

Mapping Mangroves in the Mesoamerican Reef Ecoregion at 10-Meter Spatial Resolution Using Google Earth Engine

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by

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INTEGRATED
RIDGE TO REEF
MANAGEMENT OF THE
MESOAMERICAN REEF
ECOREGION PROJECT



Thank you to the MAR Fund for making this project possible
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1. Objective

We mapped the mangrove ecosystems of the Mesoamerican Reef Ecoregion (MAR) for 2020 at 10-meter spatial resolution. Our map is the highest resolution map of MAR mangrove ecosystems currently available, and it is the first time that all of the MAR's mangroves have been mapped at this high resolution at the same time using one standardized methodology.

This map 1) provides a highly detailed and accurate depiction of mangrove ecosystems in the MAR as of 2020 and 2) establishes a consistent baseline for monitoring future changes to MAR mangrove ecosystems.

2. Methods

We mapped MAR mangroves by classifying 10-meter resolution Sentinel-2 imagery captured in 2020. We performed this analysis in Google Earth Engine, a free, cloud-based platform for remote sensing analysis.

The MAR includes the Caribbean coastlines of the following four countries: Belize, Guatemala, Honduras, and Mexico (Figure 1). We performed four separate classifications, one for each country's portion of the MAR. We performed each classification using the same standardized methodology.

We piloted our methodology in Belize, and we published the results of that pilot study in the journal *Applied Sciences* in May 2021 (Cissell et al., 2021). After verifying the effectiveness of our methodology through this pilot study, we extended our methodology to the Guatemala, Honduras, and Mexico portions of the MAR. Our methodology is outlined in detail below.



Figure 1. Map of the MAR study area. This figure originally appeared in Cissell et al. (2021).

2.1. Image Preprocessing

First, we created a 2020 study image for each country by assembling a composite of cloud-free Sentinel-2 Multispectral Instrument (MSI) surface reflectance data captured between January 1, 2020, and May 31, 2020. Each composite included the blue (Band 2), green (Band 3), red (Band 4), and near-infrared (Band 8) spectral bands. For each of the four spectral bands, each pixel's spectral reflectance value was the median value of the pixel across all available Sentinel-2 imagery captured between January 1, 2020, and May 31, 2020. We used the median value for each pixel to minimize the influence of potential outlier values on the classification process. We used the date range of January 1, 2020, to May 31, 2020, because the entire date range falls within the region's dry season, reducing the potential influence of seasonality on the spectral reflectance values in the study image.

Second, we created a series of exclusion masks to eliminate portions of each study image that did not contain mangroves, and therefore did not need to be included in the classification process. We used the Normalized Difference Water Index (NDWI) (McFeeters, 1996) to mask areas of open water (NDWI value > 0.0) out of each study image. We then used Shuttle Radar Topography Mission (SRTM) elevation data to mask areas of greater than or equal to 20-meter elevation out of each study image. Finally, we used the Normalized Difference Mangrove Index (NDMI) (Shi et al., 2016) to reduce the number of non-mangrove pixels in the study image. For the Belize, Guatemala, and Honduras study images, we masked out pixels with a NDMI value > 0.1 . For the majority of the Mexico study image, we also used a NDMI threshold of 0.1. However, we used a NDMI threshold of 0.4 in the Sian Ka'an Biosphere because of the unique spectral signature of the biosphere reserve's vast dwarf mangrove ecosystems.

2.2. Image Classification

We used a random forest classification to classify each masked study image into the following two land-cover classes: mangrove and non-mangrove.

For the Belize classification, we used 339 training points collected during field campaigns in 2017 and 2019. For the Guatemala, Honduras, and Mexico classifications, we used training points that we generated by interpreting 1-meter resolution Google Earth imagery. We used 388 training points for the Guatemala classification, 797 training points for the Honduras classification, and 519 training points for the Mexico classification.

