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Research Article

Change Detection of a Coastal Woodland Mangrove Forest in Fiji by Integration of Remote Sensing with Spatial Mapping

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ABSTRACT

Mangroves play key ecological role in structuring the availability of coastal resources. The current study was focused on change detection in a large mangrove patch located in Votua area of the Ba province in Fiji. Globally, the mangrove population continues to decline with the changes in climatic conditions and anthropogenic activities. Baseline information through wetland maps and time series change are essential references for the development of effective mangrove management plans. These maps reveal the status of the resource over a period of time and the impacts from anthropogenic activities. Remote sensing techniques were integrated with geographic information system tools for mapping and detecting temporal change over a period of 20 years. Remotely sensed imagery data from Landsat satellite was sourced from the year 1999 to 2018 for this investigation. The mapping analysis of temporal changes in mangrove forests was carried using the versatile ArcGIS and ENVI software. The pilot change detection analysis revealed a small but important change in the mangrove patch over these years. Landward creep of mangroves was also detected. The outcomes of this study serve as baseline and conservation information for the development and implementation of effective management plans for one of Fiji's largest mangrove patches.

Key words: Coastal, GIS, Landsat, temporal change, climate change, anthropogenic activities

INTRODUCTION

Mangroves are one of the most productive natural ecosystems that perform a vital role in enriching the habitat for diverse marine and terrestrial fauna and flora (Reddy & Pattanaik, 2007). Globally, the annual monetary value of mangrove ecosystem and tidal marsh services are approximated to be around USD$32 billion, while the valuation of mangroves of the Pacific Islands countries (PICs) ranges from $4,300USD-$8,500USD per hectare yr^{-1} (Atkinson *et al.,* 2016); Pascal & Bulu, 2013). An increasing population coupled with urban and industrial development and a changing climate pose a significant threat to mangrove forests. Retreat of mangrove seaward edge caused by rising sea levels and projected altered climatic conditions is projected to cause accelerated rates of mangroves losses in a number of PICs including Fiji calling for the need for spatial and temporal mangrove monitoring (Ellison, 2018).

In the PICs, the coastal communities make use of the mangrove areas to harvest fish and other aquatic resources for food. Mangroves are also used as fuelwood and building materials (Field, 1999; Adeel & Pomeroy, 2002; Alongi, 2002; Gilman *et al.,* 2006; Dasgupta & Shaw, 2017; Devi, Lowry & Weber, 2017; Veitayaki *et al.,* 2017). Goods and services provided by mangroves are essential for the large coastal communities across PICs. Coastal communities in Fiji, especially women play key role as caretakers and support conservation efforts for mangrove forests (Pearson, McNamara & Nunn, 2019; Thomas *et al.,* 2020). Coastal communities possess valuable insights for management of mangroves however, this needs to be combined with scientific investigations and reliable information for directed efforts towards effective management. Limited detailed studies in Fiji on spatial and temporal variation in mangrove structure creates knowledge gaps critical for decision making towards conservation efforts at both government and community level (Sangha *et al.,* 2019: Cameron *et al.,* 2021). Thus, it is important to monitor mangrove ecosystem using advanced mapping systems for effective conservation and management.

Literature sources have shown that mangrove areas in PICs display distinctive patterns in terms of location and diversity. The largest mangrove area in the South Pacific region are found in Fiji, New Caledonia, Solomon Islands and Papua New Guinea (Ellison & Fiu, 2010; Bhattarai, 2011; Cameron *et al.*, 2021). Mangrove plants in Fiji consist of the species *Rhizophora stylosa*, *Rhizophora samoensis*, *Bruguiera gymnorrhiza*, *Lumnitzera littorea*, *Heritiera littoralis*, *Excoecaria agallocha* and *Xylocarpus granatum* (Ellison & Fiu, 2010).

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In Fiji, according to Woodroffe (1987), the most diverse mangroves are found in Rewa Delta, where rivers deposit large quantities of sediments on lowlands. The largest mangrove patches in Fiji occurs in the Votua region of the Ba province and Nabouono of the Macuata and Cakaudrove Province (Aksornkoae, 1986; Ellison & Fiu, 2010). Fiji's economy is heavily reliant on revenue from tourism activities (Scheyvens & Russell, 2012; Carrizosa & Neef, 2018; Jayaraman, Choong & Fatt, 2018). Patches of mangrove have been removed in the past for construction of hotels and other attraction sites (Levett & McNally, 2003; Becken, 2005). Yet, the systematic overall change detection study of mangrove patches is lacking in Fiji and the Pacific.

The benefits of mangrove forest to the coastal environment and its inhabitants are well known and recognized. They provide various critical ecosystem services as well as support of local livelihoods including storage and sequestration of blue carbon (Fromard *et al.*, 1998; Komiyama, Ong & Poungparn, 2008; Donato *et al.*, 2011; Saatchi *et al.*, 2011; Siikamäki, Sanchirico & Jardine, 2012). Mangroves act as hosts for various flora and fauna belonging to both aquatic and terrestrial ecosystems as well as provide resources to support socioeconomic livelihoods of coastal communities (Kathiresan & Rajendran, 2005; Gilman *et al.,* 2006; Aburto-Oropeza *et al.*, 2008; Walters, 2008; Barbier, 2016; Narayan *et al.,* 2016; Himes-Cornell, Pendleton & Atiyah, 2018). Over the years, efforts have been directed to help mangrove forests restoration in Fiji. For instance, during the year 1985 to 1986 a Mangrove Management Plan (MMP85) was prepared by the South Pacific Commission with the government of Fiji's Department of Fisheries (Watling, 2013). MMP85 has been discussed widely over the past decade, however, lack of funding and leadership have hindered its implementation. Dunlap and Singh, (1980) stated that in 1980, the National Trust for Fiji proposed the need for certain mangrove regions to be fully protected. These culminated into the recent Mangrove Management Plan MMP2013 that aims to act as a guideline to administer, facilitate and regulate the development and management of mangroves within Fiji (Watling, 2013). Despite, the MMP2013 plan, legislation for the protection of mangroves, actions taken and the outcomes are not being properly reported due to a lack of monitoring and evaluation mechanism. A major challenge faced by many PICs', including Fiji in developing and implementing effective management plans is the unreliable data for vegetation maps over a time series (Kairo, Kivyatu & Koedam, 2002). Hence, remote sensing combined with Geographic Information Systems (GIS) tools can provide a suitable platform for devising such a management plan.

