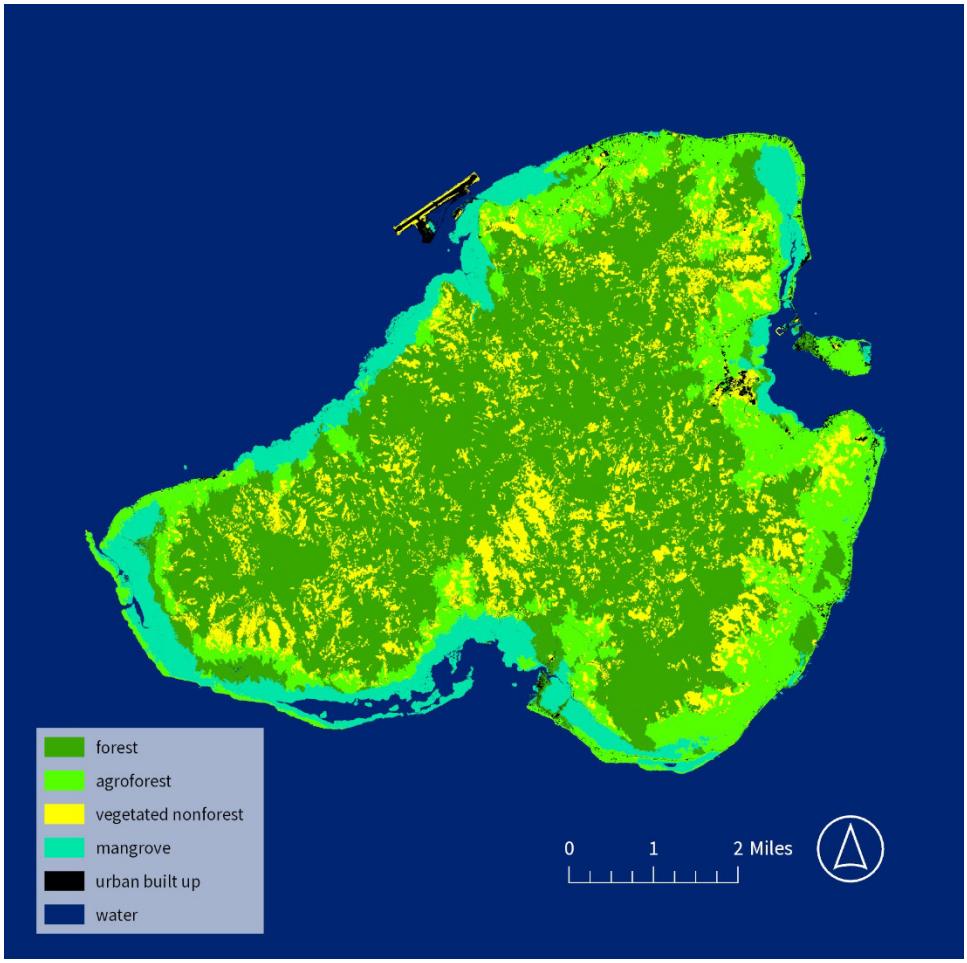
Kosrae Vegetation Map 2019-2023



Kosrae, Federated States of Micronesia

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Map 1. Cover Image Vegetation and land cover mapped on Kosrae, Federated States of Micronesia, from 2019-2023 WorldView scenes and ancillary data. USDA Forest Service map.

Contents

Summary

Vegetation in Kosrae, Federated States of Micronesia (FSM) was mapped from satellite imagery and related data using a combination of computer modeling and visual interpretation. Forested area has decreased by 3,300 acres since 2005, representing a loss of 13%.

Class	Acres
agroforest	5,424
forest	14,814
mangrove	2,932
other vegetated non-forest	3,710
urban built up	371
total	27,251

Table 1. 2023 Land cover class acreages

Data

In addition to the small format maps contained in this report, GIS data (updated January 2025) accompanying this report is available in Shapefile (SHP) format.

