Technical report: Spatial Assessment of Total Mangrove and Littoral Forest Cover for Belize, 2014-2019

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1. Background

The following constitutes the final technical report for the consultancy to conduct a spatial assessment of total mangrove and littoral forest cover for Belize (contract no. P131408/CS-73). This work is funded under Belize's Marine Conservation & Climate Adaptation Project (MCCAP), via the Protected Areas Conservation Trust (PACT), with the ultimate beneficiary being the Coastal Zone Management Authority & Institute (CZMAI).

2. Objectives

The overall objective of the study is to use remote sensing to examine how the areal cover of mangrove and littoral forest ecosystems have changed across Belize's landscape over the period 2014-2019, roughly coinciding with the MCCAP's duration. In addition to focusing on mangrove cover across all of Belize, the study is particularly focused on changes in mangrove cover within three priority coastal planning regions identified by the CZMAI, specifically Caye Caulker, Central Region, and South Northern Region. This study is also intended to update the most recent assessment of Belize's mangrove cover, completed in 2018 (Cherrington et al. 2018). The results of this study were also validated using a standard accuracy assessment.

3. Methods

As with the two earlier studies on which this one is built (Cherrington et al. 2010, Cherrington et al. 2018), the basis of this study was change detection, to identify both areas where mangroves and littoral forest ecosystems were cleared, and areas where they may have regenerated. The geographic domain for the entire study is the country of Belize, while the sub-domain was the three previously indicated coastal planning regions. In terms of the sources of data, the study made use both of a 'mask' of mangrove and littoral forest ecosystems generated by Cherrington et al. (2018) based on Zisman (1998) and Meerman (2004), the former focusing on mangrove cover, and littoral forest extent extracted from the latter. In addition to that mask, which was used to identify areas under mangrove and littoral forest cover in 1980 and 2014, the project's other major source of data – for the change detection – was the open archive of satellite imagery from the Landsat satellites launched by NASA from 1972 (Landsat-1) through 2013 (Landsat-8). While the EROS Data Center of the U.S. Geological Survey (USGS) maintains the official archive of Landsat imagery, that data is also replicated in the open archive maintained by the commercial company Google, and available through their open big data processing platform, Google Earth Engine, GEE (http://code.earthengine.google.com).

While the previous study had relied on the then open access CLASlite desktop computing platform (Asner et al. 2009), in late 2018, the program's no cost basis was suspended, and as of 2019, there is a cost to acquiring CLASlite licenses. With a view of making the project's workflow not only replicable, but also open, the decision was therefore taken to utilize an openly available change detection algorithm, and the LandTrendr algorithm (Kennedy et al. 2010, Kennedy et al. 2018) available through GEE was found to be comparable to the approach taken by CLASlite. LandTrendr was used to examine both forest disturbance (i.e. loss) and forest gain (i.e. regrowth) across all of Belize, for a period spanning from approximately November 1984 through November 2019. All of the Landsat data for that period were theoretically used. Where LandTrendr works by fitting regressions on clumps of pixels to look at how reflectance signals have changed over time, the default parameterization was modified to select changes where the model fit met or exceeded 0.70, and with a minimum mapping unit of nine (9) 30m x 30m pixels.

The Normalized Burn Ratio (NBR) index was selected for examining change, and it should be clarified that the NBR is useful not just for examining the impact of fires (Robert Kennedy, personal communication). The result of the processes run were 2 maps: one depicting forest loss across all of Belize between 1984 and 2019, and forest gain across Belize for the same period, with changes depicted on an annual basis. The results were then subset to the period 2014-2019, and further subset only to the mangrove and littoral forest mask. Following that subsetting, change pixels were filtered by size, with only changes above 1 hectare selected. Visual inspection of the change pixels were carried out, and compared with 30m Landsat and Sentinel-2 mosaics for 2013-2019, allowing for removal of spurious changes. That inspection was corroborated by using 3m PlanetScope imagery (January 2017 – November 2019) as references, via Planet Labs' Planet Explorer interface, which is openly accessible for viewing.