The employment of remote sensing is an attractive means of obtaining data via satellites on defining areas of loss and formulation of management plans (Zuhair, Hussin & Weir, 2001; Thenkabail, Lyon and Huete, 2012; Gupta, 2018). GIS is instrumental in monitoring and studying anthropogenic activities in terrestrial, coastal and aquatic ecosystems which can otherwise prove to be quite challenging in terms access to the ecosystem and performing spatial analysis (Davis & Quinn 2004; Aswani & Lauer 2006; McCoy *et al.,* 2015; Elliott *et al.,* 2018). GIS has the capacity to combine diverse data and techniques into a mapping framework. In addition, the use of such techniques has the capacity to provide information on large geographical areas on earth over a short period of time. This is attributed to advancements made in Earth Observation technology such as better sensors, higher resolution images for object identification and better high-quality image processing techniques (Purnamasayangsukasih *et al.,* 2016). Therefore, leveraging GIS with Earth Observation technology offers a convenient and efficient system for data collection, management and depiction, while enabling easy mapping and a wide range of analytical options. The importance of baseline information on mangroves using spatial imagery for management purposes has been highlighted previously (Gilman *et al.,* 2006).

Although mangrove forests are categorized as highly important, reliable and comprehensive information on changes taking place in the mangrove distribution in Fiji is inadequate. The quantification and rate of change to the mangrove forest distribution, abundance and diversity is also unknown but can be accurately and cost-effectively determined using GIS and remote sensing. The objective is to integrate remotely sensed imagery with GIS analysis tools to conduct a reliable and accurate change detection study of the mangrove forest in Votua area of the Ba province in Fiji between the years 1999 and 2018.

MATERIALS AND METHODS

Study Area

The study site includes the mangrove area in the coastal estuarine and river system in Votua, Ba region, Fiji. It is located off the coast of Northern Viti Levu, which is the largest island out of approximately 330 islands in the Fijian archipelago. Geographically, the site is situated between the longitudes 177º 37' E - 177 º 45' E and latitudes 17º 26' S - 17º 30' S as shown in Figure 1.

Data Collection

Landsat satellite imagery for October 1999 and July 2018 was acquired from the United States Geologic Survey (USGS) website (USGS 2018). These dates were selected to observe a 20-year change. Image for same months would have been ideal but could not be used due to obstructions in the images such as cloud cover. The Landsat Enhanced Thematic Mapper (ETM) has seven spectral bands with a horizontal resolution of 30m. Landsat 8 has 9 spectral bands with a horizontal resolution of 30m for bands one-seven and nine with the exception of band 8; the panchromatic band which has a resolution if 15m (Table 1). The spectral bands of both the satellites are similar but Landsat 8 provides enhancement to instruments through two new spectral bands. For water resources and investigation of coastal zone, there is a visible deep blue channel. Band 9 is a new infra-red channel which is used for cloud detection. The images are orthorectified and radiometrically calibrated using digital elevation model data and ground control points. These are Level-one products of the highest quality and are suited for pixel-level time series analysis (Barsi *et al.,* 2014, USGS, 2018). Aerial photographs and Google Earth Pro were used to validate the interpreted mangrove maps.

The date of image acquisition is very important since vegetation is affected by the rainy season due to temperature disparity and phenology; hence there is variation in reflectance between dry and rainy season (Dan *et al.,* 2016). Mangroves grow on the land and sea interface which accounts for three major features that