2023 Kosrae Vegetation Zipped ESRI Shapefile (SHP.ZIP) format associated with this report is available at https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd1223285.zip

This methods report can be downloaded here:
https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd1223286.pdf

This map is an update to the Forest Service 2008 map (Liu) which was based on 2005 Quickbird II satellite imagery composites. Similar to this effort, the methods included image segmentation using eCognition. Classification methods were less automated in the earlier effort and were assisted by field confirmation of the more detailed land use and land cover classes. The vegetation data is here:
https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fsbdev3_045209.zip

Additional vegetation maps of Pacific islands are available on the Region 5 State & Private Forestry (R5 SPF) Pacific Island Vegetation Mapping (PIVM) web page: https://www.fs.usda.gov/detailfull/r5/forest-grasslandhealth/?cid=fsbdev3_046690

Data Sources

Figure 1. WorldView-2 and WorldView-3 scenes used

Scene Code	% Coverage	Date	Sensor	Maxar Image ID
Kos0	60	2023-10-27	WV-3	104001008B439500
Kos2019	27	2019-12-24	WV-2	103001009C5B7400
KosE	5	2023-04-01	WV-3	1040010080673F00
KosW2	4	2023-07-25	WV-3	1040010089BDFB00
KosW3	2	2023-02-22	WV-3	10400100804D8500
KosW4	3	2022-10-24	WV-3	104001007E6D1E00

