Mozambique Mangrove Extent 1995-present

Technical Report · November 2018

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Mozambique Mangrove Mapping via Satellite from 1994-present

Background

Mozambique has over 300,000 hectares of mangroves along its coast, which is the largest tract of mangrove forest in Africa, and ranks the country 13th in the word in terms of mangrove extent. WWF-Germany and WWF-Mozambique have partnered to map Mozambique's mangroves in efforts to conserve, manage and restore them. This analysis estimates mangrove extent in Mozambique over nearly three decades using consistent methods and the newest satellite technologies available. This report presents the mapping results by province and is the first extensive national level assessment of mangroves at the national scale using highest resolution available.

This assessment uses several satellite technologies: the Landsat Thematic Mapper, Enhanced Thematic mapper and Optical Land Imager provide the long term time series for change mapping at 30m resolution. Additionally, data from the new Sentinel-2 were used. This sensor launched in 2015 by the European Space Agency, and provides data similar to Landsat 8, but with 3times higher resolution and additional spectral bands. This dataset was used to map Mozambique's mangroves at 10m resolution for the year 2016.

Methods

All processing of imagery and subsequent mangrove classifications were performed in Google Earth Engine. The methods used were based on (Shapiro *et al.* 2015), and automated and applied to all Landsat sensors and the spectral characteristics of Sentinel-2, and using a supervised classification method to improve results with less manual editing required.

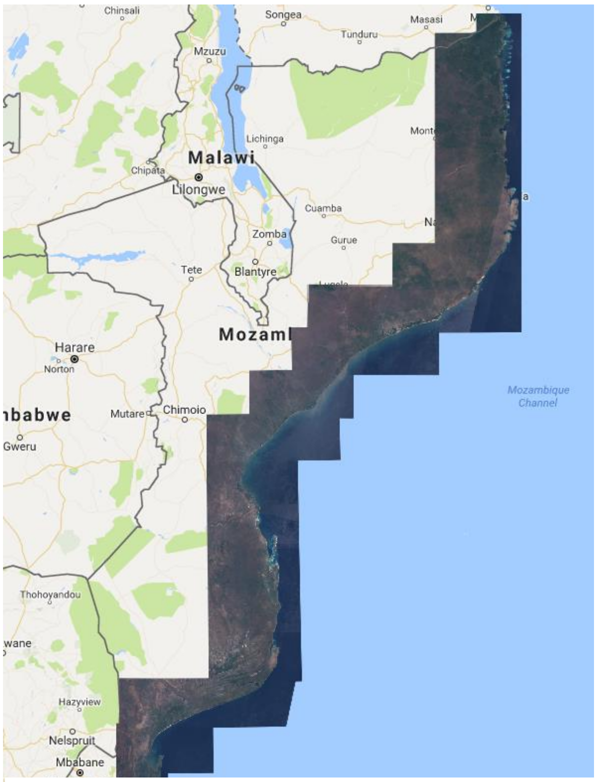


Figure 1: Cloud-free S2 composite for 2016

The workflow is as follows:

First, available Landsat or Sentinel-2 (from now on referred to as S2) data from the year of interest were selected and filtered by cloud cover and composited into a single cloud-free image. This was achieved by selecting only pixels from images with a reported cloud cover of less than 5%, which aren't flagged as cloud or cirrus in the quality assessment band, and calculating a median value of all valid observations. This produced the cloud-free S2 mosaic shown in figure 1.

Next, training data were identified from existing maps (Giri *et al.* 2011; RCRMD 2015) and field information. Polygons of known areas of mangrove and non-mangrove were drawn onto the map and used as samples for a Random Forest classification.
The satellite image was then masked to reduce as much as possible to mangrove areas. This step removed all water, any areas with an elevation greater than 35m above sea level (which is the range of mangrove extent as provided by Fatoyinbo *et al.* (2008), and all areas further than 1km from known mangrove locations from Giri, 2011.

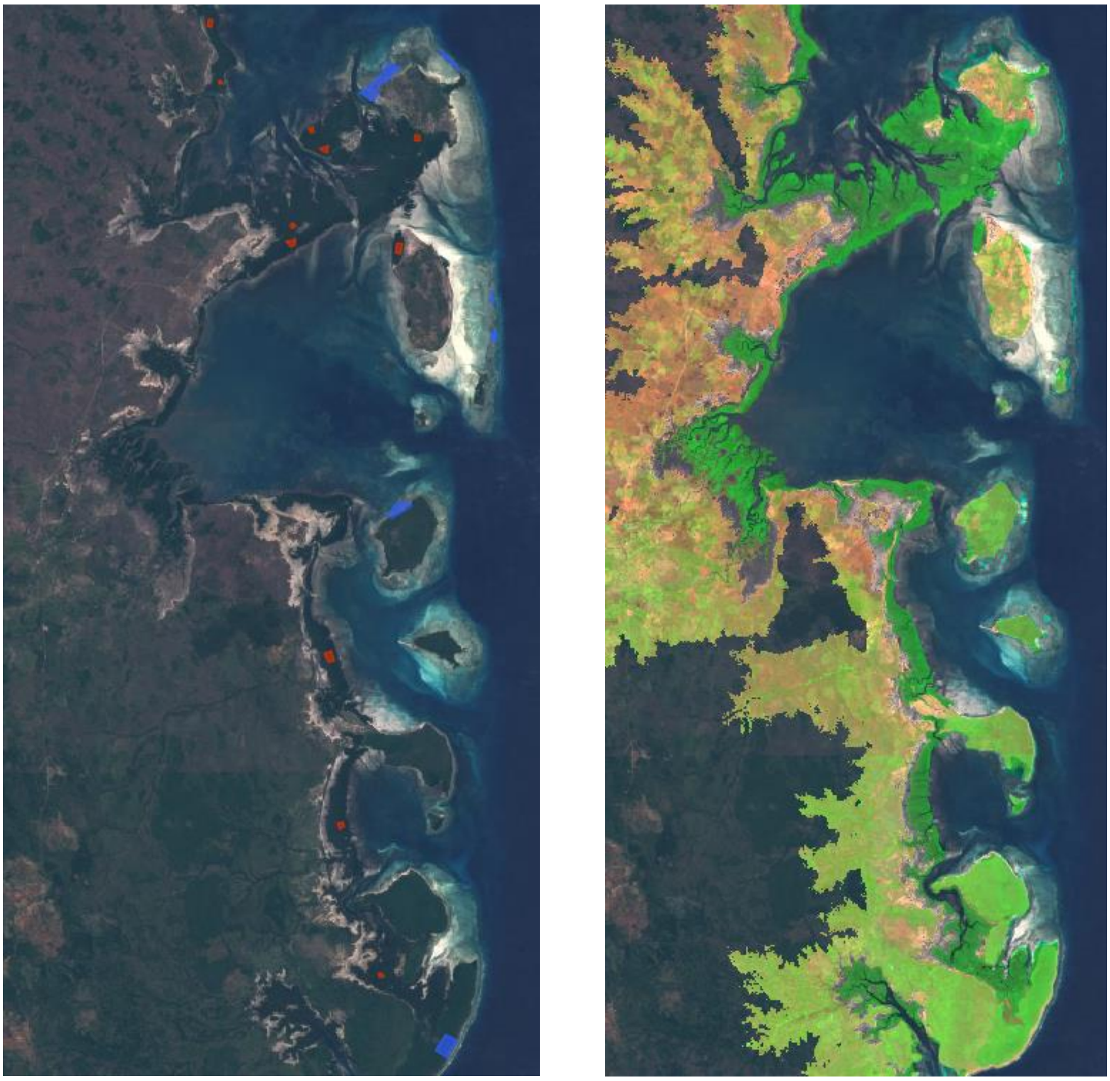


Figure 2. Left: Examples of training data polygons (red = mangrove, blue = not mangrove) in Quirimbas National Park, shown over the image composite. Right: The same area with water and higher elevation masked. Mangroves are visible in dark brown.