Validation

The results of the study were also validated using the very high spatial resolution (VHSR) PlanetScope data. Similar to the approach taken in 2018, points were randomly generated, confined to the boundaries of a mask created from the mangrove dataset. Specifically, some 46 points were assigned to the areas mapped as changed, and another 60 points were mapped to the areas mapped as not having changed (see **Figure 1**). The protocol for determining whether the points represented mangrove or non-mangrove (i.e. change) was as follows. The change areas were examined (visually inspected) based on the year of change determined by LandTrendr. For example, if a change was detected as occurring some time in 2017, PlanetScope imagery from both 2016 and 2018 were examined (i.e. the year prior to the change, and the year following when the change was determined to have occurred). If it was possible, based on the imagery, to determine that areas had gone from vegetated to non-vegetated in a given period, they were confirmed as having changed. However, if the area was seen as still being vegetated, it was assigned "no change." If it wasn't possible, based on looking at before and after images, to determine if change occurred, those points were excluded from the analysis. The validation only focused on changes from 2016-2019 due to the unavailability of PlanetScope data prior to 2016. For the 60 points mapped as "no change," these were just examined using the most recent PlanetScope imagery (from 2020). If it was not possible to determine if the area had indeed remained mangrove or had changed, those points were also excluded from the analysis. Of the 106 sites examined, only one site was removed from the analysis as being inconclusive due to its essentially being on the edge of a cleared area.