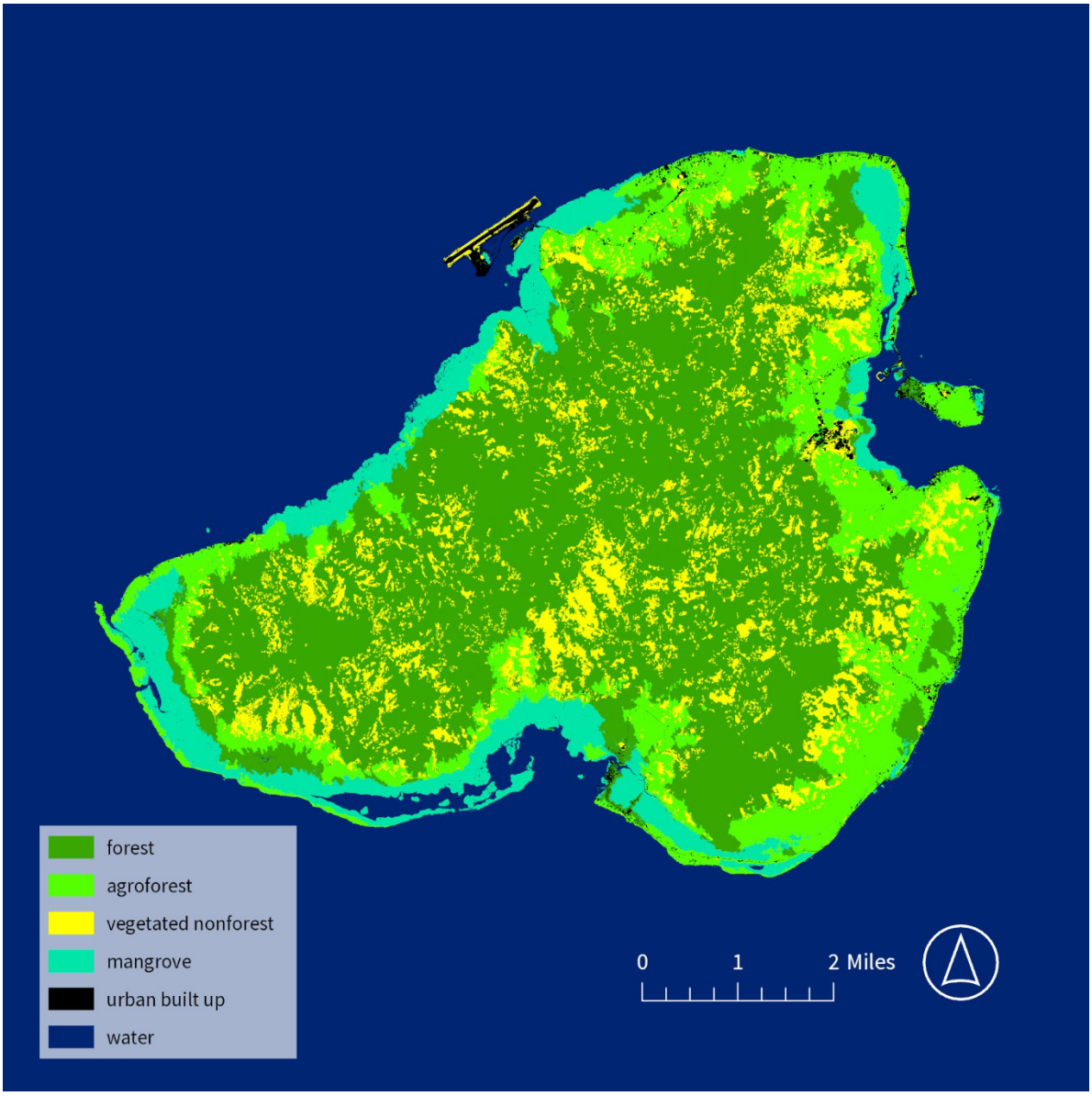
Table 2. Image Sources

- Primary Imagery: 6 WorldView-2 (WV-2) and WorldView-3 (WV-3) scenes from 2019-2023. Eight band (1.9m/1.2m) + panchromatic (0.5/0.3m) (Table 2). The imagery was acquired from Maxar's Digital Globe under the U.S. Government's Enhanced View Program
- Additional Imagery to aid automated classification: Sentinel-2 bands from two 2023 scenes: 18 August and 2 October, were incorporated into the image classifier
    - Code snippet from GEE script:

```
 // Set up Sentinel Composite KosS2_2023
var S2_20231002 =
ee.Image('COPERNICUS/S2_SR_HARMONIZED/20231002T234459_20231
002T234453_T58NBL'); // least cloudy west
var S2_20230818 =
ee.Image('COPERNICUS/S2_SR_HARMONIZED/20230818T234501_20230
818T234458_T58NBL'); // least cloudy east
```

- Elevation Models: from 2018 Vricon 50cm photogrammetrically derived digital surface model (DSM) and digital terrain model (DTM) datasets
- Existing vegetation and substrate classifications and maps

The mapped area includes Kosrae land cover classes that were adapted from Liu (2008) and Whitesell et al. (1986). Classes include forest, agroforest, mangrove, urban built up, other vegetated (non-forest), water, wetland, and bare ground. Table 2 describes the classes, and lists land cover types from the other studies included in the scheme. This mapping effort uses hybrid methods that balance a few considerations including classification accuracy, spatial detail, and user needs.



Map 2. Kosrae Vegetation and land cover

Class	Description	Includes
agroforest	cultivated forests, silviculture including palm plantations (local knowledge could further refine)	forests intersecting or within 50m of mapped agroforest in historical sources, tree gardens, coconut stands, islets with visible coconut stands
forest	tall upper canopy with woody vegetation excluding mangroves and agroforest	upland forest, upland broadleaf forest, atoll/beach forest, palm forest
mangrove	tidal forested wetlands	
other vegetated non-forest	vegetated landcover excluding forest	grassland, savanna, cropland, urban cultivated, brush, low pandanus, large taro patches, vines including merremia
urban built up	unvegetated, paved, compacted, or impervious	developed/disturbed
water	near shore and inland open water	water, intertidal mud and sand flats, eelgrass beds