A number of spectral indices were developed from the imagery, and stacked with the raw bands to provide additional information for the classification (Green *et al.* 1998). These include:

- NDVI – normalized difference vegetation index
- NDWI – normalized difference water index
- NDWBI – normalized difference index between green and NIR
- mNDWBI – normalized difference between green and SWIR
- Band ratios (from Green et al, 1998) SWIR/NIR, and RED/SWIR
- Band ratio BLUE/SWIR to improve detection of clouds and water.

The Random Forest machine learning algorithm (Breiman 2001) takes the training areas, samples them against the different spectral bands and indices and then uses a random sampling scheme to assign pixels into classes of mangrove and non-mangrove. The classification results were filtered to remove small individual pixels and noise, producing the mangrove map in figure 3.

Mangrove areas were calculated by province from the 10m resolution map (with a 0.5 minimum mapping unit applied) for 2016 producing the following estimates:

Table 1. Mangrove area by province in 2016 mapped with Sentinel-2

Province	Mangrove Cover (ha)	% of total
Cabo Delgado	30,733	13.60
Gaza	276	0.12
Inhambane	14,898	6.59
Maputo	5,148	2.28
Nampula	37,507	16.60
Sofala	49,711	22.00
Zambezia	87,721	38.82
Total	**225995**	**100**

Accuracy Assessment using 2000 randomly located points, and the presence of mangroves determine from Google Earth imagery is shown in Table2.

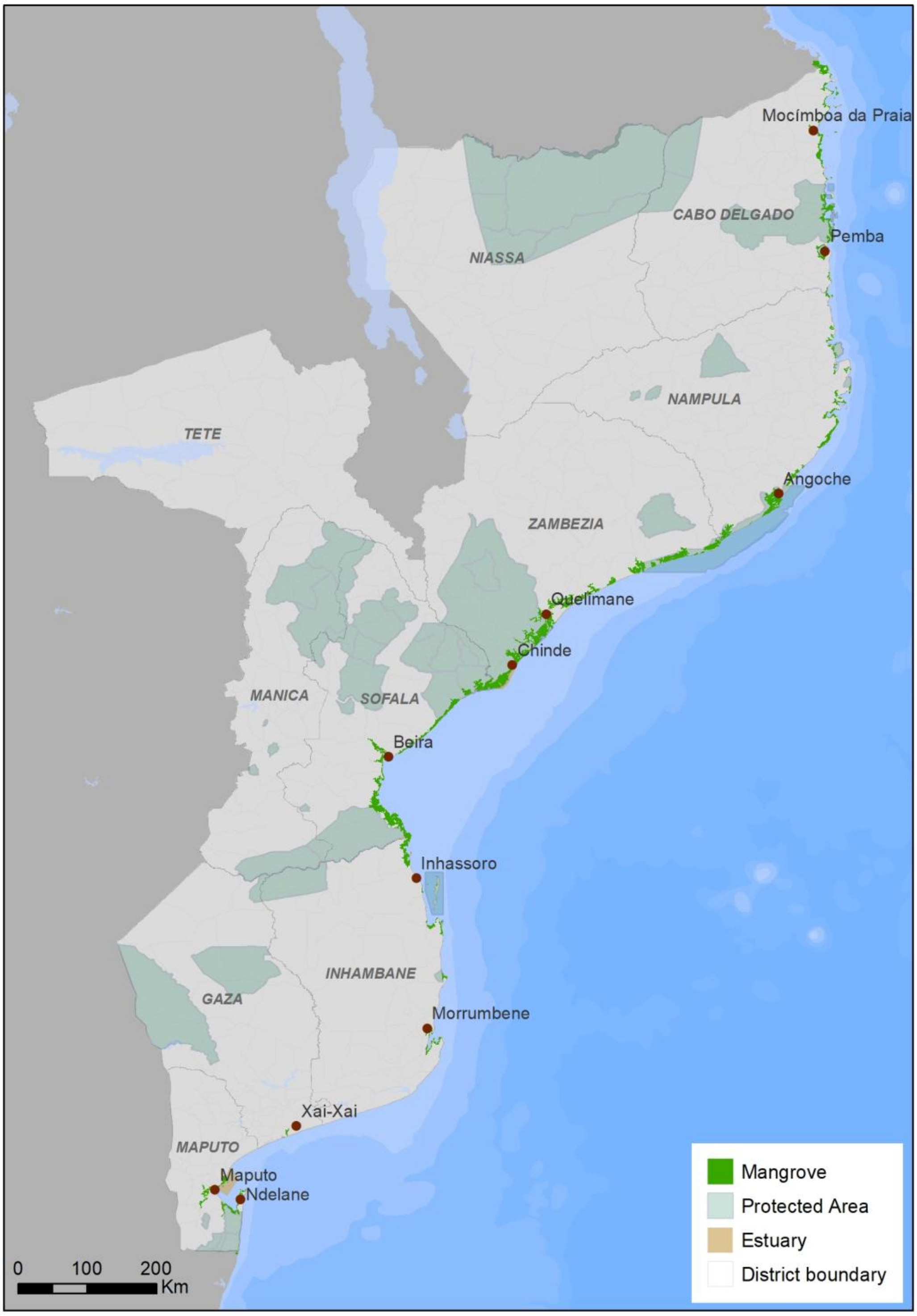
Table 2. Standard Accuracy Assessment of Mangrove Mapped with S2

	Producers Accuracy	Users Accuracy	Omission errors	Commission errors
Mangrove	77.00%	97.59%	23.00%	2.41%
Non-Mangrove	98.1%	81.01%	1.90%	18.99%

Overall accuracy = 87.55%

The accuracy assessment indicates that the higher resolution dataset tends to underestimate mangrove compared to field data. These estimates still lower than those determined by recent studies with remote sensing (Fatoyinbo *et al.* 2008; Fatoyinbo & Simard 2013), which are all much lower than previous studies from Saket and Matusse (1994) which use differing methods or lower resolution imagery, which can overestimate forest cover.