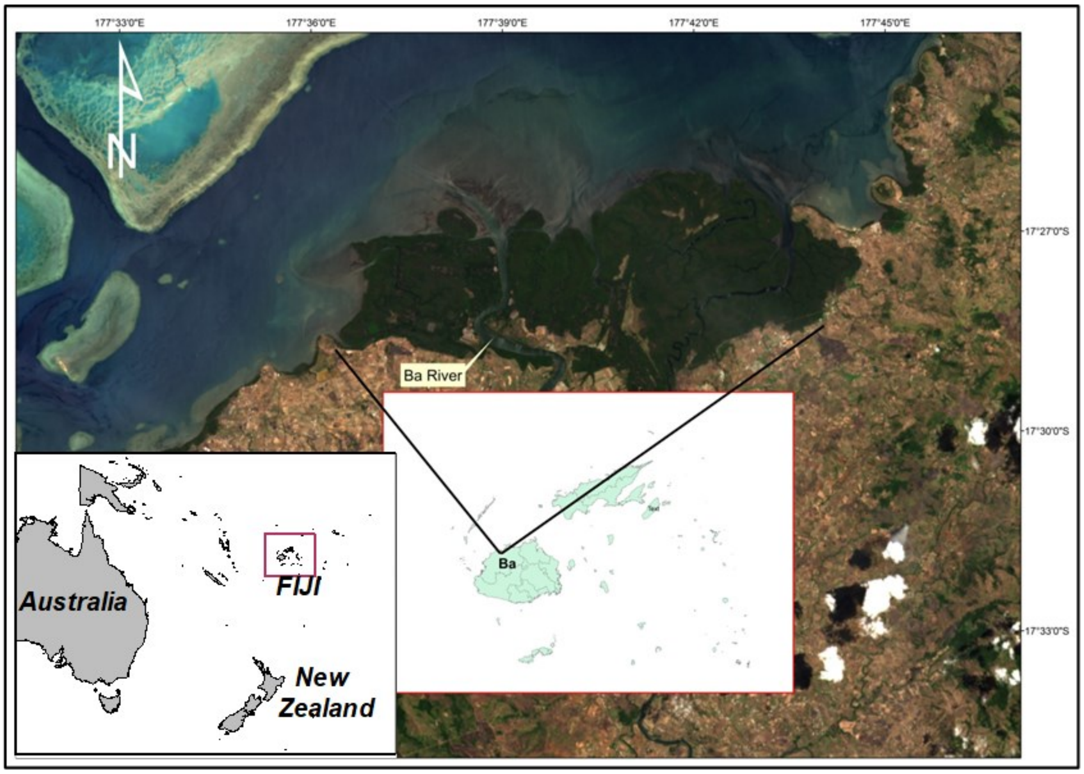

Figure 1. Location of study site at the Ba River estuarine and river system on Viti Levu, which is the largest Island in Fiji. Inset shows the location of Fiji Islands with the South Pacific Region. Geographical coordinates for the study site are: longitude 177˚ 37' - 177 ˚ 45' and latitude 17˚26' - 17˚30'.

Table 1. Landsat 7 TM and 8 OLI spectral bands showing the wavelengths and resolutions for each spectral band. (Sources: Barsi *et al.,* 2014; USGS, 2018).

Image type	**Bands**	**Wavelength (micrometers)**	**Resolution (meters)**
Landsat 7 - Enhanced Thematic Mapper Plus (ETM+)	Band 1 – Blue	0.45-0.52	30
	Band 2 – Green	0.52-0.60	30
	Band 3 – Red	0.63-0.69	30
	Band 4 - Near Infrared (NIR)	0.77-0.90	30
	Band 5 - Shortwave Infrared (SWIR) 1	1.55-1.75	30
	Band 6 – Thermal	10.40-12.50	60[a] (30)
	Band 7 - Shortwave Infrared (SWIR) 2	2.09-2.35	30
Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS)	Band 1 - Ultra Blue (coastal/aerosol)	0.435 - 0.451	30
	Band 2 – Blue	0.452 - 0.512	30
	Band 3 – Green	0.533 - 0.590	30
	Band 4 – Red	0.636 - 0.673	30
	Band 5 - Near Infrared (NIR)	0.851 - 0.879	30
	Band 6 - Shortwave Infrared (SWIR) 1	1.566 - 1.651	30
	Band 7 - Shortwave Infrared (SWIR) 2	2.107 - 2.294	30
	Band 8 – Panchromatic	0.503 - 0.676	15
	Band 9 – Cirrus	1.363 - 1.384	30
	Band 10 - Thermal Infrared (TIRS) 1	10.60 - 11.19	100 [b] (30)
	Band 11 - Thermal Infrared (TIRS) 2	11.50 - 12.51	100 [b] (30)

[a]ETM+ Band 6 is acquired at 60-meter resolution, but products are re-sampled to 30-meter pixels.
[b]TIRS bands are acquired at 100-meterresolution but are re-sampled to 30 meters in delivered data product.

contribute to pixel compositions in satellite imagery at this interface including vegetation, soil and water affected by a mixture of these surface appearances. These features are influenced by diurnal and seasonal intertidal actions (Kuenzer *et al.,* 2011). In Fiji has two distinct seasons; dry season is from May and October and wet season is from November to April. Hence imagery acquisition times were checked against tidal activity to ensure there wasn't any disparity. Both images used were taken at low tidal conditions.

Image processing

As described by Kuenzer *et al.,* (2011) the image processing algorithms and methods available for mapping mangrove cover vary widely. Most of the methods can be combined or used exclusively, however, in principle, a mangrove mapping method should include the components of visual interpretation, on-screen digitizing, detailed ground information as the reference input and supervised or unsupervised classification methodologies. Such analysis entails four main stages: (i) pre-processing of data, (ii) classification of image, (iii) accuracy assessment, (iv) change detection analysis.

This study entails the stages mentioned above using ArcMap 10.5 and ENVI 5.5. ENVI 5.5 was used for satellite image pre-processing (radiometric, geometric and atmospheric correction), supervised image classification, accuracy assessment and doing the change detection analysis. ArcMap 10.5 was used to construct the geo-database, generate random sampling points to aid in the image analysis - classification and accuracy assessments. The processes are discussed in more details in the following sections.

Image pre-processing

Satellite imagery may show some form of distortion in geometric location between different sensors. In addition, misalignment of pixels could occur due to different viewing geometry as well as distortions in terrain. Consequently, the ENVI5.5 Image Registration Workflow was used to geometrically align the images to get them into the same coordinate system; WGS 84 UTM 60S. This workflow generates tie points automatically and correctly eliminating the need for user interaction and editing. The 2018 Landsat 8 image was used as the base image. The 1999 Landsat 7 image was aligned, resampled and then wrapped to the Landsat 8 image. The resulted in corresponding pixels representing same objects in both the imagery.

