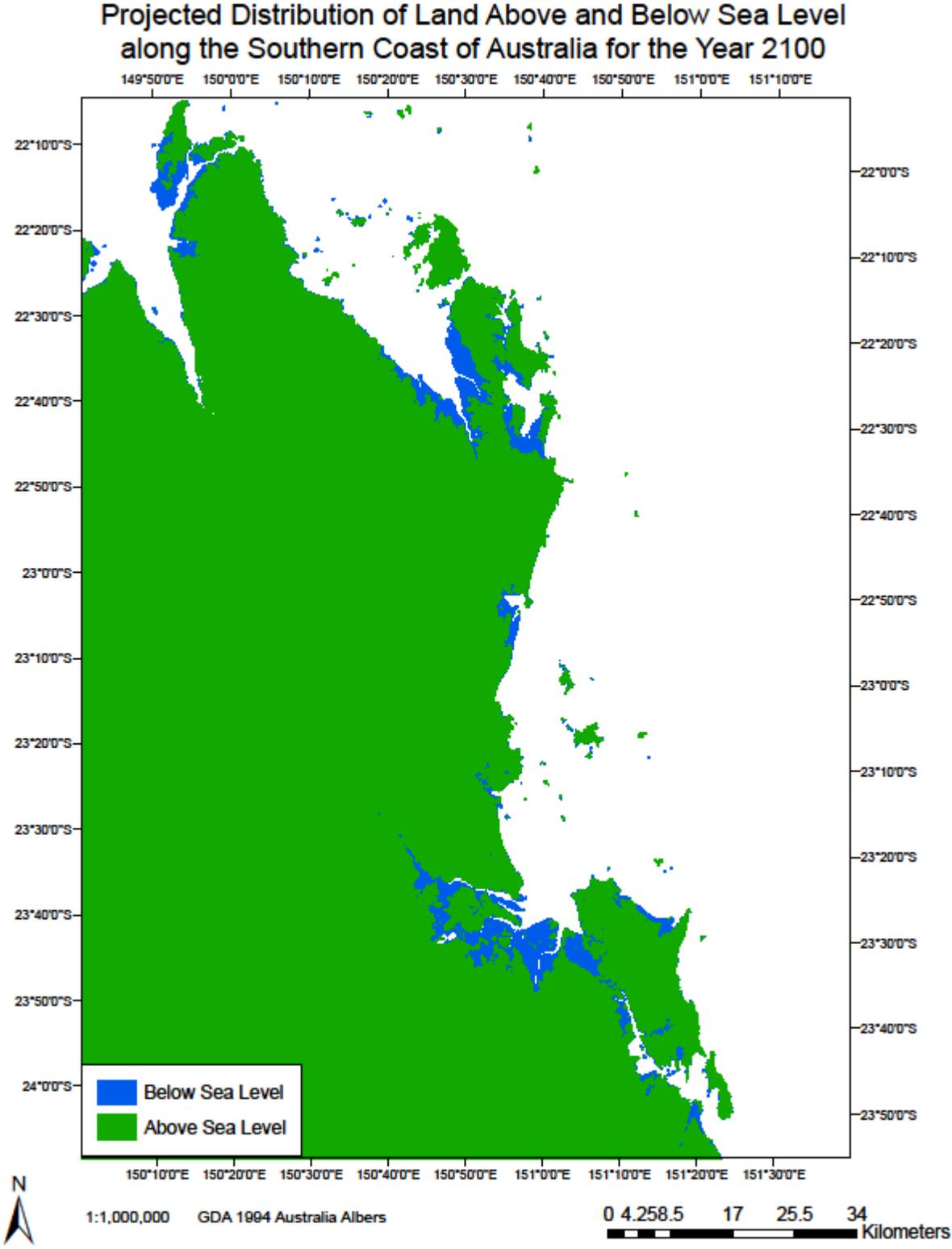
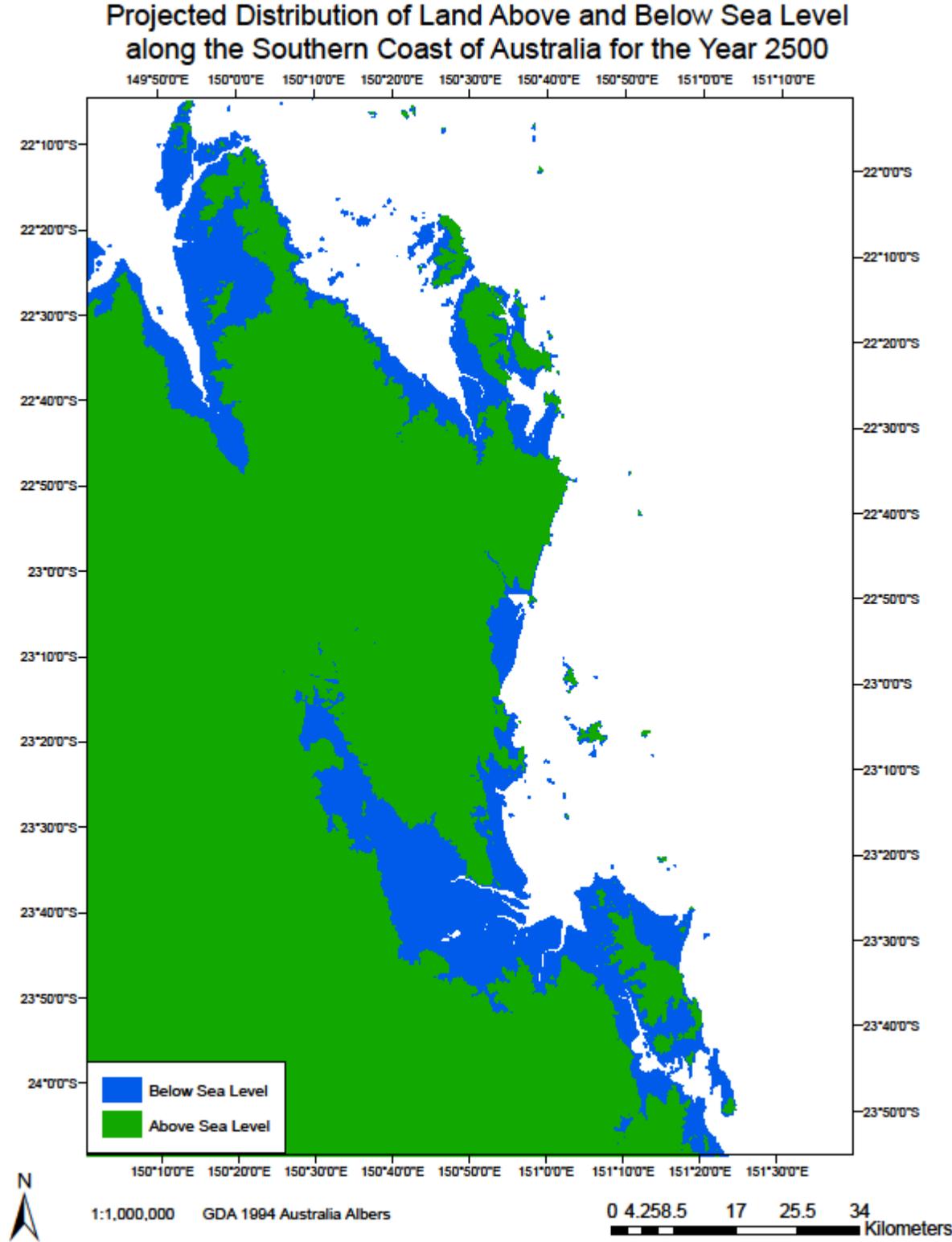