Figure 3. Mozambique Mangroves 2016 mapped with Sentinel-2



The same methods were applied to Landsat image mosaics (30m) composited for the years 1994, 2001, 2008, and 2015 to determine change over time. And generally, lower resolution has been shown to increase accuracy.

These results are shown on the following page, and while the pattern of mangroves is very similar, the results do in fact differ somewhat from the S2 estimates. The producer's accuracy is higher and the errors of omission are lower than with Sentinel-2.

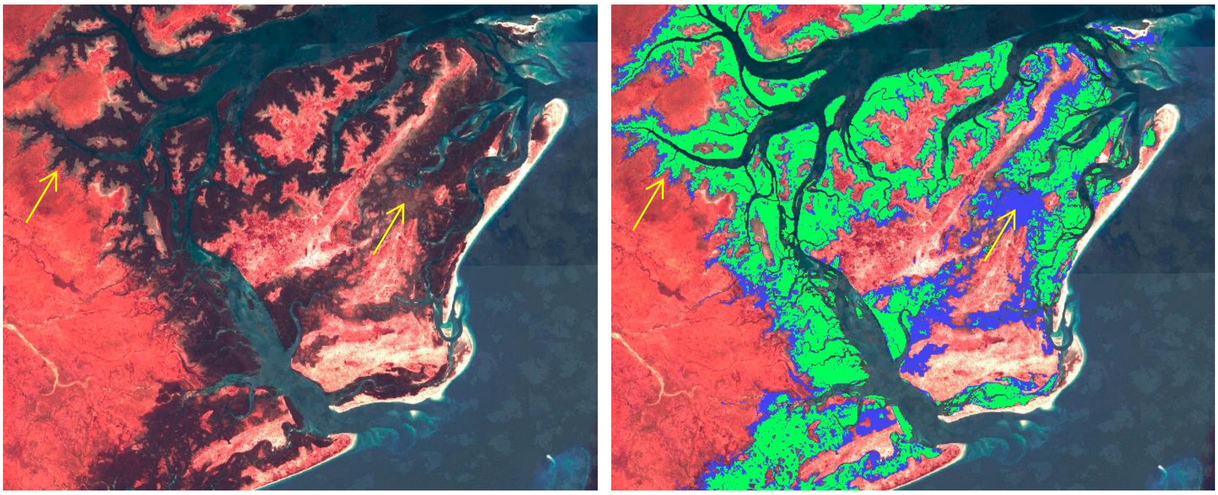
Table 3. Standard Accuracy Assessment of Mangrove Mapped with Landsat

	PA	UA	O	C
Mangrove	87.50%	97.33%	12.50%	2.67%
Non-Mangrove	97.60%	88.65%	2.40%	11.35%

Overall accuracy =	**92.55%**
Khat =	0.8510

The Landsat map turns out to be more accurate, and also estimates more mangroves similar to other studies. This is likely due to resolution, as S2 is 3 times more detailed imagery, S2 can detect small holes or openings in mangrove stands, or thinned stands, more detailed edges, and perhaps does not really represent "forest" but more at a scale of "trees." It also seems like it can does not identify degraded or dried mangrove areas, such as this example on the island off of Angoche, so that this map might be referred to as small-scale "intact" forest. More analysis is needed to determine this.

Figure 4. Example of differences in mangroves detected by Landsat and Sentinel-2. The false color S2 image on the left shows the mangroves in deep red, with lighter areas on the edges, presumably mud flats or less vegetated areas. These are detected as mangroves in coarser resolution Landsat imagery, as shown on the right image, where mangroves mapped with Landsat is seen in blue and fewer areas are detected as mangroves with S2 (green).



The Landsat constellation has an important benefit of being able to provide a temporal analysis, dating back to 1994, when the first clear images were collected in Mozambique. The analysis of mangrove extent, gain and loss from 1994 to 2001 to 2008 to 2015 is presented in table 4.

Table 4. Mangrove gain and loss from 1994-2001-2008-2015 determined from Landsat imagery (30m resolution). 'Stable mangroves' denotes the extent of mangroves which did not change throughout the study period, and the dynamic class comprises areas that experience both gains and losses in the time period.

		1994	1994-2001				2001	2001-2008				2008	2008-2015				2015
Province	**Stable Mangrove**	**Mang**	**Gain**	**Loss**	**Net**	**Net (%)**	**Mang**	**Gain**	**Loss**	**Net**	**Net (%)**	**Mang**	**Gain**	**Loss**	**Net**	**Net (%)**	**Mang**
Cabo Delgado	34,422	33,646	0	455	455	*1.35*	33,339	2,385	0	2,385	*7.15*	35,725	1,072	245	1,317	*3.69*	37,041
Gaza	297	311	4	120	124	*39.81*	247	36	-17	19	*7.81*	266	14	7	21	*7.89*	287
Inhambane	17,995	17,374	163	4,541	4,705	*27.08*	17,112	787	-186	602	*3.52*	17,713	591	156	747	*4.22*	18,460
Maputo	13,294	12,918	0	7,532	7,532	*58.31*	12,587	721	0	721	*5.72*	13,307	167	190	358	*2.69*	13,665
Nampula	48,109	46,351	16	108	125	*0.27*	45,376	2,072	-7	2,066	*4.55*	47,442	995	834	1,829	*3.86*	49,271
Sofala	67,008	64,127	357	14	371	*0.58*	60,942	4,238	-503	3,734	*6.13*	64,676	4,541	1,443	5,984	*9.25*	70,660
Zambezia	74,243	69,961	4	1,701	1,705	*2.44*	64,409	5,277	-8	5,269	*8.18*	69,678	1,701	3,023	4,724	*6.78*	74,402
Total	**255,369**	**244,689**	**545**	**14,471**	**15,016**	***6.14***	**234,011**	**15,517**	**-721**	**14,795**	***6.32***	**248,807**	**9,081**	**5,898**	**14,979**	***6.02***	**263,786**