For each classification, we used the training points as the training data and the blue, green, red, and near-infrared spectral bands as the inputs to the classification algorithm. The algorithm collated the blue, green, red, and near-infrared spectral reflectance values at each mangrove and non-mangrove training point to determine the unique spectral signatures of mangrove and non-mangrove features in each study image. Then the algorithm assessed every other pixel in the study image and assigned it to either the mangrove or non-mangrove land-cover class, based upon which class's spectral signature the pixel more closely matched. After the classification was complete, we masked out the non-mangrove pixels and kept the mangrove pixels to create preliminary mangrove maps for each country.

Finally, we manually refined each preliminary mangrove map. Referencing our own knowledge of the study area, 1-meter resolution Google Earth imagery, and existing national and global mangrove maps, we visually inspected each preliminary map and manually removed

misclassified pixels. The outputs of this refinement process were the finalized 2020 mangrove maps for each country.

2.3. Accuracy Assessment

We conducted a systematic accuracy assessment of each country's finalized mangrove map. We evaluated each map against reference data at a total of 2000 control points (1000 mangrove and 1000 non-mangrove) for the Belize map, 200 control points (100 mangrove and 100 non-mangrove) for the Guatemala map, 400 control points (200 mangrove and 200 non-mangrove) for the Honduras map, and 4000 control points (2000 mangrove and 2000 non-mangrove) for the Mexico map.

To create each set of mangrove control points, we randomly generated points within the areas classified as mangrove on each map. To create each set of non-mangrove control points, we randomly generated points within a 100-meter buffer of the areas classified as mangrove on each map. We used 1-meter Google Earth imagery captured in 2020 as reference data.

We calculated the overall accuracy, Kappa coefficient, mangrove commission error, and mangrove omission error for each mangrove map. Overall accuracy quantifies how accurately the classification process differentiated between mangrove and non-mangrove features. The Kappa coefficient quantifies the overall success of the classification relative to a random classification. Mangrove commission error quantifies the likelihood that a given mangrove pixel on the map is not mangrove in real life, and mangrove omission error quantifies the likelihood that a given non-mangrove pixel on the map is mangrove in real life.

Our classifications were highly accurate, with each of the four maps having an overall accuracy greater than 95% and a Kappa coefficient greater than 90%. Table 1 summarizes the accuracy statistics for each country.

Table 1. Accuracy statistics for each country

Country	Overall Accuracy (%)	Kappa Coefficient (%)	Mangrove Commission Error (%)	Mangrove Omission Error (%)
Belize	96.30	92.60	4.00	3.42
Guatemala	95.50	91.00	5.00	4.04
Honduras	96.50	93.00	4.00	3.03
Mexico	95.03	90.05	4.85	5.09

3. Results

We identified and mapped a total of 3143.04 km² of mangrove ecosystem area for the entire MAR as of 2020. Table 2 breaks down this total MAR-wide area by country. More than 75% of the MAR's total mangrove ecosystem area is located in Mexico.

Table 2. MAR mangrove area, broken down by country

Country	Mangrove Area (km ²) inside MAR in 2020
Belize	578.54
Guatemala	8.38
Honduras	101.42
Mexico	2454.70
MAR Total	3143.04

We have included static depictions of the MAR-wide map and each country's individual map in the Appendix section at the end of this report. However, many of the finer-scale details of our maps are not visible in these static depictions. Therefore, we have also submitted with this report supplemental shapefiles and KMZ layers of each country's mangrove maps. These layers can be opened in Google Earth or any other GIS program for a more detailed exploration of mangrove ecosystem extent throughout the MAR.

The 10-meter Sentinel-2 imagery allowed us to identify and map many mangrove areas that have been overlooked by previous studies that used coarser-resolution data. This was particularly true in Belize, where many of the country's mangrove ecosystems are located on cayes that are too small to be captured by coarser-resolution satellite imagery like Landsat (Figure 2).