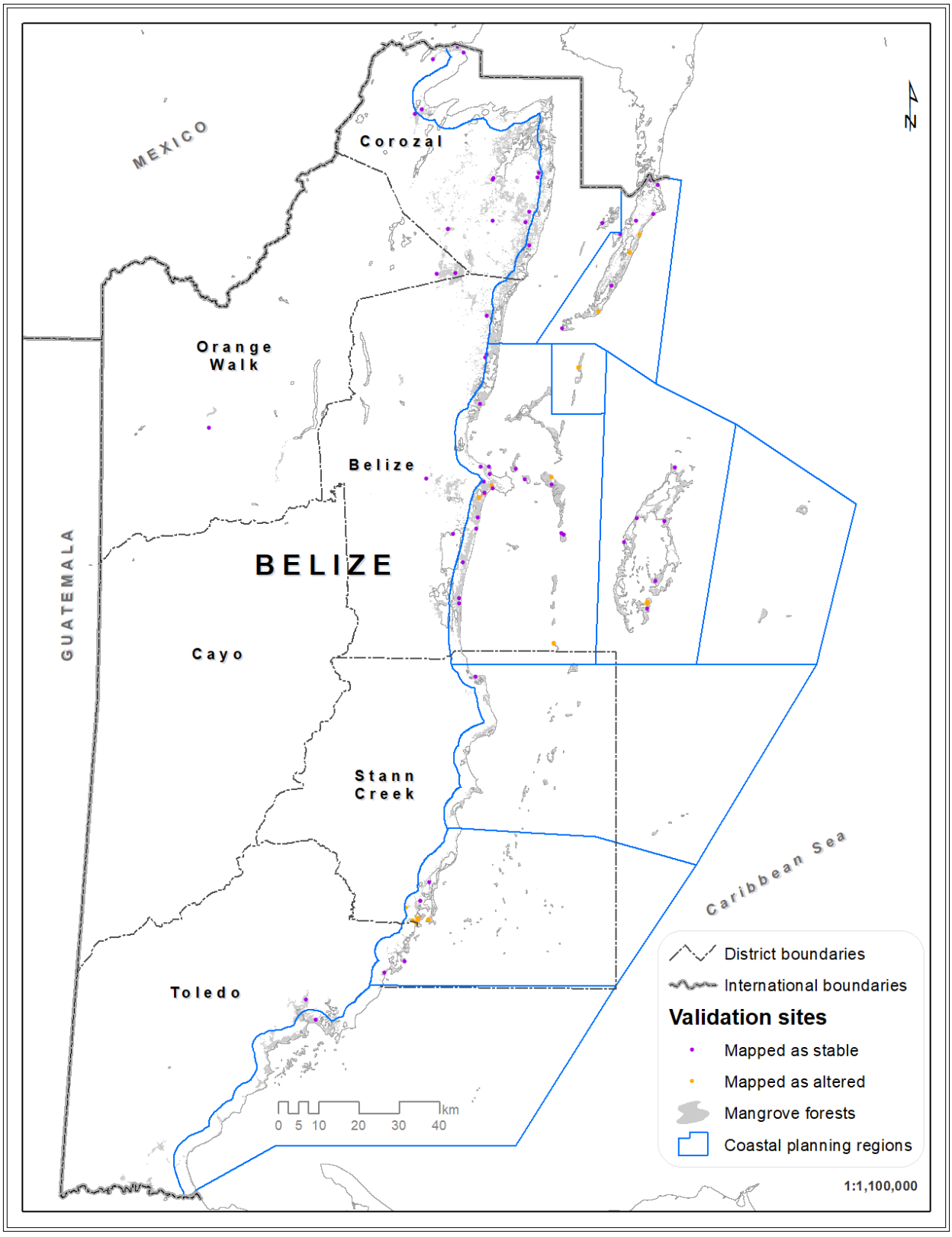

Figure 1: Locations of the sites used for validating the 2014-2019 mangrove change map

4. Results

Changes at national level

As illustrated in **Figure 2** and **Table 1**, the analysis indicates that over 2014-2019, a period spanning almost 6 years, Belize experienced a net loss of approximately 93.78 ha. of mangrove and littoral forest cover. That translates to an average annual net loss of approximately 15.84 ha. / year across all of Belize (both terrestrial and marine domains).[1] It is therefore also estimated that Belize retained 99.87% of its 2014 mangrove cover, having lost only 0.13% of its mangrove cover from 2014-2019.

Table 1: Annual net loss in Belize's mangrove and littoral forest cover, 2014-2019

Year	Area (ha.)	% loss	% remaining
2014	31.59	0.04%	99.96%
2015	19.89	0.03%	99.93%
2016	8.91	0.01%	99.92%
2017	5.94	0.01%	99.91%
2018	10.89	0.01%	99.90%
2019	16.56	0.02%	99.87%
TOTAL	**93.78**	**0.13%**	**-**

Changes within the coastal planning regions

Focusing only on the coastal and marine territory represented by the CZMAI's coastal planning regions for Belize, **Table 2** indicates that from 2014-2019, an estimated 93.78 ha. of mangrove and littoral were cleared. That translates to an annual clearing rate of some 15.63 ha. / year in Belize's coastal and marine zones. It should also be noted that in 2014, the coastal planning regions contain approximately 49,499 ha. of mangrove and littoral forest cover, some 66.1% of the country's total mangrove and littoral forest cover.

Changes within the MCCAP priority areas

Focusing only on the Caye Caulker, Central, and Southern Northern coastal planning regions – the priority zones for the MCCACP shown in **Figure 3** – **Table 3** indicates that 49.09 ha. of mangrove were cleared from 2014-2019. The data from Cherrington et al. (2018) indicated that the mangrove cover in those three regions was approximately 18,266 hectares in 2014, so the loss of 49.09 ha. from 2014-2019 thus amounted to a loss of only 0.25% of the previously existing mangrove cover. Specifically in the Central Region, only 0.21% of mangrove cover was estimated to have been lost from 2014-2019, while in Caye Caulker planning region, 1.8% of mangrove cover was estimated to have been lost, and in the Southern Northern planning region, 0.35% of the region's mangrove cover was estimated to have been lost.

[1] That is, 93.78 divided by 5.92 years (the period spanning 1 January 2014 through 30 November 2019).

Table 2: Change in Belize's mangrove and littoral forest cover across all of the CZMAI's Coastal Planning Regions, 2014-2019.