Table 3. 2023 land cover classes description

Methods

Overview

1. Review existing vegetation maps, identify current classification priorities
2. Via G-EGD, obtain recent WorldView scenes, cloud free as possible
3. Data preparation and Preliminary Classification
    a. Refine analysis area of map area of interest (AOI)
        i. a buffered spatial extent of all terrestrial areas, mangrove zones, and vegetated barrier islets within study area
    b. Collect recent inventory of satellite imagery at Maxar Discovery site , obtain subsets of 8band + panchromatic via G-EGD as needed (Table 2)
    c. Upload assets to Google Earth Engine (GEE) workspace
    d. Scripted raster stack creation in GEE
    e. Collect image training samples in ArcGIS Pro 3.2
    f. Use training samples to train random forest classifier
    g. Classification of raster stack
    h. Review interim classification and interim accuracy assessment
    i. Iterate: repeat and refine steps a-g above
    j. Export stack of preliminary classifications and additional bands
4. Segment and vectorize stack in eCognition
    a. use preliminary class as major factor
    b. Export classified image objects as classified polygons
5. Synthesize single Vegetation layer in ESRI ArcGIS Pro 3.2
6. Map Revision 1: Targeted QA of uncommon types and systemic error
7. Reclassify selected forest polygons as agroforest
8. Apply 50m^2 and 250m^2 minimum mapping units to some mapped classes
9. Internal and partner review of draft map and summary
10. Address review recommendations and apply corrections
11. Publish revised map and report

Classification priorities

Several considerations guided the development of the classification scheme throughout the mapping process. One consideration was finding the clearest and most recent imagery available. Developing a map with high spatial resolution was also important, as was good classification accuracy overall, and good accuracy by vegetation class. A mapping process that was more automated than previous efforts and applicable to other Pacific islands was also a goal.

Capturing unvegetated forest areas was an additional key priority, with attention given both during preliminary model iteration, as well as during draft review and editing. This can assist in identifying candidate sites for reforestation in cleared areas.

Source imagery

Obtaining timely imagery with limited cloud cover and haziness over Kosrae continues to pose a challenge. Six WV2 and WV3 scenes with relatively limited cloud cover from 2019 to 2023 were identified and acquired under the NextView license. Scenes were obtained in multiple formats, including 8 band and panchromatic for analysis and classification, and in pansharpened format to aid visual interpretation and classification of image samples. Data acquisition requests for newer imagery were happily fulfilled in late 2023 (Table 2), allowing for an updated map. Scripting the composite of images allowed for easy updating of the image stack on Google Earth Engine soon after new imagery became available.

Uploading assets

In addition to subsets of the WV scenes listed in Table 2, other uploaded assets include

- DSM
- DTM
- polygons by scene
- sample classification points

Raster stack creation

A script was developed in Google Earth Engine to compile the stacks, train, run and test a classifier, display various results, and finally to export preliminary classifications for vectorization and further refinement in eCognition and ArcGIS Pro.

Two separate stacks are referred to in this process, an analysis stack and an export stack. Both are based on the 8-band multispectral, with additional elements from the supplementary data sources. Bands were normalized to 8-bit values with the 'ee.Image.visualize()' function in Google Earth Engine. Band and image specific parameters were used for normalization.

The analysis stack includes these bands:

1. Green
2. Blue
3. Red edge
4. Yellow

5. NDVI = (NIR-Red)/(NIR + Red)
6. NDWI = (NIR-Green)/(NIR + Green)
7. EVI = (NIR 2 - Red) * 2.5 / (NIR 2 + 6*Red -7.5*Blue + 1)
8. SAVI = (NIR 1 - Red) * 1.5 / (NIR 1 + Red + 0.5)
9. Texture band. gray level co-occurence matrix (glcm) inverse distance moment (idm) derived from WV panchromatic
10. Texture band. glcm entropy (sent) derived from WV panchromatic
11. Elevation value. Derived from Vricon 2018 DTM
12. 'MVI' index derived from Sentinel-2. MVI = (NIR - Green)/(SWIR1 - Green)
13. 'ndNSW1' index derived from Sentinel-2. ndNSW1 = (NIR – SWIR1 / NIR + SWIR1)

The first 8 bands are derived from WV-2 or 3 (Table 2). The remainder are derived from the elevation models and Sentinel-2. Indices using the SWIR band can be useful for identifying mangroves such as MVI (Tran et al. 2023) (Figure 2). To include this predictor, several bands used by the classifier are derived from harmonized Sentinel-2 scenes. They incorporate shortwave infrared band 11 (SWIR1), near infrared band 8 (NIR), and Green band 3.