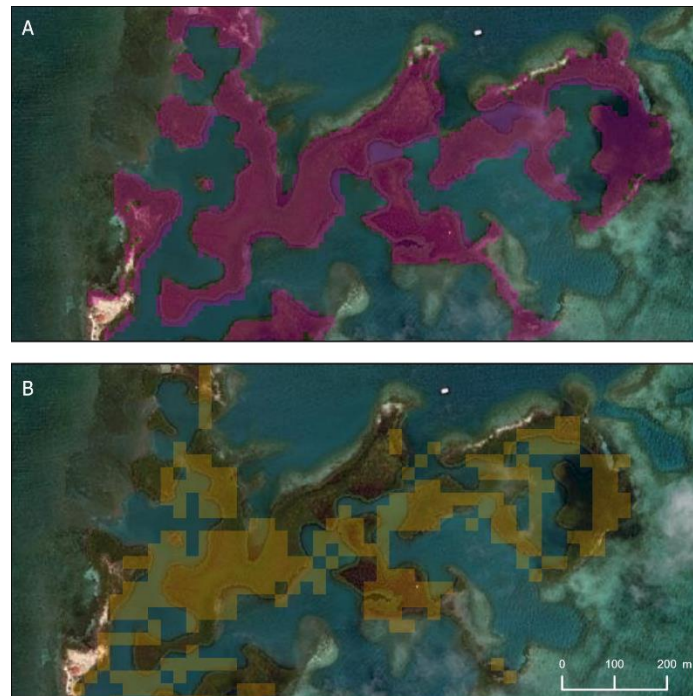


Figure 2. Comparison of Belizean mangrove cayes mapped by (A) Cissell et al. (2021) and (B) Bunting et al. (2018), showing the benefit of the higher-resolution Sentinel-2 data that we used in this project. This figure originally appeared in Cissell et al. (2021).

4. Next Steps

As mentioned above, the results of the Belize portion of this project were published in the journal *Applied Sciences* in May 2021. As of July 2021, we are preparing a manuscript that will publish the results of the Guatemala, Honduras, and Mexico portions of the project. We anticipate submitting this manuscript by October 2021.

5. References

- Bunting, P., A. Rosenqvist, R.M. Lucas, L.M. Rebelo, L. Hilarides, N. Thomas, A. Hardy, T. Itoh, M. Shimada, and C.M. Finlayson. (2018). The Global Mangrove Watch – A New 2010 Global Baseline of Mangrove Extent. *Remote Sensing* 10(10): 1669.
- Cissell, J.R., S.W.J. Canty, M.K. Steinberg, and L.T. Simpson. (2021). Mapping National Mangrove Cover for Belize Using Google Earth Engine and Sentinel-2 Imagery. *Applied Sciences* 11(9): 4258.
- McFeeters, S.K. (1996). The use of the Normalized Difference Water Index (NDWI) in the delineation of open water features. *International Journal of Remote Sensing* 17(7): 1425-1432.
- Shi, T., J. Liu, Z. Hu, H. Liu, J. Wang, and G. Wu. (2016). New spectral metrics for mangrove forest identification. *Remote Sensing Letters* 7(9): 885-894.

6. Appendix

This section contains the following five static maps:

- Map 1: Map of MAR mangrove area in 2020
- Map 2: Map of Belize mangrove area in 2020
- Map 3: Map of Guatemala mangrove area (inside MAR) in 2020
- Map 4: Map of Honduras mangrove area (inside MAR) in 2020
- Map 5: Map of Mexico mangrove area (inside MAR) in 2020