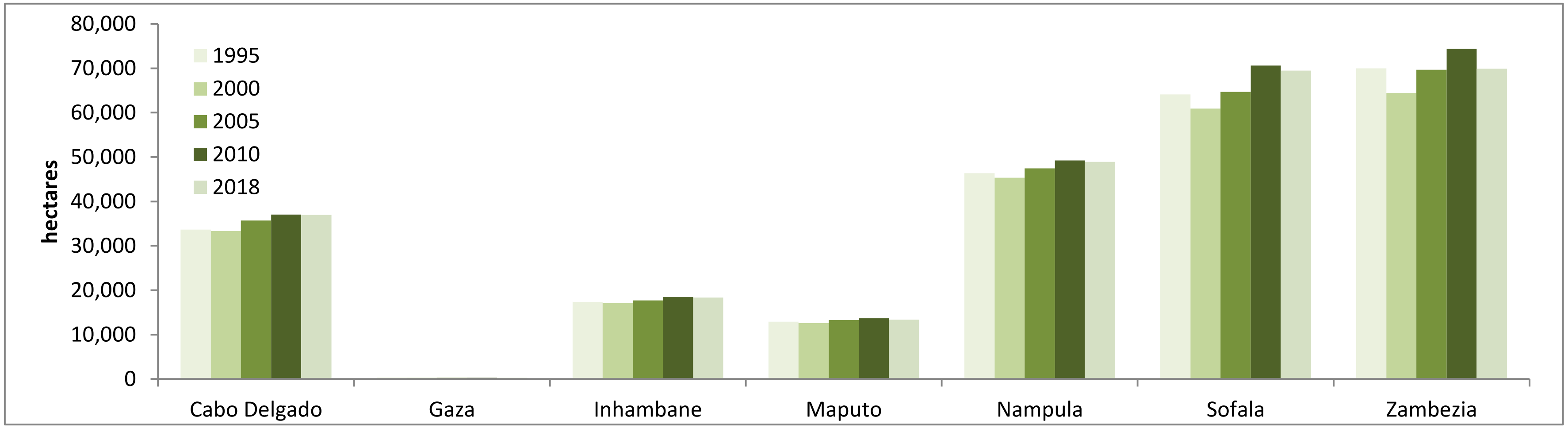


Figure 5. Province and national mangrove cover in hectares from 1994 to 2015

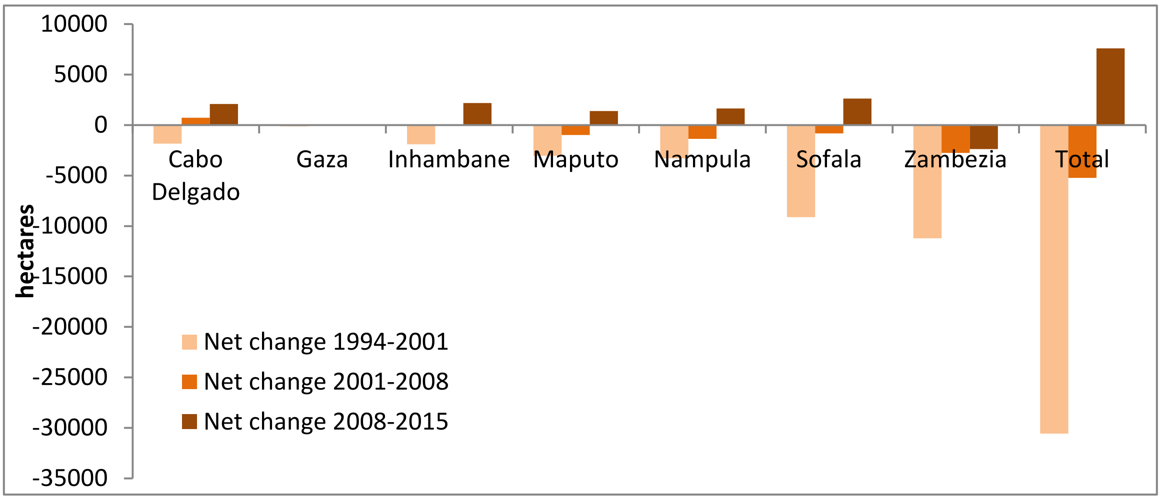


Figure 6. Net mangrove change by time period for each province.

While overall extent is increasing, there remains negative changes in Zambezia, which has the largest extent of mangroves in Mozambique. The rate of loss however, is decreasing.

In Comparison with previous estimates, the trends until 2001 are generally similar, particularly for Cabo Delgado, Nampula, Inhambane and Zambezia Provinces.

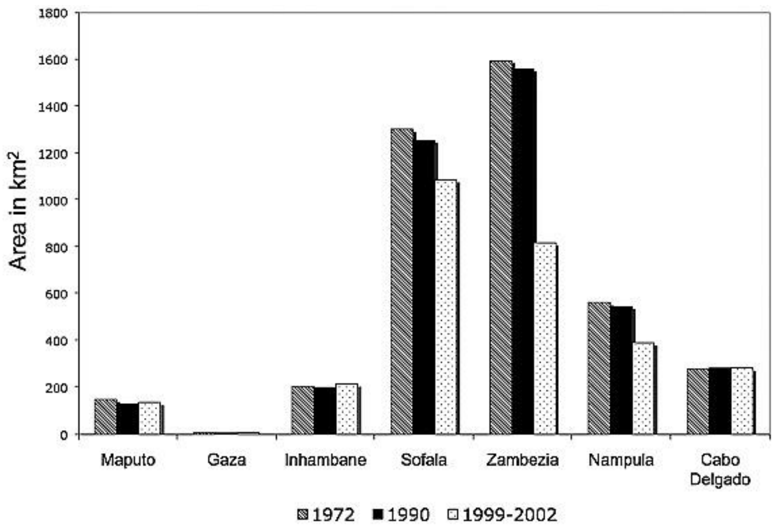


Figure 7. Previous estimates of mangrove extent in Mozambique from 1972-2002 (from Fatoyinbo et al., 2008)

The mangroves of Mozambique are very dynamic and change over time, either from human activities which cause loss, or natural accretion or erosion along the coasts. The overall trends however onwards from 2001 show that mangrove, despite losses are showing a net increase in many provinces, with the exception of Zambezia province, which shows a net loss after 2008. Results from this analysis are similar to in progress (unpublished) results from NASA trend analyses, which show increases in many provinces, including in Maputo province just north of the capital. There are significant gains and losses in Zambezia, particularly around Quelimane which show more dynamic ecosystems.

An analysis of mangrove cover in protected shows that mangrove extent is similarly dynamic, and in the Zambezi delta and Primeiras and Segundas, mangrove loss is still outpacing gain. Quirimbas is experiencing relatively little change and net gain.