The images were downloaded as product level L1T and L1TP for the 1999 and 2018 imagery respectively. ENVI's Radiometric Calibration (Harris Geospatial Solutions, 2018) was used to calibrate the raw imagery to produce radiance image by multiplying metadata based gain with the pixel value as well as adding the offset. Then the atmospheric effects were reduced by implementation of radiometric corrections using Fast Line-of-sight Atmospheric Analysis of Hypercubes (FLAASH) technique. Following that image registration was performed since remotely sensed data may have some form of distortions when acquired from different sensors (Dan *et al.,* 2016).

Image Classification

Using ArcMap 10.5 software, 250 sampling points were randomly generated on a high resolution (20 cm) aerial photograph of the study site. The aerial imagery was taken in the month on June, 2018. To avoid autocorrelation and multiple points being generated in one image pixel, a 30m threshold for minimum distance between sampling points was set. Since most mangrove mapping applications focus on discrete differentiation amongst mangroves and non-mangrove area (Vo *et al.,* 2013), the points were characterized into the following classifications: 'mangrove', 'mudflats' and 'up-land-vegetation'. The aerial photographs were used to classify the points. Later, the points were randomly separated with half the points, 125 sampling points for the training sample to classify the image and the remaining 125 sampling points as validation points to be used for accuracy assessment of the generated maps. The most frequent approach to mapping mangroves using satellite imagery is a pixel-based classification (Tong *et al.,* 2004; Béland *et al.,* 2006; Vo *et al.,* 2013; Dan *et al.,* 2016,) and has been adopted in this study.

One of the most widely used classification techniques; Maximum Likelihood Classification (MLC) was used to classify pixels. In a similar study by Kanniah *et al.,* (2015), MLC provided better results and less "salt and pepper effect" with higher accuracies. MLC assumes that data has normal distribution and then it calculates the probability for each pixel to belong to a particular class before assigning it to the class that has the maximum probability.

Accuracy Assessment

An essential component of image classification is accuracy assessment (Vo *et al.,* 2013). Accuracy assessment measures the correctness of the classification and the performance of the MLC classification algorithm. ENVI 5.5 Calculate Confusion Matrix tool was used to compute confusion and accuracy metrics. This assessment report pairs the accuracy assessment points with the classes in the classified image. The resulting output displays the percentage accuracy assessment points in the respective classes (Harris Geospatial Solutions, 2018).

Change Detection Analysis

Change detection analysis is a collection of methods which may be used to quantify, describe or identify between imagery and maps of the same scene under different conditions and time (Harris Geospatial Solutions, 2018). The analysis is usually done between pairs where one represents the initial state while the other is the final state. The Thematic Change workflow can be used to analyze change in land cover, land use, deforestation, urban expansion and more. Thematic Change workflow overlays the initial and final states and performs image co-registration before performing the analysis. For the purpose of this study, supervised classification results for the 1999 Landsat 7 imagery was taken as the initial stage and 2018 Landsat 8 imagery as final. Results from the image co-registration are then used to compute which classes have changes and by how much. Table 2 shows the different classes that were used for classification of ground cover.

RESULTS

An accuracy assessment of the MLC classifier algorithm was performed resulting for the 1999 Landsat 7 imagery of Votua mangrove forest is shown in Table 3. The overall classification accuracy was determined to

Table 2. Description of classes used in the classification

Class	Description
Mangrove	Dense and sparse mangrove cover.
Mudflats	Coastal wetland formed due to deposition of mud from rivers.
Up-land-vegetation	Woodland, grass and shrub land habitats that follow immediately after the mangroves.

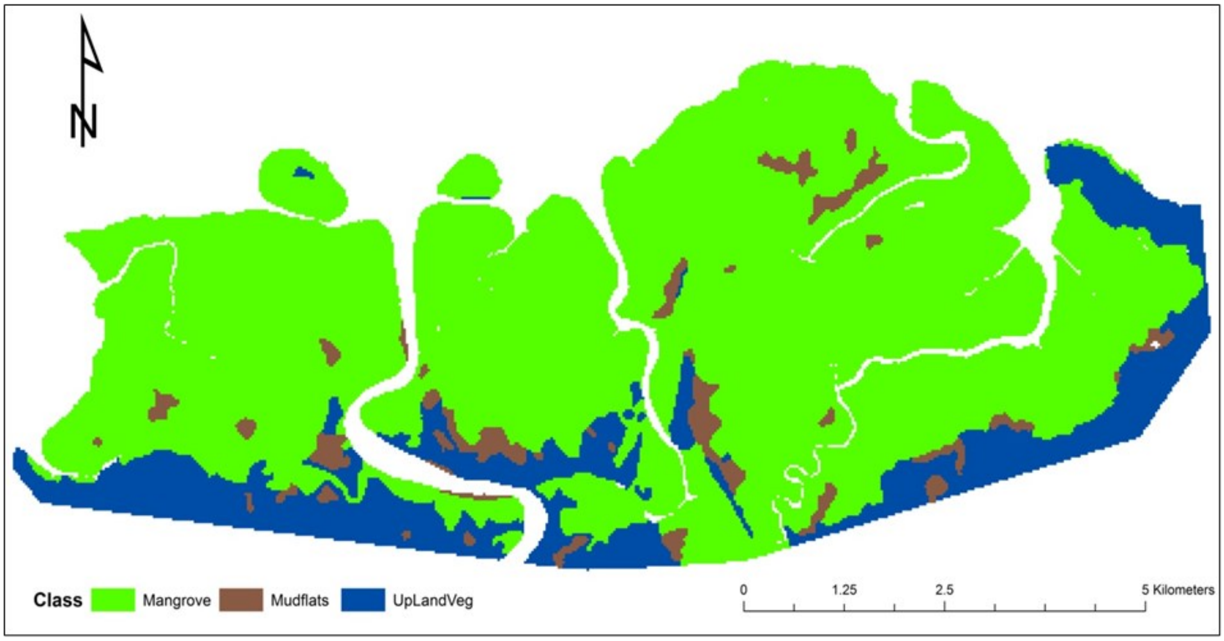

Figure 2. Landsat 7 Imagery for the year 1999 of the Votua Mangrove forest in Ba, Fiji. Shown is the coverage represented by three different ground cover classes; 'mangrove', 'mudflats' and 'up-land-vegetation'.