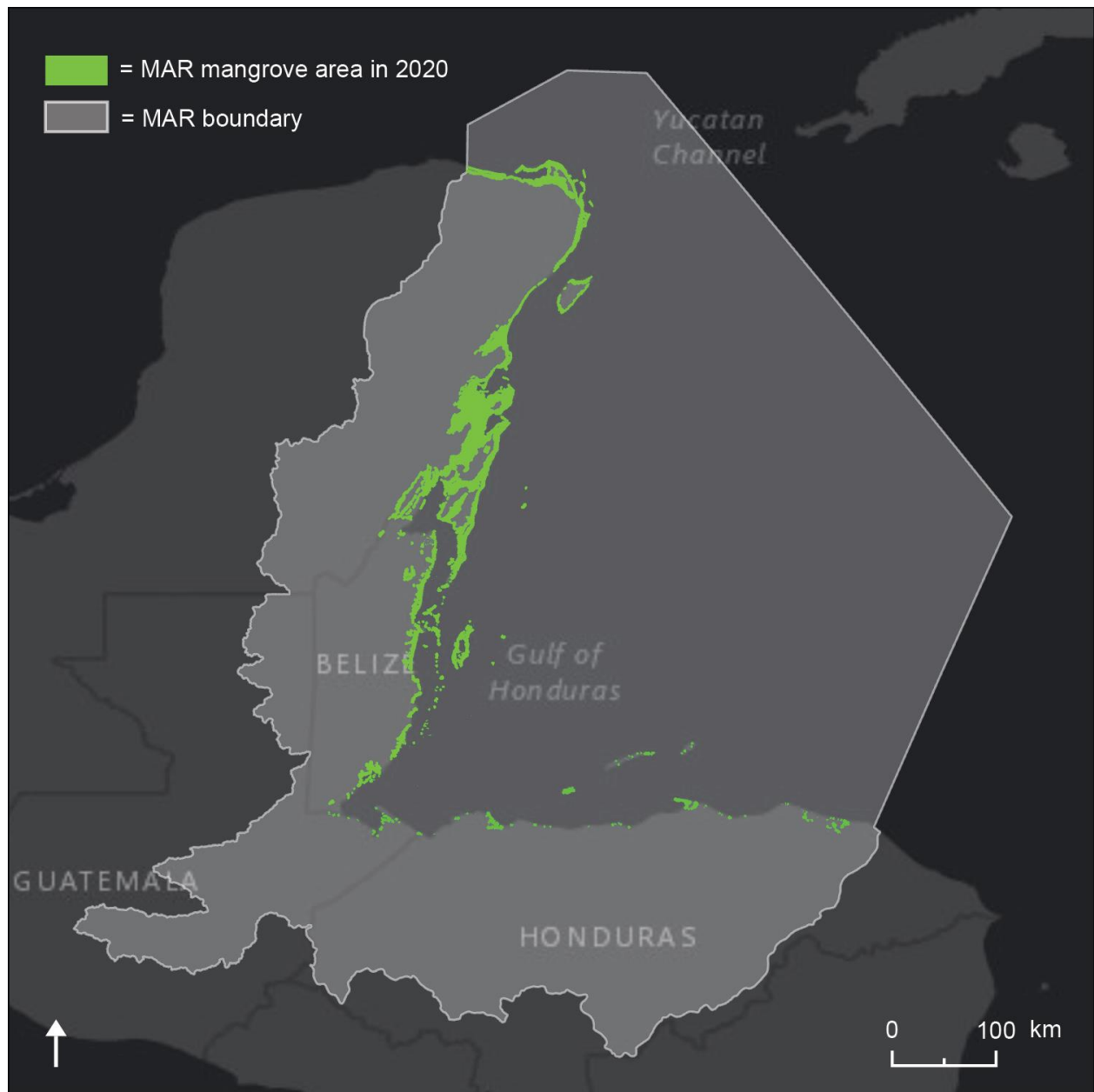
We have also submitted with this report a zip folder containing shapefiles and KMZ files of each country's mangrove map.

For best results, please use the shapefiles. All four shapefiles can be opened in ArcMap, ArcGIS Pro, QGIS, or another GIS program.