Zone	Mangrove area in 2014 (ha.)	Mangrove loss (ha.)							% loss	% remaining	Mangrove area in 2019 (ha.)
		2014	2015	2016	2017	2018	2019	TOTAL			
Northern Region	10,953	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00%	100%	10,953
Ambergris Caye	4,961	0.00	10.53	4.77	0.00	1.17	0.00	**16.47**	0.33%	99.67%	4,944
Central Region	14,792	16.83	1.53	2.88	2.16	2.88	4.14	**30.42**	0.21%	99.79%	14,762
Caye Caulker	180	0.00	0.00	0.00	1.44	1.80	0.00	**3.24**	1.80%	98.20%	177
Turneffe Atoll	6,480	0.00	0.00	1.26	0.00	1.62	0.00	**2.88**	0.04%	99.96%	6,477
Lighthouse Reef Atoll	312	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00%	100%	312
Southern Northern Region	3,294	9.54	1.89	0.00	0.00	0.00	0.00	**11.43**	0.35%	99.65%	3,283
South Central Region	3,506	5.22	5.94	0.00	2.34	3.42	12.42	**29.34**	0.84%	99.16%	3,477
Southern Region	5,021	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00%	100%	5,021
TOTAL	**49,499**	**31.59**	**19.89**	**8.91**	**5.94**	**10.89**	**16.56**	**93.78**	**0.19%**	**99.81%**	**49,405**

Table 3: Changes in Belize's mangrove and littoral forest cover in the CZMAI's three priority Coastal Planning Regions, 2014-2019.

Zone	Mangrove area in 2014 (ha.)	Mangrove loss (ha.)							% loss	% remaining	Mangrove area in 2019 (ha.)
		2014	2015	2016	2017	2018	2019	TOTAL			
Central Region	14,792	16.83	1.53	2.88	2.16	2.88	4.14	30.42	0.21%	99.79%	14,762
Caye Caulker	180	0.00	0.00	0.00	1.44	1.80	0.00	3.24	1.80%	98.20%	177
Southern Northern Region	3,294	9.54	1.89	0.00	0.00	0.00	0.00	11.43	0.35%	99.65%	3,283
TOTAL	**18,266**	**26.37**	**3.42**	**2.88**	**3.60**	**4.68**	**4.14**	**45.09**	**0.25%**	**99.75%**	**18,221**

Table 4: Error matrix for the 2019 mangrove cover change map.

	User validation dataset (VHSR imagery)							
Producer classification dataset (2019 mangrove cover map)	**Class**	**No change**	**Change**	**TOTAL**	**User accuracy**	**Total class accuracy**	**Map area (ha.)**	**Weighting**
	No change	60	0	60	100%	96.77%	74,672	0.9987
	Change	2	43	45	95.56%	95.56%	94	0.0013
	TOTAL	62	43	**105**			74,766	1.0000
	Producer accuracy	96.77%	100%			**98.10%**		