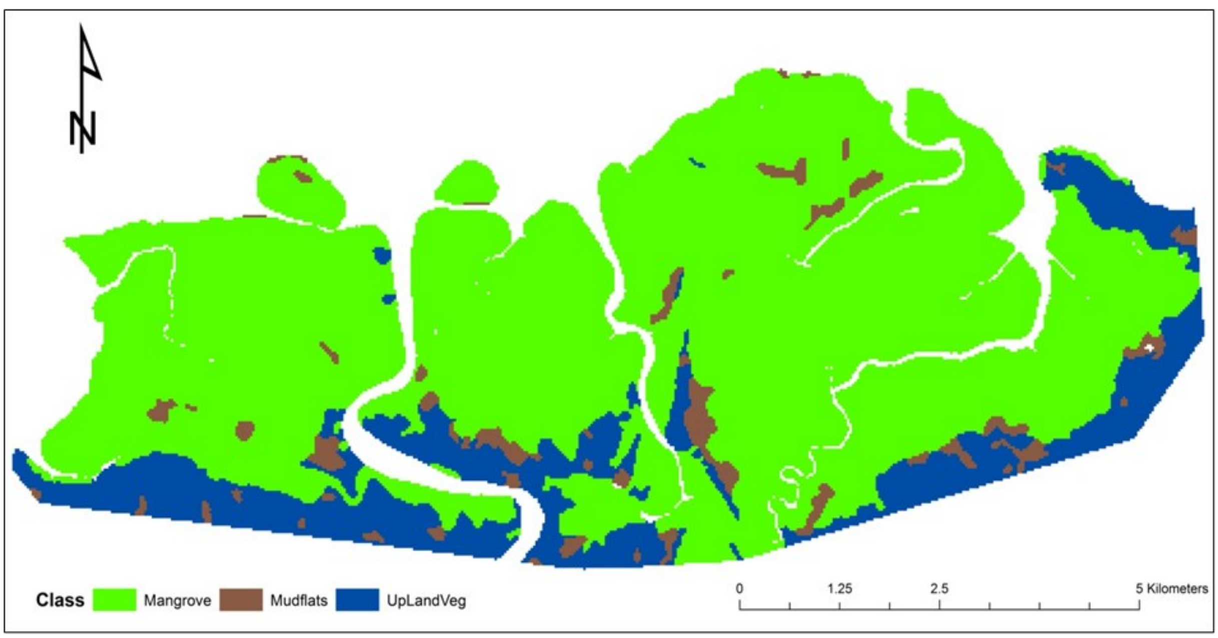

Figure 3. Landsat 8 Imagery for the year 2018 of the Votua Mangrove forest in Ba, Fiji. Shown is the coverage represented by three different ground cover classes; 'mangrove', 'mudflats' and 'up-land-vegetation'.

Table 3. Confusion matrix and the coverage area for the four different classes and accuracy assessment for 1999 Landsat 7 Imagery of the Votua Mangrove forest in Ba, Fiji.

Class	Producers Accuracy	Users Accuracy	Overall Accuracy	Kappa Coefficient	Cover Area (km^2)
Mangrove	100	93.18	92.31%	0.87	45.4401
Mudflats	85.71	96.00			2.3139
Up Land Vegetation	77.078	77.78			9.5301

Table 4: Confusion matrix and ground cover for the four different classes and accuracy assessment for 2018 Landsat 8 Imagery of the Vogue Mangrove forest in Ba, Fiji.

Class	Producers Accuracy	Users Accuracy	Overall Accuracy	Kappa Coefficient	2018 (km^2)
Mangrove	97.56	97.56	94.87 %	0.91	45.7263
Mudflats	92.86	96.30	-	-	2.2284
Up Land Vegetation	88.89	80.00	-	-	9.3294

be 92%. The Kappa hat classification value, which is a measure of the alignment of the reference data point to the classification map classification, was found to be 0.87. This is substantial agreement of the aerial image interpretation with the data identifying the resulting map as highly reliable with reference to the Kappa hat value (Landis & Koch 1977; Tymków & Wroclow, 2011; Bogoliubova & Tymków, 2014). Figure 2 shows the final classified images using the *MLC trained classifier*. Figure 2 and Table 3 clearly show that in 1999 the ground cover at the study site was dominated by mangrove trees followed by mudflats and up-land-vegetation.

For the 2018 Landsat imagery of Votua mangrove forest, the MLC classifier shows an overall accuracy of 95% and the Kappa hat classification is calculated to be 0.91 (Table 4). These values indicate the map is Of highly reliable accuracy (Landis & Koch 1977; Tymków & Wroclow, 2011; Bogoliubova & Tymków, 2014). Ground cover classification from Table 4 and Figure 3 show the dominance of mangrove forest cover followed by mudflats and up-land-vegetation, which is similar to the year 1999 results (Table 3, Figure 2).