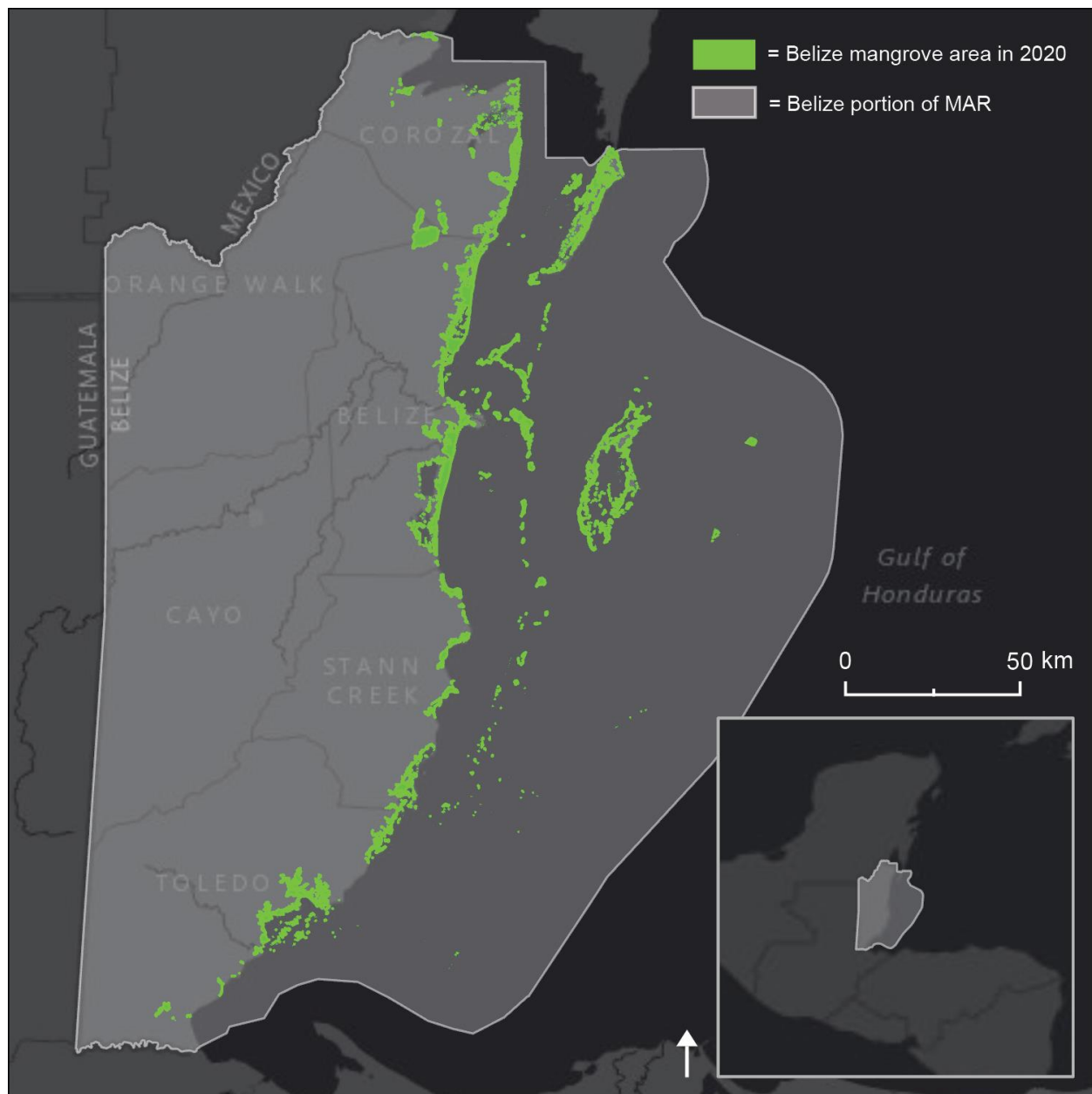
Please exercise caution when using the KMZ files. Because the Mexico KMZ file is so large, Google Earth cannot open the file. Google Earth can open the Belize KMZ file, but the program runs very slowly. Both the Mexico and Belize KMZ files can be opened in ArcMap, ArcGIS Pro, QGIS, or another GIS program. The Guatemala and Honduras KMZ files can be opened in Google Earth, ArcMap, ArcGIS Pro, QGIS, or another GIS program.

QGIS is available for free download at www.qgis.org.