Figure 13: Map of the projected land area along the southern Australian coast by 2500



Results

Table 1: Extent of Coral Reef area along the GBR at present day, 2100, and 2500

Coral Reef	Present Day	Year 2100	Year 2500
Area above 40 m depth (km ²)	39,713	39,709	39,621
Area below 40 m depth (km ²)	152	156	243

Table 2: Extent of Mangroves along the Australian coast at present day, 2100, and 2500

Mangrove	Present Day	Year 2100	Year 2500
Area above sea level (km ²)	1,506	1,236	9.49
Area below sea level (km ²)	975	1,245	2,471

Table 3: Land area near the eastern coast of Australia expected to be below sea level by 2100 and 2500

Land Area	Year 2100	Year 2500
Area above sea level (km ²)	784,946	768,097
Area below sea level (km ²)	2,577	19,426

Discussion and Conclusions

Sea level rise should result in relatively little loss of coral reef area due to submersion beyond depths that can support the growth of tropical, reef-building corals. Only an additional 4 km² are expected to be below 40 m by the year 2100, and only an additional 91 km² by the year 2500 (Tables 1 and 2). However, the reef areas that will be most affected by rising sea levels are those that are nearshore along the southern end of the GBR (Figures 10 and 11). Still, nearshore reefs are expected to be at the front end of the expansion into new underwater habitat when coastal areas become flooded.

In contrast, much of the current mangrove habitat will be underwater by the year 2500. By the year 2100, there will be an increase from 39% to 50% of mangrove habitat that is below sea level. However, as long as mangroves are able to expand into new habitat at a pace equal or greater than that of sea level rise, then elevated sea levels should pose minimal risk to mangrove habitat.

The land area that is below sea level along the eastern coast of Australia will increase modestly by 2100 (2,577 km²) (Table 3). Furthermore, the effects of sea level rise will disproportionately affect low-lying regions on the southern end of the Australian coast (Figure 12). However, by the year 2500, the area below sea level will have increased substantially (19,426 km²) (Figure 13).

Compared to the total coral reef area at present (about 40,100 km²), the amount of land that will be submerged along the coast of Australia by the year 2500 represents a substantial increase in new potential habitat for coral reefs. An area nearly half of the current extent of the GBR will be underwater

by 2500. Although only a fraction of this underwater territory is likely suitable for coral colonization, the benefits of rising sea levels should greatly outweigh the risks to coral reefs based on the reef area that will be below sustainable depth limits.