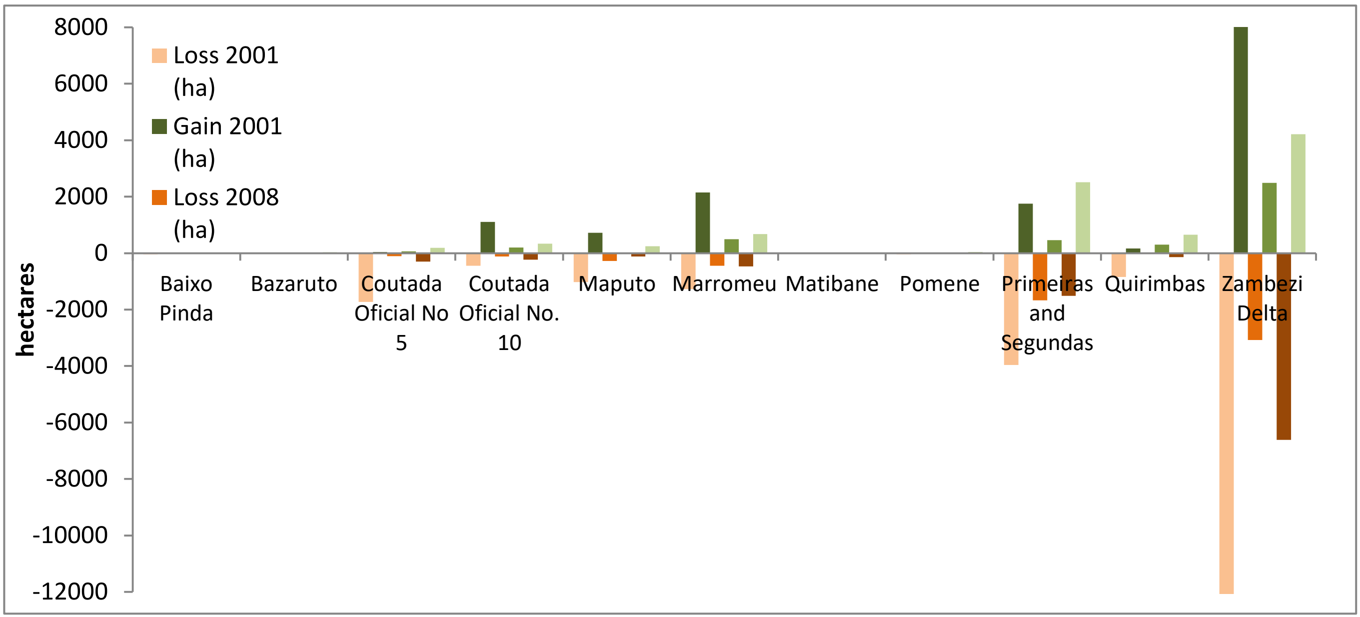


Figure 8. Gains and losses of mangroves in Protected Areas

Hotspots of change

A moving window analysis assessed the magnitude of change within a 1.5km radius. This allows visualization of hotpots of major areas of mangrove gain and loss throughout the country. In Figure 8, stable mangrove is shown in yellow, while areas of gain are shown in blue and hotspots of loss in red.

Conclusions

This assessment has produced the most consistent analysis of mangroves in Mozambique to date. Previous efforts combined different methods and data which can produce unreliable results that may not be consistent in time and space. The general trends observed show that mangrove losses are decreasing over time, while areas of gain are on the rise. Overall, mangrove area has been generally decreasing until 2008, when the mangrove extent has been shown to be on the rise. This does not mean that mangroves are not being affected by anthropogenic impacts – only that the gains are offsetting the losses.

Next Steps

The data and results are hosted on GLOBIL and provided as an interactive dashboard to provide a more flexible and detailed look at the estimates and change analysis with regards to districts, provinces and protected areas. Additional review will be made to determine the differences between Sentinel-2 and Landsat cover, and more field data will be included where available, particularly on the edges of mangrove stands to determine which sensor is more accurately mapping mangroves. Finally, an assessment of changes with regards to physical and socio-economic variables (distance to waterways, infrastructure, cities population, agriculture, coastal data such as currents and shoreline complexity, exposure) is needed to assess the driving factors for both gain and loss which can provide valuable input into conservation and restoration planning.

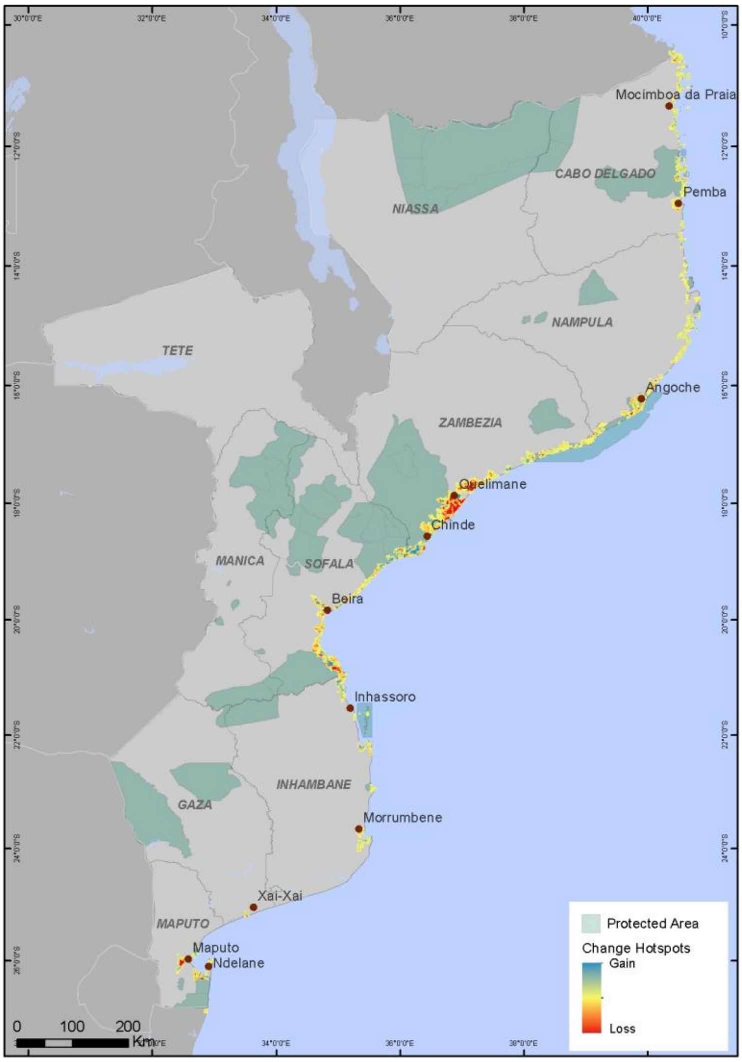


Figure 8. Hotspot analysis shows the areas of gain and loss, the most dynamic being in the Zambezi delta, and major areas of loss around Quelimane and Maputo. Gains are observed in Quirimbas National Park.