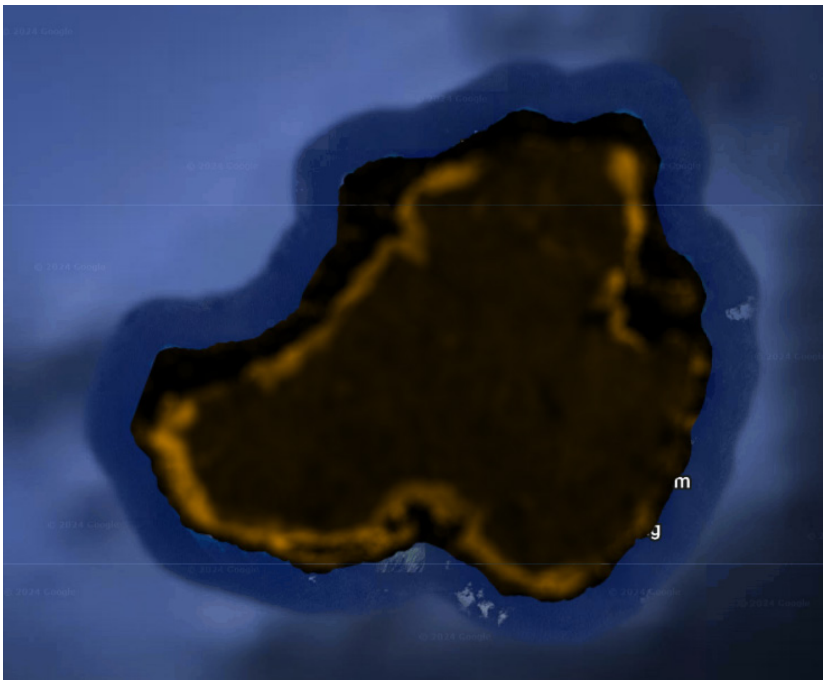


Figure 2. MVI from Sentinel-2 displayed in Google Earth Engine

Image sampling

Collection of training sample data was conducted in ArcGIS Pro 3.2. Over several iterations, about one thousand image samples were collected from land cover classes listed in Table 3.

Map 3. Image sample locations

Classification

In Google Earth Engine, a random forest classifier was trained using 80% of the image sample data, with a random 20% held in reserve for testing.

Review interim classification and iterate

After checking the accuracy, qualitative checks over the mapped area were conducted. Script development was an iterative process. This scripted model can be adapted for other Pacific Islands. It can also be updated with new imagery for Kosrae.

When image segments in the composite were updated, so were image sample points. Additional samples were collected as newer imagery was integrated into the scripted model.

Export stacks

The exported stack contains the 8 WorldView bands, the glcm derived bands, and preliminary and alternate classification rasters. The alternate classification does not use the Vricon DEM for training the model. A raster stack was exported at 1.24m resolution for import into eCognition.

Vectorization and segmentation in eCognition

After preliminary classification was completed in Google Earth Engine, refinement and vectorization were implemented in eCognition Developer 10.2 using the output of the preliminary classification and satellite imagery.

eCognition was used differently in the Kosrae mapping effort than in previous FSM mapping efforts. In Kosrae, the preliminary classification is pixel-based via Google Earth Engine scripts. Earlier efforts in Yap and Pohnpei (Salomon 2023, 2022) used eCognition more extensively for classification. For Kosrae, eCognition is used for vectorization and further segmentation within vegetated areas.

Multi-threshold segmentation by class was performed on the classified raster stacks that were exported from Google Earth Engine. Vegetated objects were further segmented using multi-resolution segmentation applied to other bands in the export stack. This allowed for easier refinement in final mapping corrections and the classification of agroforest. The results were vectorized and exported as shapefiles with preliminary land cover classification applied.

Synthesis and revision of vegetation map

A single vegetation map layer was synthesized using classified shapefiles from the previous steps in eCognition. In ArcGIS Pro, the two spatially overlapping datasets were combined into a single vegetation map without overlaps. Additional systematic rule-, size- and location-based edits were performed on the draft vegetation map in preparation for delivery. Very small polygons of all classes that were less than 25 m^2, excepting small mangrove islands, were eliminated by merging with adjacent larger polygons. Larger minimum mapping units of 250 m^2 were used for secondary vegetation and other non-forest vegetation. Land cover polygons were dissolved by class into single part polygons to reduce the number of output features.