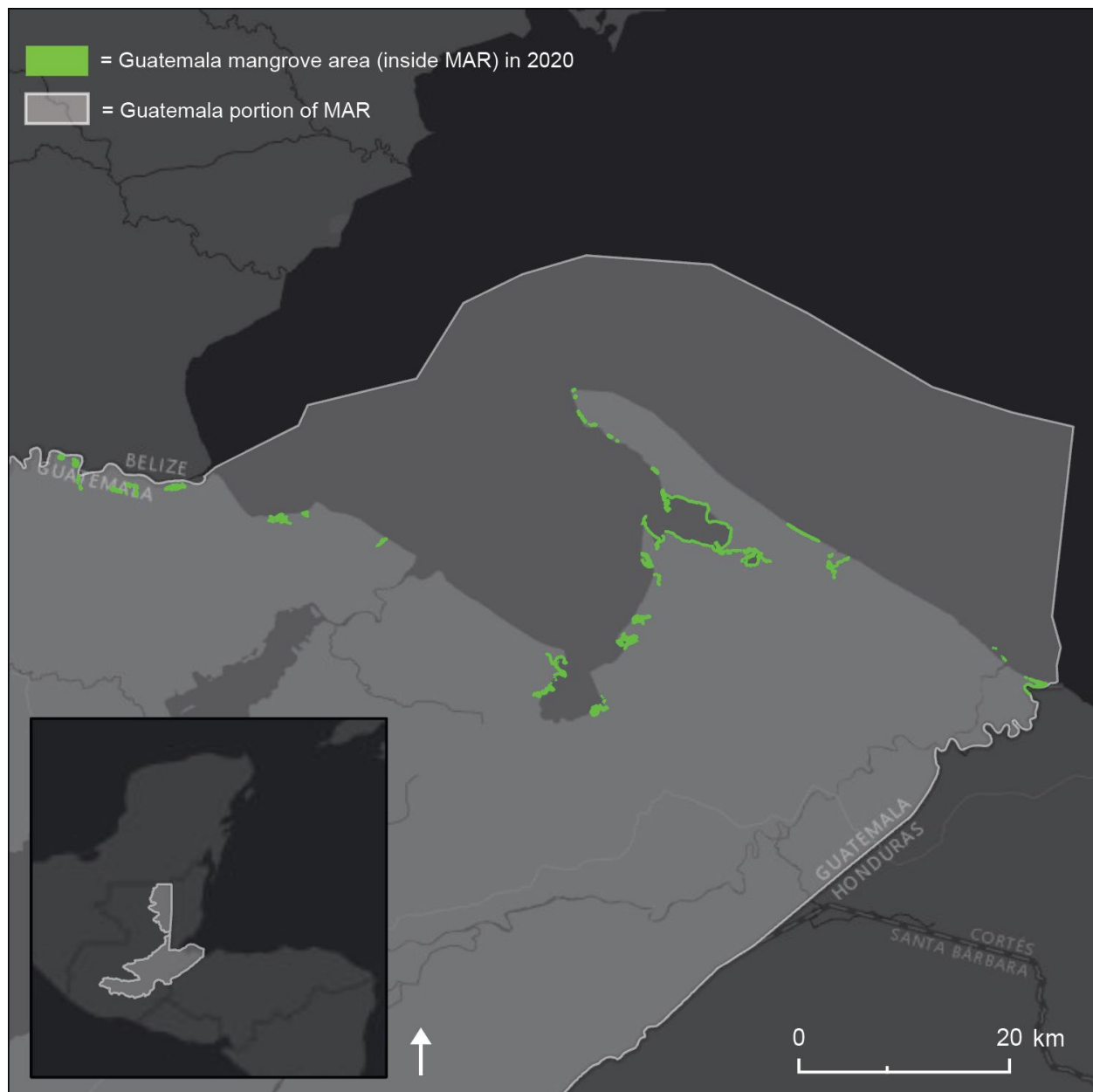
Because of the high level of detail in our maps, a combined shapefile or KMZ file for the entire MAR is too large to open and display in Google Earth or other GIS programs. However, the individual country files can be opened and displayed together to give a complete depiction of MAR mangroves.