References

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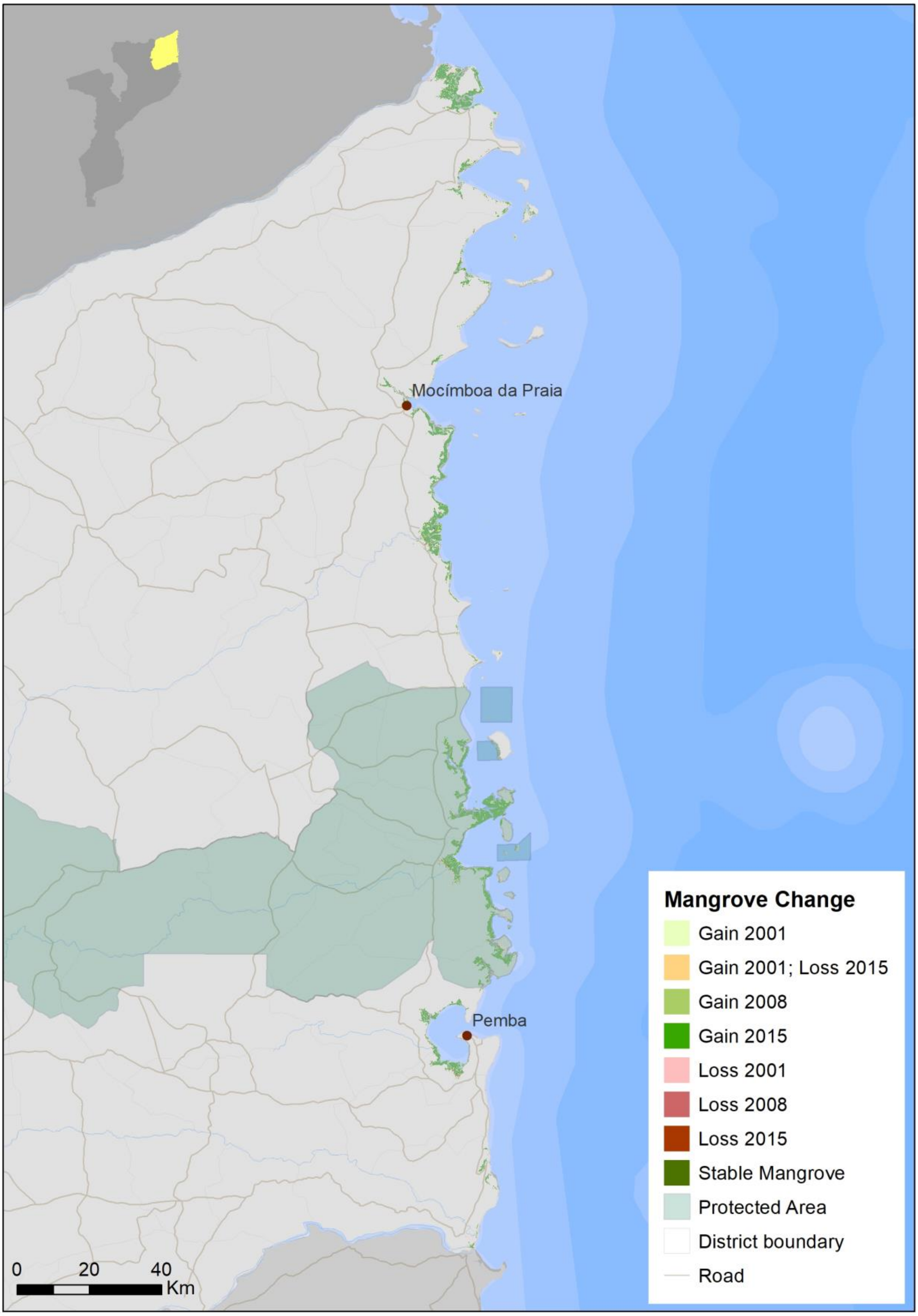
Appendix