Next, the change detection analysis at these two epochs (1999 and 2018) was performed. The change detection analysis presented in Figure 4 shows the differences in the mangrove forests classed as "decline", “generation” and “no-change”. While the larger proportion of the mangrove cover seems to be intact, most of the changes seem toward the inland area of the forest. Along the edges of the mangrove forest, significant changes can be observed for 'collapse' and 'generation' of mangrove trees (Figure 4).

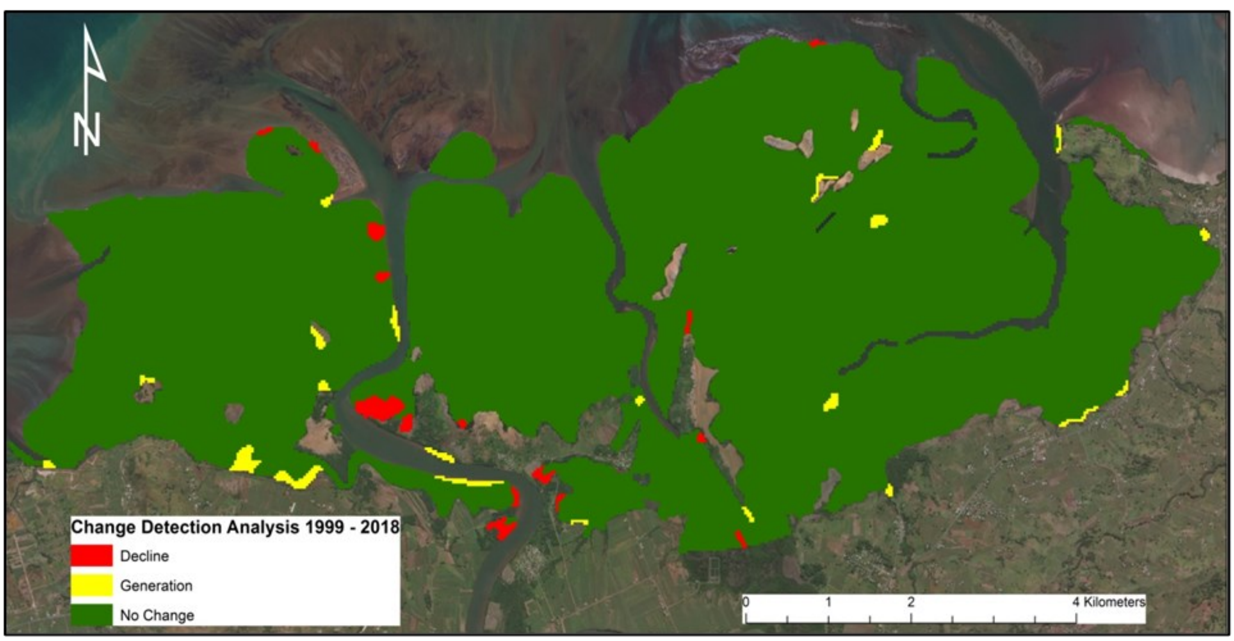

Figure 4: Change detection analysis of mangrove cover between the years 1999 and 2018 at Votua Mangrove forest in Ba, Fiji. Three class of change are shown; 'decline', where mangroves have ceased to exist, 'generation', where new mangrove cover has arisen and 'no change', where no change in mangrove cover was detected.

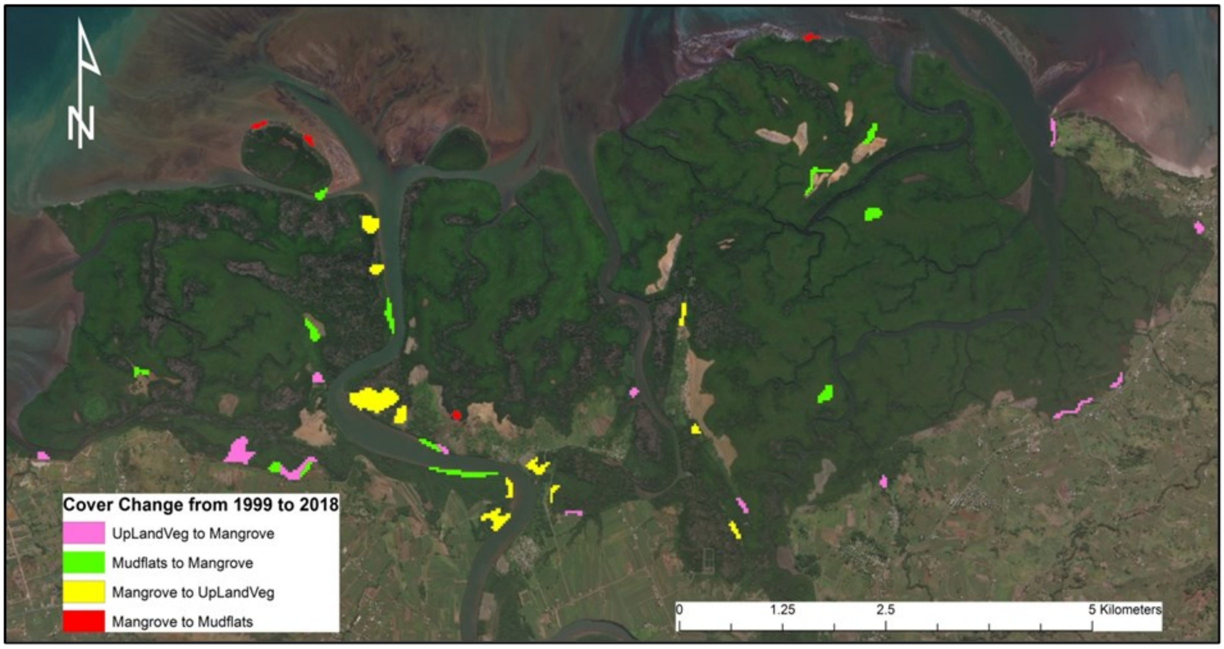

Figure 5: Changes in different classes of ground cover from one type to another between the years 1999 – 2018 for the Votua Mangrove forest in Ba, Fiji. Four types of ground cover changes were identified as 'uplandveg to mangrove', 'mudflats to mangrove', 'mangrove to uplandveg' and 'mangrove to mudflat'.