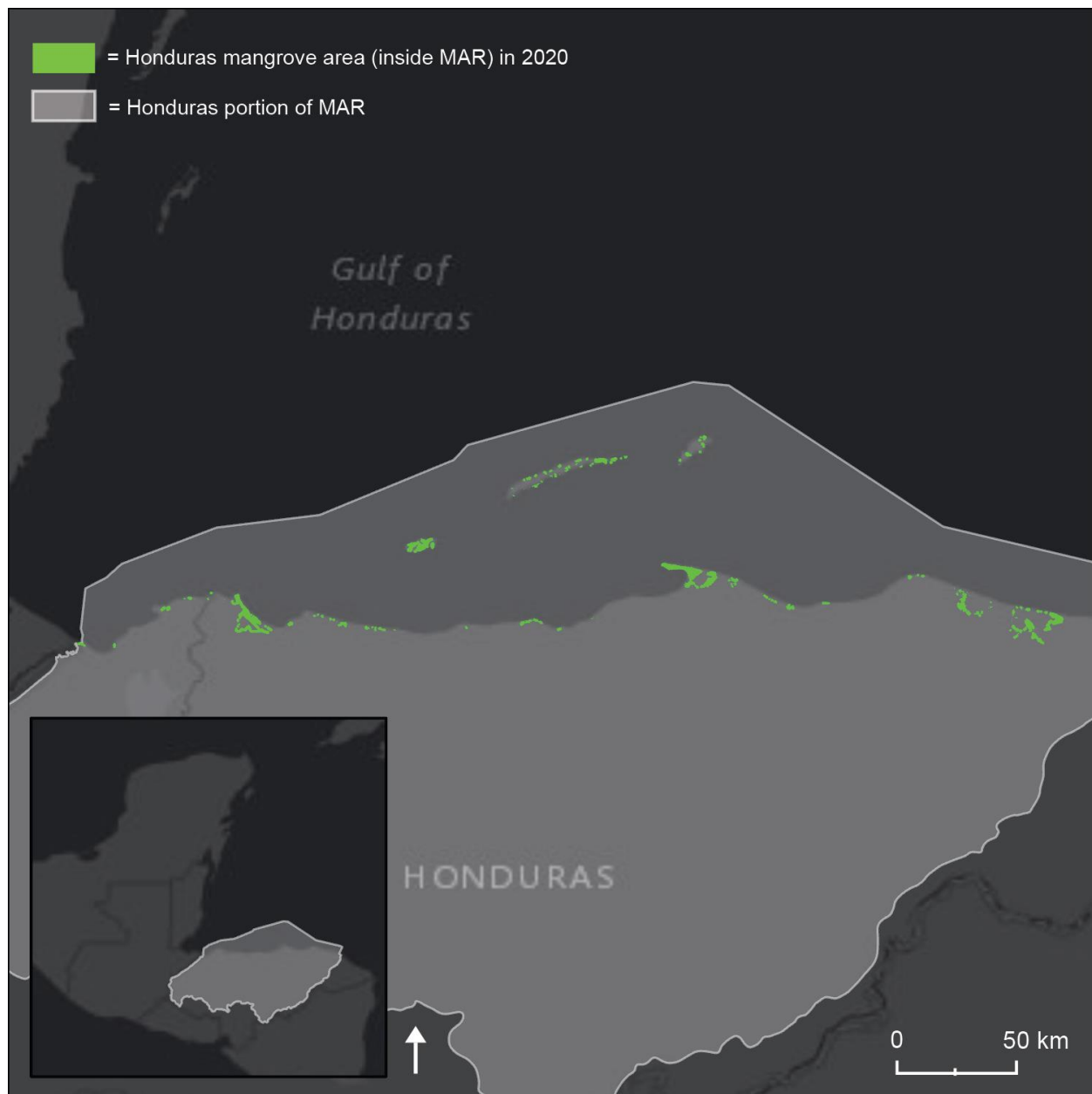
Map 1. Map of MAR mangrove area in 2020



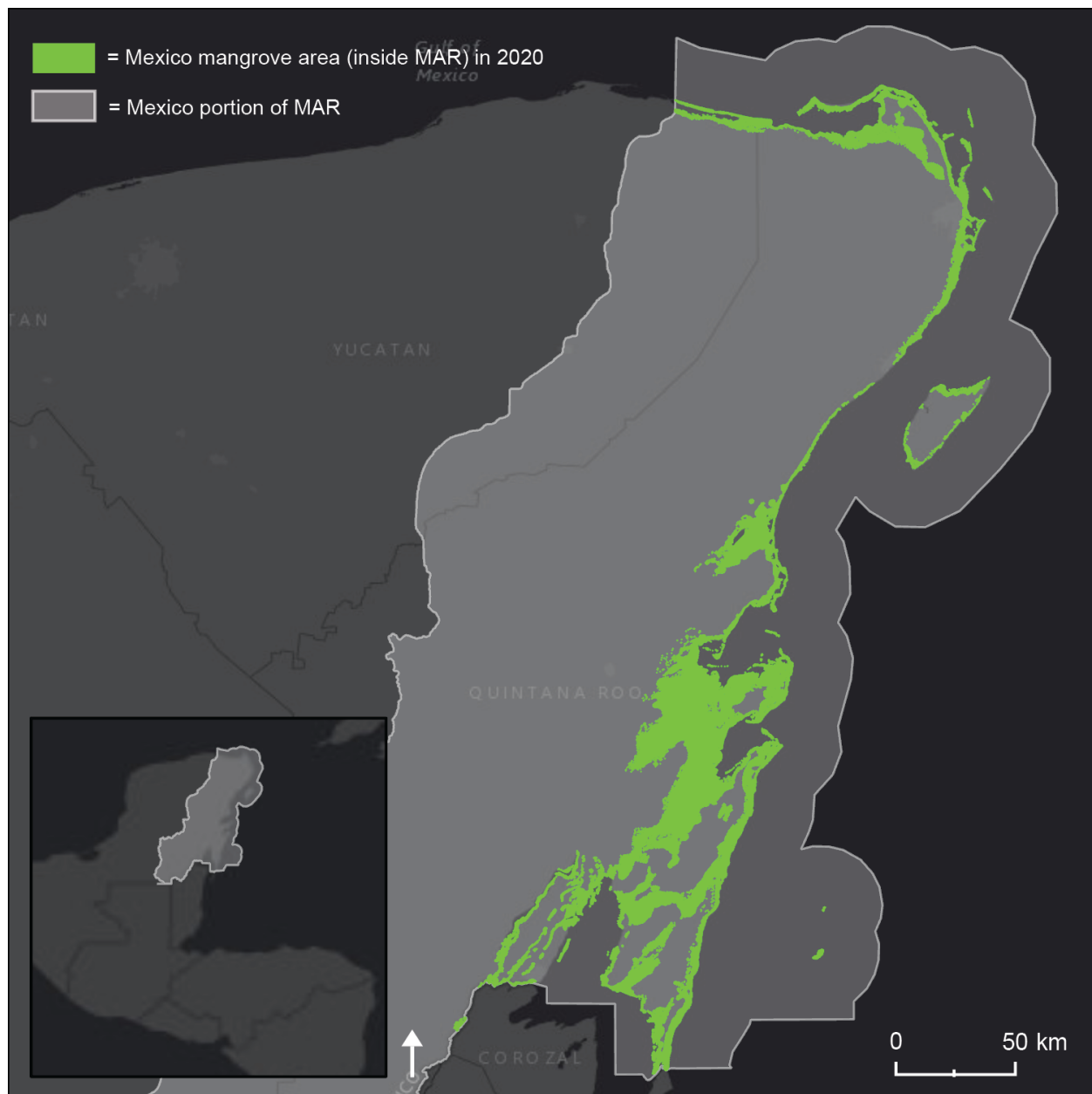
Map 2. Map of Belize mangrove area in 2020



Map 3. Map of Guatemala mangrove area (inside MAR) in 2020



Map 4. Map of Honduras mangrove area (inside MAR) in 2020



Map 5. Map of Mexico mangrove area (inside MAR) in 2020