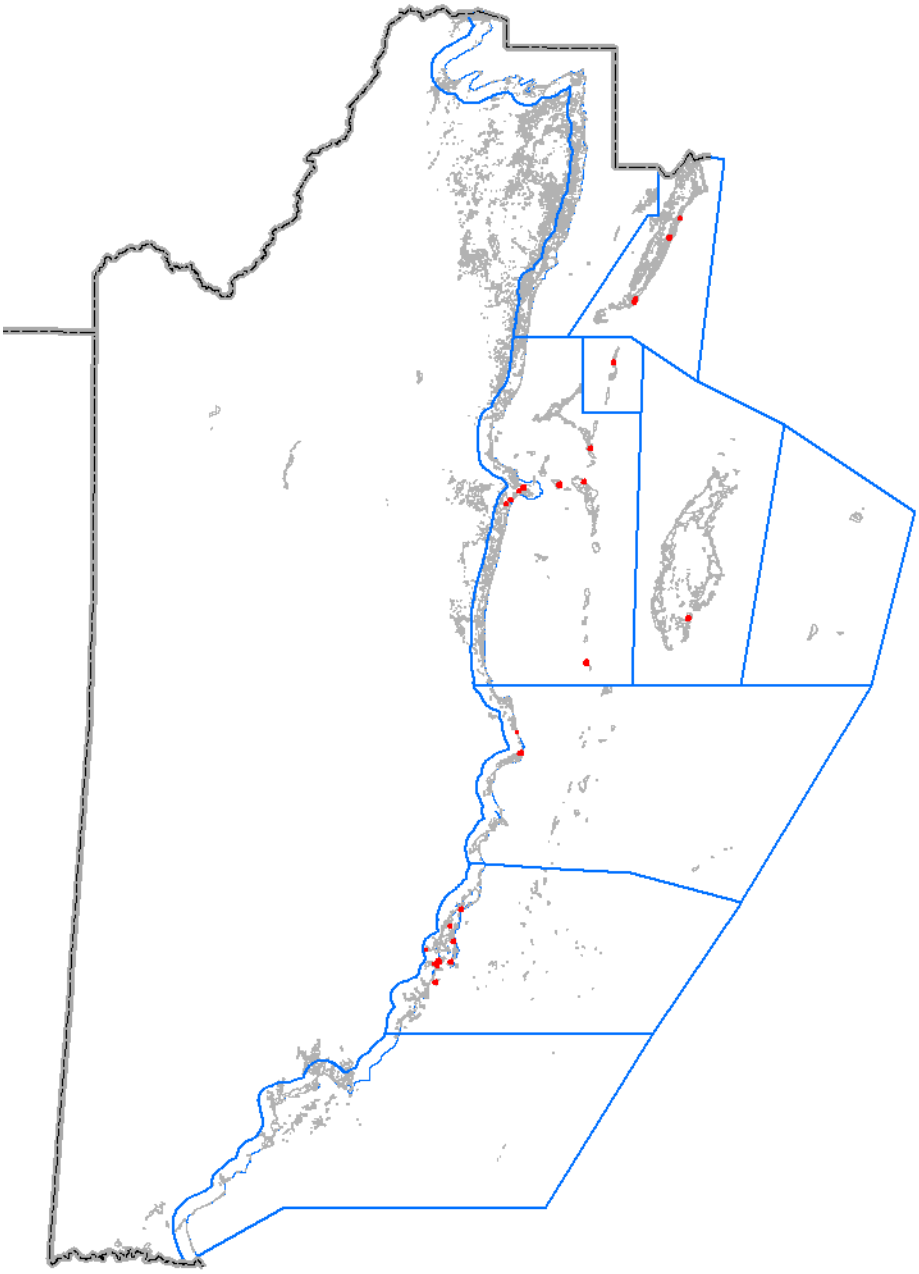

Figure 2: Mangrove / littoral forest cover change (2014-2019) across Belize's territory and coastal planning regions; mangroves are depicted in grey, and areas of change (staggered) are depicted in red.