Mangrove change maps by province

Figure A1. Mangroves of Cabo Delgado Province



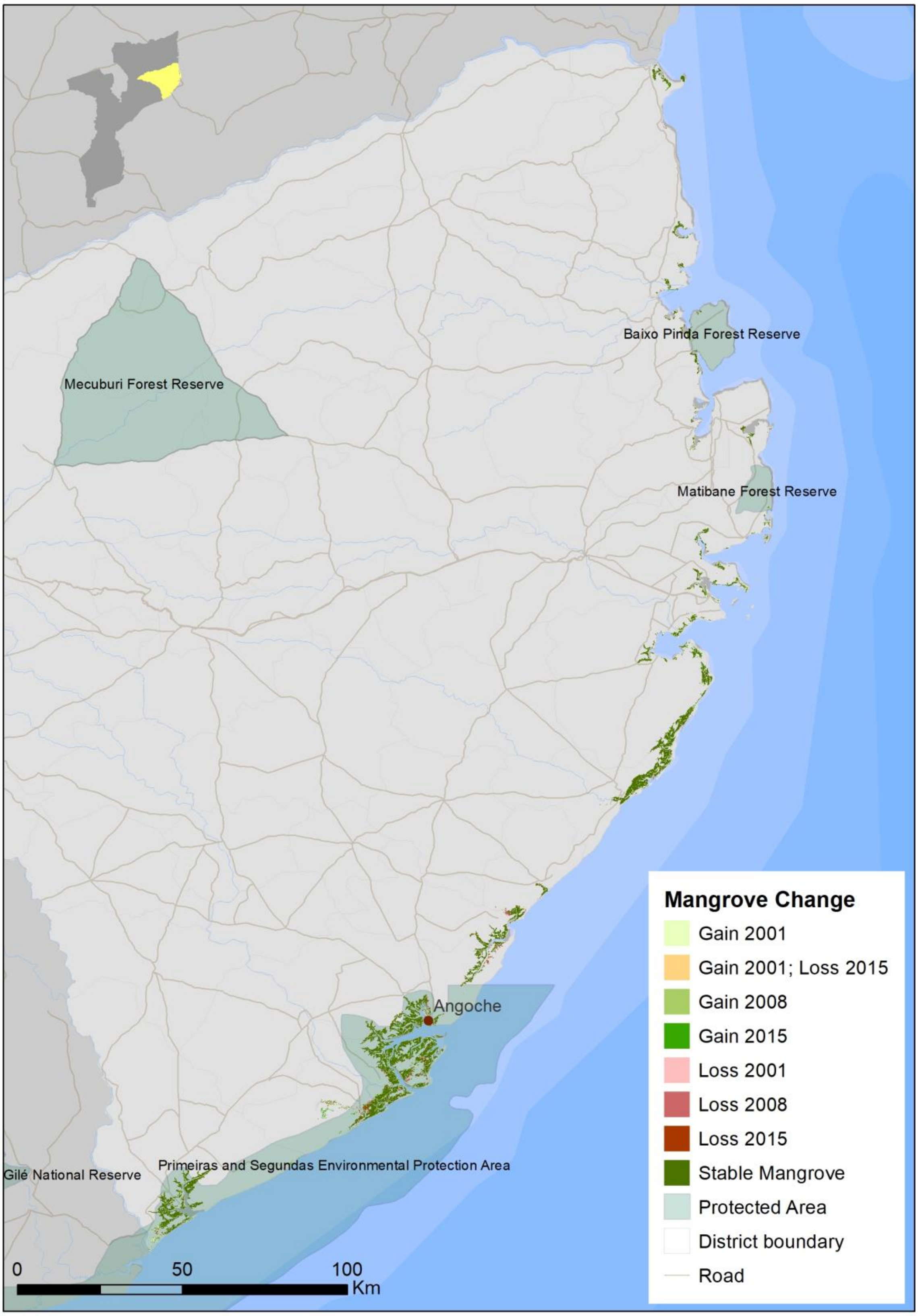


Figure A2. Mangroves of Nampula province

Figure A3. Mangroves of Zambezia Province

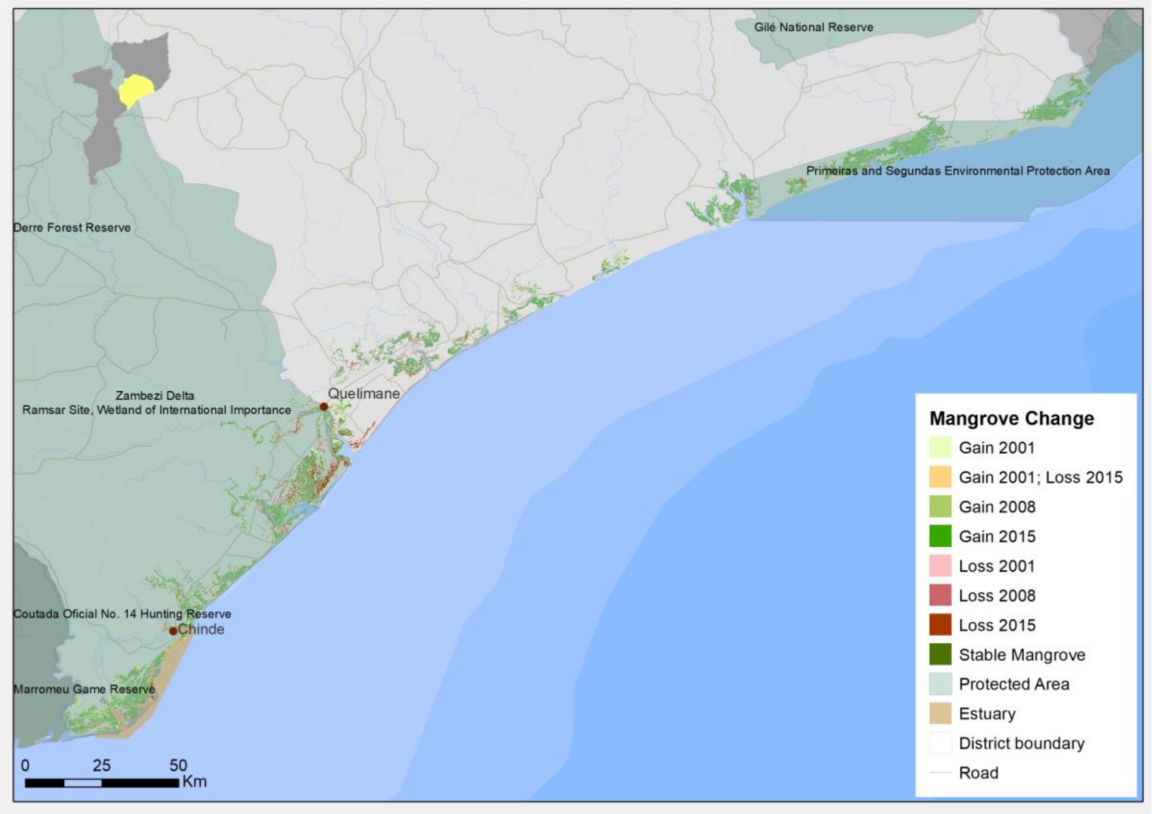