Table 5. Changes in land area coverage between the years 1999 and 2018. (NB: Cover change is in reference to the areas covered within the mangrove forest area shown in Figure 2 and Figure 3).

Class	1999 (km^2)	2018 (km^2)	Change (km^2)	Change (%)
Mangrove	45.4401	45.7263	+0.2862	+0.63
Mudflats	2.3139	2.2284	-0.0855	-3.7
Up Land Vegetation	9.5301	9.3294	-0.2007	-2.11

A further analysis was performed to determine the types of ground cover changes between 1999 (Figure 2) and 2018 (Figure 3). Four classes were identified (Figure 5) including 'upland veg to mangrove', where the up-land-vegetation cover has changed to mangrove cover, 'mudflats to mangrove', where the mudflats have changed to mangrove cover, 'mangrove to uplandveg', where mangrove cover has changed to up-land-vegetation and 'mangrove to mudflat', where the mangrove cover has turned into mudflats. Table 5 summarizes the changes in land cover between 1999 and 2018. The changes are in reference to the ground coverage classifications for the years 1999 and 2018. The area of mudflat cover has reduced significantly while mangrove coverage has increased. This is evidence that in total more mudflat area may have turned into mangrove cover compared to mangrove areas turning into mudflats. Figure 5 also shows that over the 20 year period there has been a creep of mangrove cover further inland where mudflats and upland vegetation have turned into mangrove cover.

DISCUSSION

Mangrove forest cover is controlled by biotic and abiotic variables including environmental factors such as tidal inundation, soil pore size, water salinity level, pests, diseases and sediment stability. These factors have impact on mangrove forests distribution, development and growth (Dissanayake & Chandrasekara, 2014). Mangrove plants are quite sensitive to trivial changes in coastal conditions. Different mangrove species have specific tolerance ranges towards change in the environmental variables which restricts the mangroves to zones that is most optimum for growth and development (Kairo, Kivyatu & Koedam, 2002). These forests are commonly known to attract eco-tourism, fishers and bird watchers and offer valuable national income sources. They also provide potential economic gains for the locals who rely on the natural resources supported by mangroves (Alongi, 2002; Vo *et al.,* 2013). A major area of concern continues to be the impacts induced through human activities. These include population growth rate especially in urban zones of tropical coastal areas which are potentially harmful to the mangrove forests. In Fiji, mangrove forests are under continuous threat from harvest for wood (firewood and building), cyclone, reclamation for agricultural and tourism (Ellison, 1999; Ellison, 2003; Ellison & Fiu 2010; Collins *et al.,* 2017; Cameron *et al.*, 2021).

The results here show that the percentage change in mangrove mass was relatively minute over the ~20 year study period (+0.63%). This gives an average gain of 0.034% per year. This is opposed to a recent estimate by Cameron *et al.*, (2021), which showed an average mangrove loss of 0.11% per year for the whole main Island of Viti Levu in Fiji. Another study by Hamilton and Casey, (2016), estimated national average mangrove loss in Fiji at a rate of 0.19% per year. Votua mangrove forest has shown a different characteristic of increase in forest spatial cover. This study shows substantial movement in mangrove cover towards inland areas. The inland migration of mangroves has been attributed to sea level rise leading to further inland saltwater intrusion making the soil conditions conducive for mangrove growth (Doyle *et al.,* 2010; Peterson & Bell, 2015; Blankespoor, Dasgupta & Lange*,* 2017). Visible occurrences of saltwater intrusions are noticeable in low lying areas around many islands in Fiji but limited research and data are available for these areas. Doyle *et al.* (2010) studied the migration and retreat of mangroves along the northern Gulf of Mexico in relation to the sea level rise. Results showed that the mangrove migration in different areas was dependent upon sea level rise and salt water intrusions which are governed by the slope of the land geography and tidal forcing. The inland migration of mangroves is expected to be further compounded by the changing climate (Doyle *et al.,* 2010; Ward *et al.,* 2016). In a study done on Cannon Island in Florida, it was shown that mangrove propagules have a greater establishment success moving landward as compared to those transported seaward. This resulted in the migration of the mangrove boundary further inland and was attributed to tidal changes and sea level rise (Peterson & Bell 2015). This landward creep can be significantly hampered if mangroves do not have enough room to move further inland due to development and other anthropogenic margins such as agriculture (Ward *et al.,* 2016; Blankespoor, Dasgupta & Lange*,* 2017). Geographical terrestrial area surrounding Votua mangrove forest is mostly undeveloped with exception of small populations of villages with very low levels of development. This may have allowed better inland movement of mangroves as well as a much lower level of mangrove exploitation in the past. On the other hand, it is quite possible that the inland migration rate of mangroves may not be fast enough to keep in synchrony with sea level rise rate. This will result in progressively reduced mangrove areas over time ending with perishing of the forests (Blankespoor, Dasgupta & Lange*,* 2017). In Ellison (2018), retreat of seaward edge of mangrove has been projected to cause accelerated loss of mangroves in Fiji. Landward expansion of mangroves leading to increased mangrove cover as presented here seems to be temporary in nature. In either case, this calls for the need to regularly monitor mangrove forests for conservation effort to be directed effectively and monitored.