Reclassify selected forest polygons as agroforest

Forest polygons from the synthesis layer were reclassified as agroforest if they spatially intersected or were within 50m of agroforest classes in the 1986 or 2008 USDA Forest Service vegetation maps. GIS data from these earlier efforts was spatially shifted to better align with the current mapping effort.

Review, Revision, and Publication

Internal review was conducted. Comments were solicited on the draft report and vegetation map. The draft was shared with partners including foresters in Micronesia and Kosrae State, as well as regional and subject matter experts within the USDA Forest Service and academia. Internal map accuracy assessments were also conducted. Further revisions were implemented. Final changes were made to the vegetation map and document based on review comments and internal accuracy assessments. The final accuracy assessment of the vegetation map is shown on Table 4.

Accuracy Assessment

Accuracy assessment was conducted on the final layer after internal and external review. Assessment based on image interpretation estimates 90% overall accuracy.

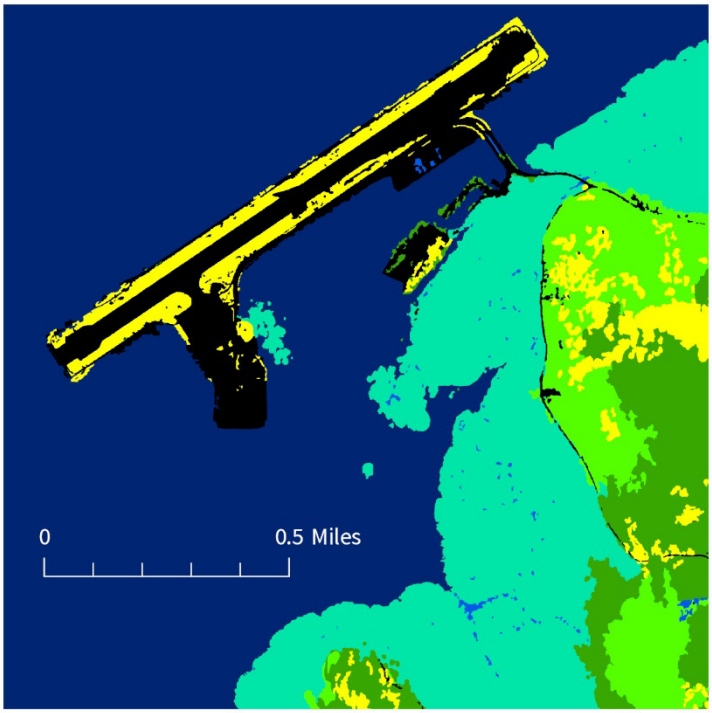
True class	agroforest or forest	mangrove	other vegetation	urban built up	water	total correct	total mapped	user's accuracy %
Map class								
agroforest or forest	185	1	15	1	0		202	92
mangrove	2	52	0	0	0		54	96
other vegetation	11	0	44	0	0		55	80
urban built up	1	0	4	36	0		41	88
water	0	1	0	0	19		20	95
total samples	199	54	63	37	19	336	372	
producer's accuracy %	93	96	70	97	100			90