Figure A4. Mangroves of Gaza province

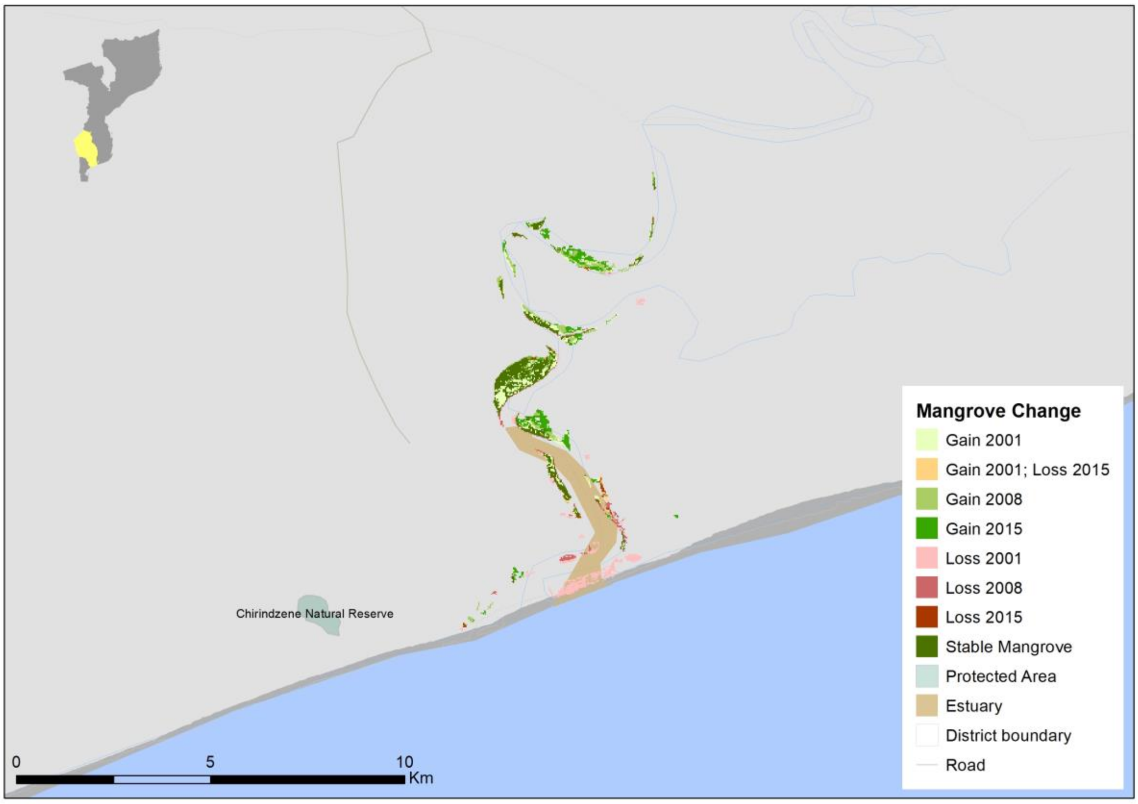


Figure A5. Mangroves of Sofala Province

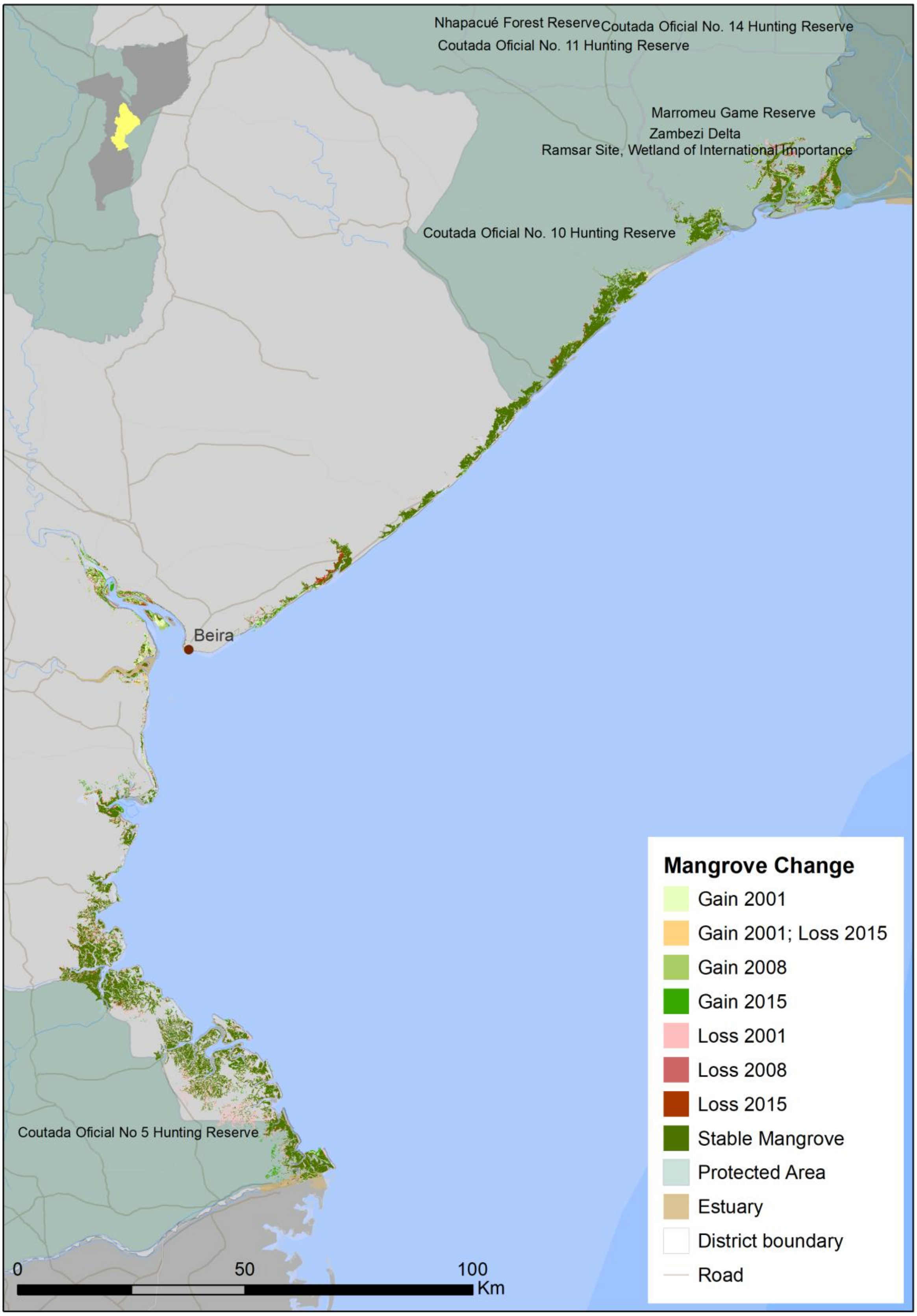


Figure A6. Mangroves of Inhambane province

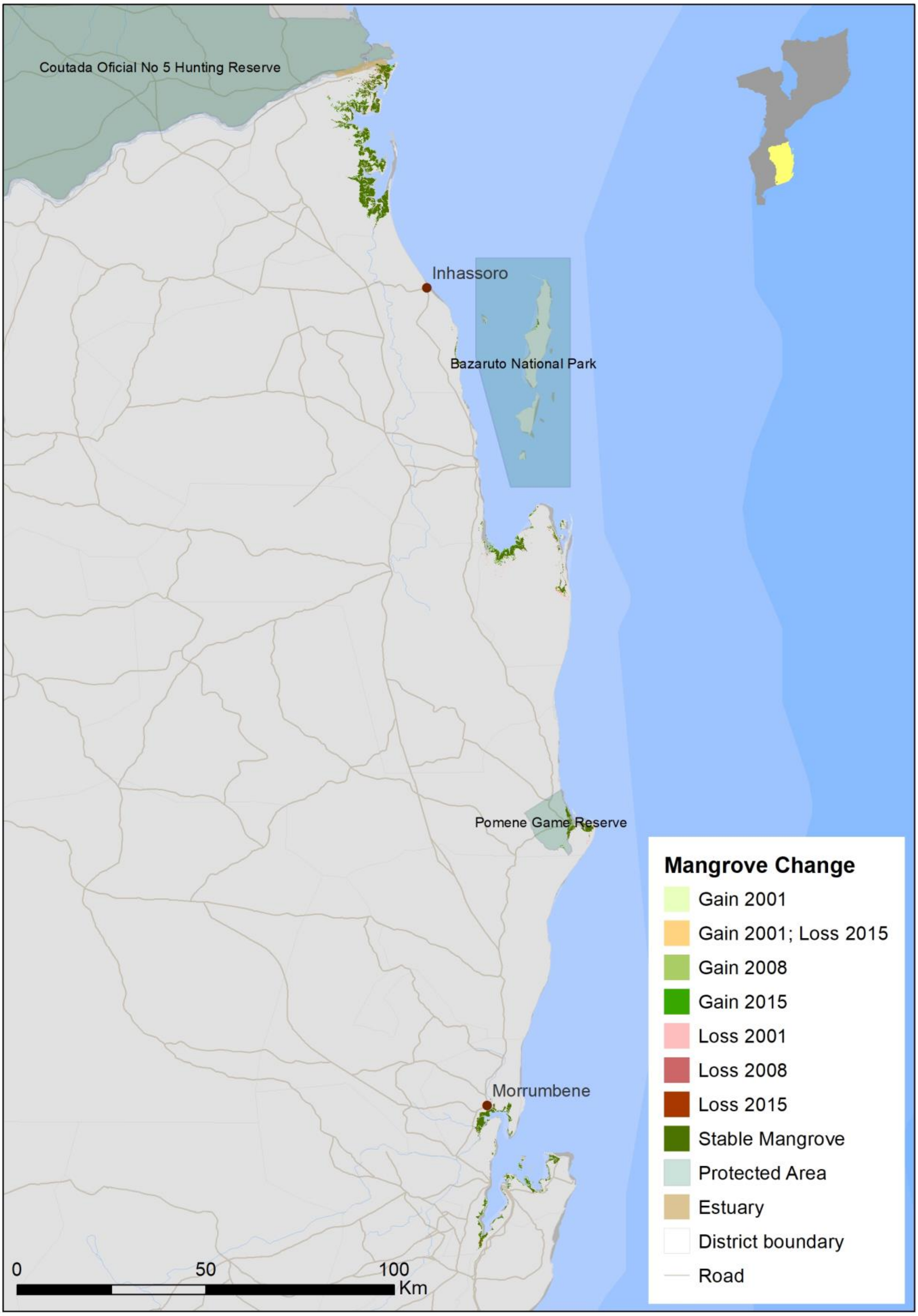


Figure A7. Mangroves of Maputo province