The regeneration of mangroves was evident in a number of areas (Figure 4). The mangrove change detection results between 1999 and 2018 suggest that there has been a slight increase in mangrove regeneration (+0.63%). This restored mangrove cover over time may be due to the efforts of concerned environmental groups concentrating on conservation and sustainable development of mangrove areas and emplacing the mangrove ecosystem as a marine protected area. The important roles of mangrove forests in Fiji's coastal areas have already been witnessed and known in regards to climate change impacts. Therefore, environmentalists and researchers in Fiji are constantly stressing the importance of mangrove reforestation. A similar study at a larger scale was undertaken by Giri *et al.,* (2015) considering three case studies in South East Asia to assess the spatial changes in mangrove density. It was found that the mangrove areas either remained the same or increased at a slight rate for all three areas. On the contrary, there are various studies that have shown a reduction in mangrove patches. For instance, a study by Vo *et al.,* (2013) revealed that uncontrolled increase in shrimp aquaculture has resulted in a considerable decline of mangrove forests in Vietnam. While there are parts of the globe with an increased yield of mangroves, others show a rapid decline due to various impacts. Mangrove sustainability is dependent on the actions taken to preserve mangrove forests. Although this case study shows a slight increase in mangrove cover over the years, the average for larger parts of the country as well as the entire country has shown a gradual decline (Hamilton and Casey, 2016; Cameron *et al.*, 2021). At the national level, mangrove forests in Fiji are at risk and there is a genuine need for sustainable management practices by governance structures. Between 1999 and 2018 there have been seven strong cyclones that have passed over or in close proximity to Votua mangrove forest (National Oceanic and Atmospheric Administration, 2020). Despite this, the forest area remains resistant. This might be due to the much larger size of Votua mangrove forest as compared to other parts of the country (Aksornkoae, 1986; Ellison & Fiu, 2010; Cameron *et al.*, 2021). It might be a good idea to consider Votua mangrove forests one of the reserve areas for mangrove conservation and protection of biodiversity and ecosystem services.

The mudflat ecosystem also showed a slight change for the last ~20 years. This loss was approximately -3.7% with reference to 1999 levels. Mudflats provide habitats for a diverse group of specialized organisms and are critical to the functional ecologies found in the coastal area (Kanou, Sano & Kohno, 2004; Tse, Nip and Wong, 2008; Paterson *et al.,* 2019). Large areas of mudflats have been lost globally as a result of coastal erosion, land reclamation and coastal squeeze (Mazik *et al.* 2010; Wu *et al.,* 2018). Mudflats are amongst the world's most vulnerable ecosystems, having losses ranging from 30% to as high as 80% of the original area in various regions globally (Beck & Airoldi, 2007; Chen *et al.,* 2016; Wu *et al.*, 2018;). Mudflats are usually indicators of rich mangrove areas. The intertidal extent of mudflats is controlled by sedimentation, amongst other factors, which makes understanding of the spatio-temporal distribution very important to understand the changes in the mudflats (Jaffe, Smith & Foxgrover*,* 2007). Understanding long-term erosion and deposition trends are significant to understand this loss and subject to further study of the area over time. Upon initial consideration, the loss in mudflats for this study area may be attributed to land clearing for developments, land reclamation or loss of beaches due to building and construction. This also puts mangroves at risk of loss since the mudflats provide the correct aquatic environment for mangrove trees to thrive.

While the overall mangrove forest cover is in balance, specific losses in land area (mud flats) is still a problem around the coastal regions which could lead to inundation and loss of marine biodiversity due to anthropogenic activities. There has been a significant increase in upland vegetation described by sandy, well drained and low-fertility soil in the last 20 years. While upland vegetation zone is not very fertile, it provides biodiversity niches in the area (Barrett *et al.,* 2016). This increase in the upland vegetation could be attributed to the loss of trees and mangroves from the area as a result of land reclamation. This is of serious concern as this could mean greater threats to nearby communities in terms of inundation and loss of terrestrial biodiversity and ecological niches. The continued trend would threaten the livelihood of people as more coastal arable land could eventually be lost.

Like most PICs, goods and services provided by mangroves are essential for the sustenance of the socio-economic livelihoods of large coastal communities in Fiji. Around 45% of coastal community members around Votua mangrove forest pay daily visits to the mangrove forest in search of food resources (Avtar *et al.,* 2021). The need to conservation efforts is critical, however information gaps limit effectiveness of conservation efforts. Women in Fiji have valuable traditional knowledge and are tasked as caretakers for mangrove forests (Pearson, McNamara & Nunn, 2019; Thomas *et al.,* 2020). Their knowledge needs to be combined with scientific information for better decision making and effective directed conservation efforts for better resource management (Sangha *et al.,* 2019: Cameron *et al.,* 2021). The results presented here can be used to aid in decision making towards mangrove conservation.

CONCLUSION

Effective management plans for mangroves requires reliable baseline information on the status of mangrove forests. This work serves as a baseline as well as an indication of temporal and spatial changes in mangrove and mudflat covers over time. The inland creep of mangroves is not positive indication for the future survival and distribution of the plants. It is indicative of sea level rise influence which will likely accelerate due to the changing climate. Optimal land use plan is needed for the mangrove forest to ensure sustainability of mangroves forest cover and minimize future loss. Also, nearshore land use need to be planned carefully to allow enough space for inland creep of mangrove cover as one of the sustainability measures. The findings are intended to highlight the changes that can occur to a mangrove forests over time in Fiji. Such works provide important baseline information required for the design, implementation and improvement of management plans for these critical habitats.

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