Table 4. Accuracy assessment and confusion matrix

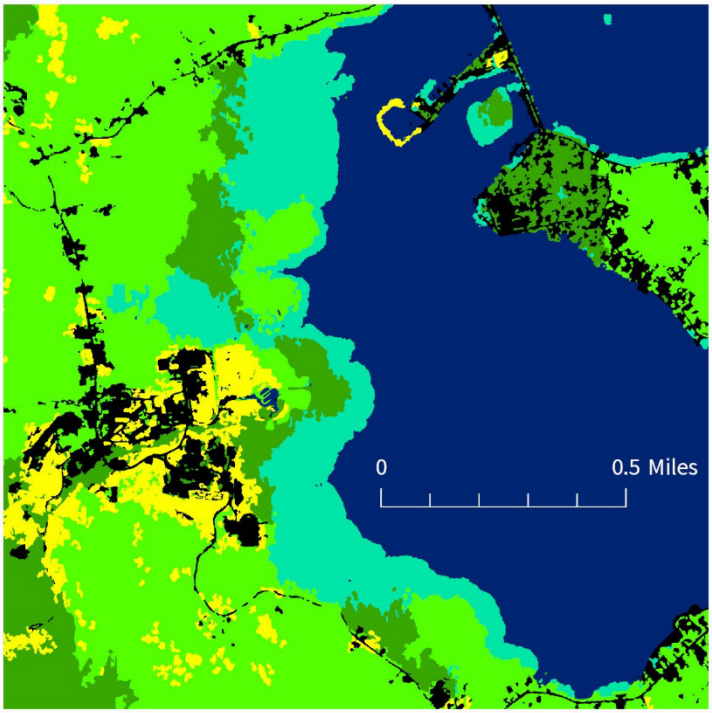
Results

Acreages of each land cover class were calculated (Table 1). Including mangroves, 27,251 acres were mapped. Kosrae is 85% forested and 99% vegetated. Maps on the following pages show several views of the dataset in comparison with contemporary imagery.

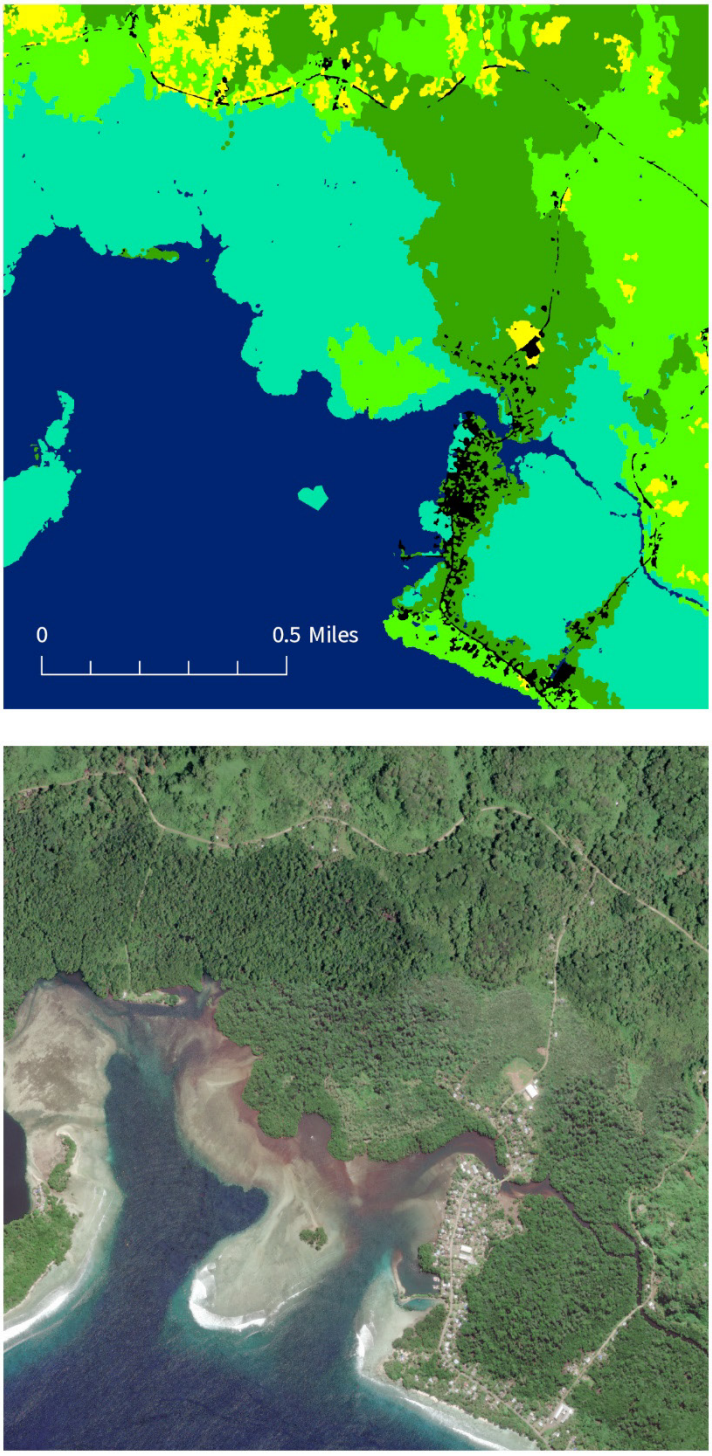
Table 5 compares the classification between this vegetation map and two historical vegetation maps. The Whitesell et al. 1986 mapping effort used manual mapping methods at a smaller scale combined with botanical expertise, 1976 aerial photo interpretation, and extensive field confirmation. Previous mapping efforts conducted by Liu were based on 2005 satellite imagery.