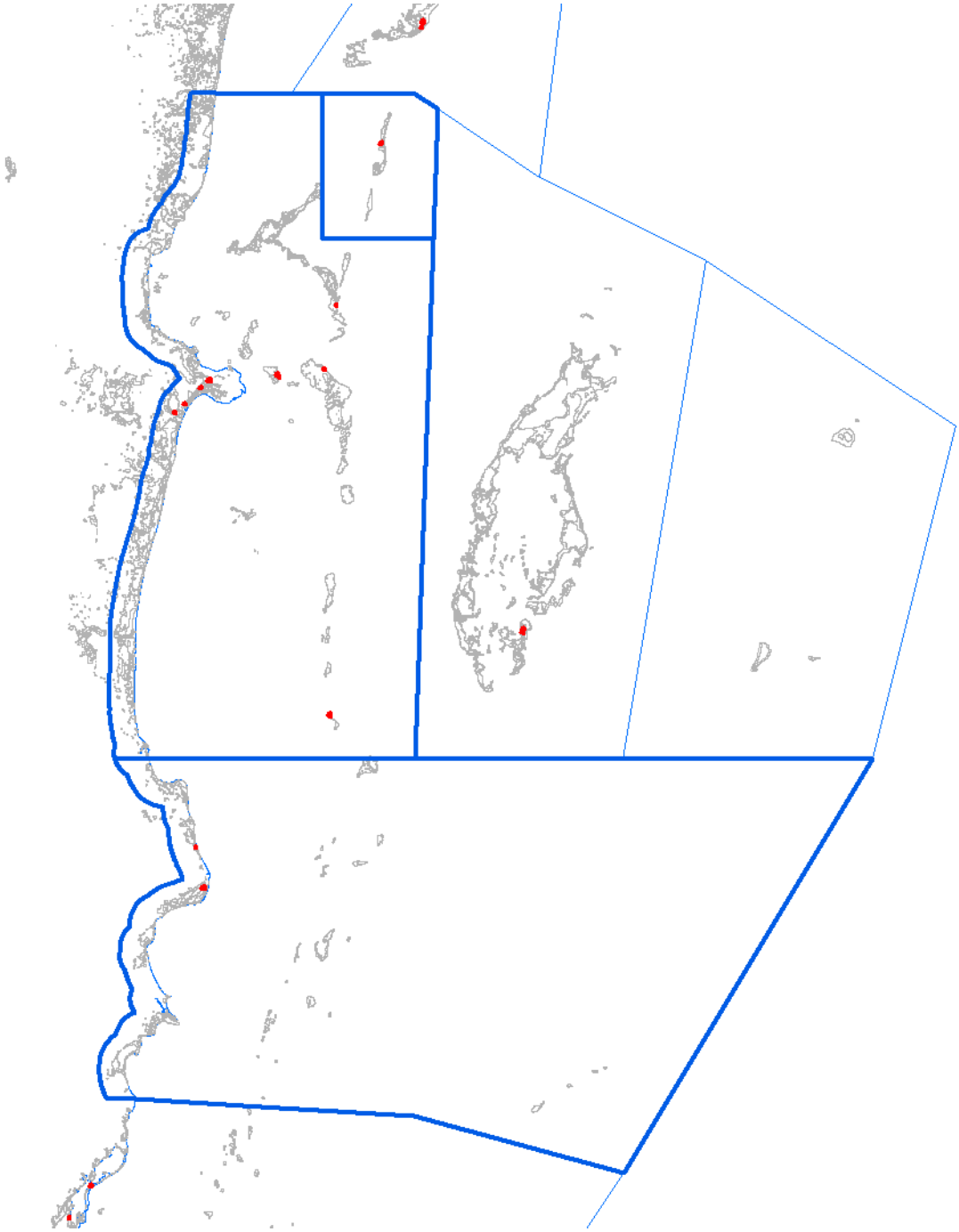

Figure 3: Mangrove / littoral forest cover change (2014-2019) in the Caye Caulker, Central Region, and Southern Northern Region coastal planning regions; mangroves are depicted in grey, and areas of change (staggered) are depicted in red.

Accuracy assessment

In terms of the validation exercise, the accuracy assessment determined that the overall accuracy exceeded 98%. In addition, there were high class accuracies for both the mangrove areas mapped

as changed and the areas mapped as stable (both exceeding 95%). The user accuracies and producer accuracies for the change and no change data likewise exceeded 95%.

5. Discussion

The results indicated that at the national level, Belize lost approximately 94 ha. of mangrove cover over a six-year period spanning January 2014 to December 2019. Relative to the 2014 baseline, the country lost only 0.13% of its total mangrove cover in those 6 years, which can be considered relatively small when compared to the mangrove clearing rates of neighboring countries, if one is able to consider longer time spans. The rate of loss translates to the clearing of approximately 15.6 ha. / year, compared to an estimated rate of clearing of 235 hectares per year in the neighboring state of Quintana Roo in Mexico, for instance (Valderrama-Landeros et al. 2017). However, the earlier Cherrington et al. (2018) study – which did use a slightly different methodology – estimated that Belize's rate of mangrove clearing, albeit over the period 1980-2017, was on the order of between 44 and 89 hectares per year. To a certain extent, the rate of clearing of 15.6 ha. / year may represent a slowdown in mangrove clearing. Whether that slowdown is due to enhanced protection of mangroves or lower development pressures remains to be seen.

Another finding of note – visible in **Figure 2** – is that all of the clearings of mangroves occurred either offshore or within the three-kilometer buffer from the coast, i.e. the areas represented by CZMAI's coastal planning regions. Of the nine coastal planning regions, however, mangrove clearings were not observed in three zones (i.e. the Northern Region, the Lighthouse Reef Atoll, and the Southern Region). While most of the clearings were observed to have occurred in the Central Region which includes the area around Belize City – and closely followed by the South Central Region which includes the Placencia Peninsula – the region with the highest relative rate of change was actually the Caye Caulker region. Due to the small size of that planning region, the clearing of only 3.24 ha. of mangrove between 2014 and 2019 translated to a loss of 1.8% of the region's 2014 mangrove cover.

It should also be noted, however, that the Central Region and the South Central Region's mangrove clearings accounted for almost two thirds of the clearings observed from 2014-2019. Likewise, the absolute area of clearing in the Ambergris Caye planning region represented a little over half that of the Central Region's clearings (i.e. 16.47 ha. to 30.42 ha.), while the Southern Northern Region's clearings – at 11.43 ha. were roughly a third the area of the clearings in either the Central Region or the South Central Region. In the other planning region where changes were observed, i.e. the Turneffe Atoll, only approximately 2.88 ha. of mangrove was cleared from 2014-2019.

Where the Central Region, Caye Caulker region, and Southern Northern Regions were the focus areas for the MCCAP, the changes observed – amounting to approximately 45.09 ha., or almost half of the overall clearing in Belize – represented a decline of 0.25% relative to the 2014 baseline for mangrove cover. That can likewise be considered minimal. A potential cause for concern, however, would be that much of the clearings observed have been occurring on offshore cayes, as shown in **Figures 2-3**. For instance, in the Central Region, almost half of the 30.42 ha. cleared were observed to have occurred on offshore islands (compared to the other half of clearings which occurred near Belize City). Anecdotal information – like the presence of survey lines seen in the

VHSR imagery used for validation – would also suggest that Caye Caulker will be an epicenter for future mangrove clearing.

The accuracy assessment would indicate that the overall veracity of the data generated is high. The areas mapped as changed but which were determined to have remained mangrove, were fairly close to areas with change, so the discrepancy might merely have been due to differences in the spatial resolution of the input data for the change detection (i.e. 30m), and that of the data used for the validation (i.e. 3m). Overall, the results would indicate that the LandTrendr algorithm performed well in correctly identifying areas of change, and while there were errors of commission (potentially overestimating), there were no errors of omission noted. Compared with the CLASlite-based methodology of Cherrington et al. (2018), the use of LandTrendr appears to have yielded improved results, although the period of analysis was also shorter.

6. Conclusions

This study utilized remote sensing to examine changes in the cover of mangrove and littoral forest across coastal Belize for the period 2014-2019. It found that within the three priority coastal planning regions for the MCCAP, the reduction in mangrove and littoral forest cover (2014-2019) was estimated at 45.09 ha., amounting to a loss of 0.25% of the areas' overall mangrove and littoral forest cover. Losses in mangrove cover (2014-2019) were observed for the Central Region, Caye Caulker and Southern Northern planning regions, with respective losses of 0.21%, 1.8%, and 0.35% of 2014 mangrove cover of those regions. Across Belize, however, the net loss of mangrove and littoral forest cover is estimated at 93.78 ha., equaling an average annual net loss of approximately 15.63 ha. / year. That equated to an estimated loss of 0.13% of Belize's 2014 mangrove cover, indicating that in late 2019, 99.87% of Belize's 2014 mangrove cover remained. The overall accuracy of the data generated was estimated at 98.1%.

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