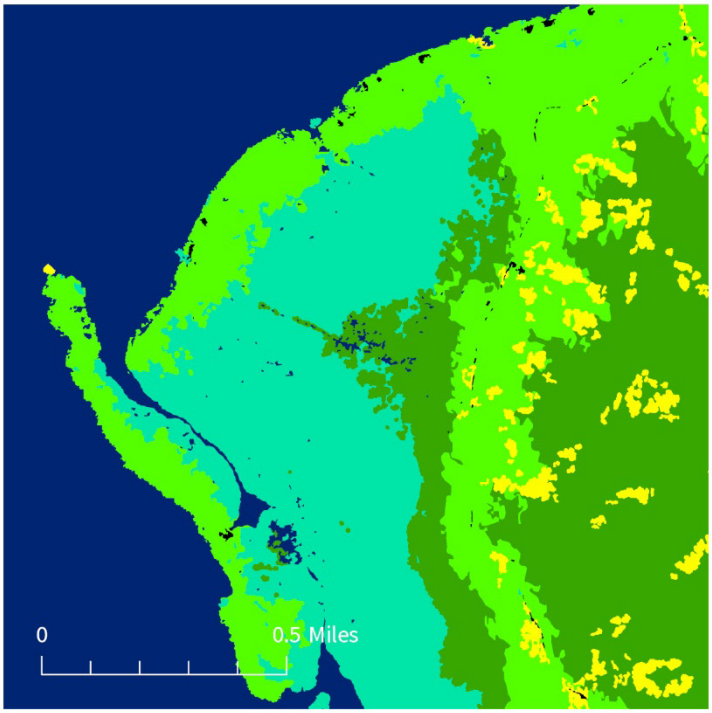
Map 4. Near Airport



Map 5. Tofol



Map 6. Utwa Ma



Map 7. West Kosrae

Salomon (2019-23)	Whitesell et al. (1976–86)	Acres	Liu et al. (2005)	Acres	~1980	~2005	~2023
agroforest	agroforest	4,280	agroforest	3,684	4,280	3,684	5,424
forest	upland broadleaf forest	14,608	upland forest	18,223	16,123	19,350	14,814
	swamp forest	1,346	swamp forest	1,127			
	montane cloud forest	170					
mangrove	mangrove forest	3,723	mangrove forest	3,451	3,723	3,451	2,932
other vegetation	savanna/grassland	41	grassland or savanna	15	2,330	1,258	3,710
	secondary vegetation	2,253	secondary vegetation	649			
	freshwater marsh	36	marsh	151			
			urban cultivated	438			
			cropland	4			
urban built up	developed/disturbed	514	urban builtup	313	514	353	371
			barren	40			
	Total	26,971		28,094			27,251

Table 5. Comparison with circa 1980 and 2005 acreages

References

Region 5 State and Private Forestry publications

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Maxar (DigitalGlobe) satellites https://www.maxar.com/constellation

WorldView-2 and -3 single scenes. Refer to Table 2

Elevation from 2018 Vricon 50cm photogrammetrically derived DSM and modeled DTM datasets

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