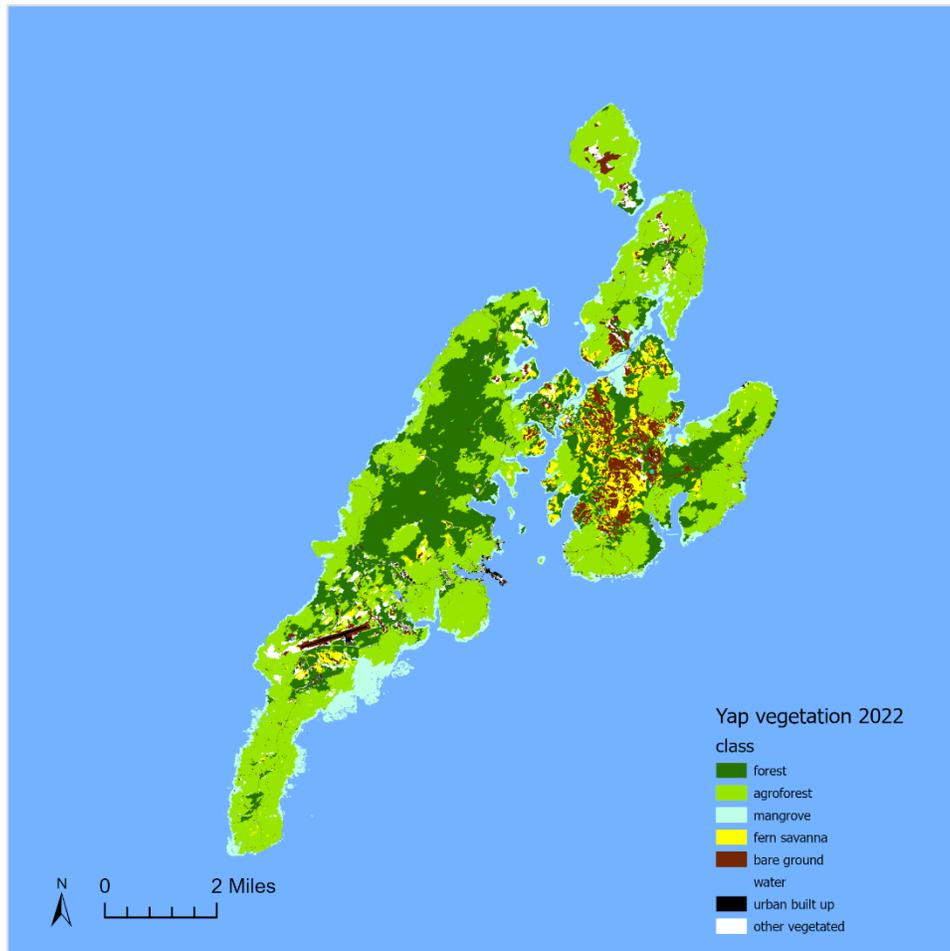




Yap Island Vegetation Map 2022



Yap State, Federated States of Micronesia

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June 2023

Map 1. Cover Image Vegetation and land cover mapped on Yap Island, FSM, from 2022 WorldView scenes and ancillary data. USDA Forest Service map by Micha Salomon

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Contents

Yap Island Vegetation Map 2022	i
Map 1. Cover Image	ii
Summary	2
Table 1. 2022 land cover classes and acreages mapped	2
Data.....	2
Data Sources.....	4
Figure 1. WorldView-2 2022 imagery from January 20 and 7	4
Map 2. Yap Island and WV2 Image Coverage.....	6
Table 2. 2022 land cover classes description	7
Figure 2. Fern Savanna and forest landscapes	7
Methods	8
Figure 3. Image segmentation	11
Figure 4. Segmentation parameters for vegetated and unvegetated portions	12
Map 3. Field sample locations	13
Table 3: Image sample classes	14
Figure 5. Settings for eCognition Random Trees classifier.....	15
Accuracy Assessment.....	18
Table 4. Accuracy assessment	18
Results	19
Table 5. Yap Island land cover acreage and relative cover 2022.....	19
Map 4. Colonia inlet.....	21
Map 5. Airport and Mangroves near Yunuf	22
Map 6. Gilmaan, South Yap	23
Map 7. Ma’ap and North Gagil Tamil	24
Table 6. Comparison with circa 1987 and 2003 acreages.....	25
References	26
Acknowledgements.....	27

Summary

Vegetation in Yap Island, Federated States of Micronesia (FSM) was mapped from satellite imagery and related data using a combination of computer modeling and visual interpretation. Three satellite images collected in 2022 were classified into vegetation and land cover types. This map includes small islands in and around Yap Island’s surrounding reefs.

Class	Acres
forest	7,736
agroforest	10,571
mangrove	1,920
urban built up	299
fern savanna	1,551
other vegetated nonforest	1,054
bare ground	735
total	23,866

Table 1. 2022 land cover classes and acreages mapped

Data

In addition to the small format maps contained in this report, GIS data (updated 30 May 2023) accompanying this report is available in Shapelfile (SHP) format. The final dataset is available on the [R5 SPF USAPI web page](https://www.fs.usda.gov/detailfull/r5/forest-grasslandhealth/?cid=fsbdev3_046690) at https://www.fs.usda.gov/detailfull/r5/forest-grasslandhealth/?cid=fsbdev3_046690

This methods report can be downloaded [here](https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd1113668.pdf):
https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd1113668.pdf

2022 Yap Vegetation Zipped ESRI Shapefile (SHP.ZIP) format at
https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd1113669.zip

This map updates the Forest Service 2006 map (Liu) which was based on 2003-2005 Quickbird II satellite imagery composites. Like this effort, the methods included image segmentation

using eCognition. Classification methods were less automated in the earlier effort and was assisted by in situ 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_045730.zip

Data Sources

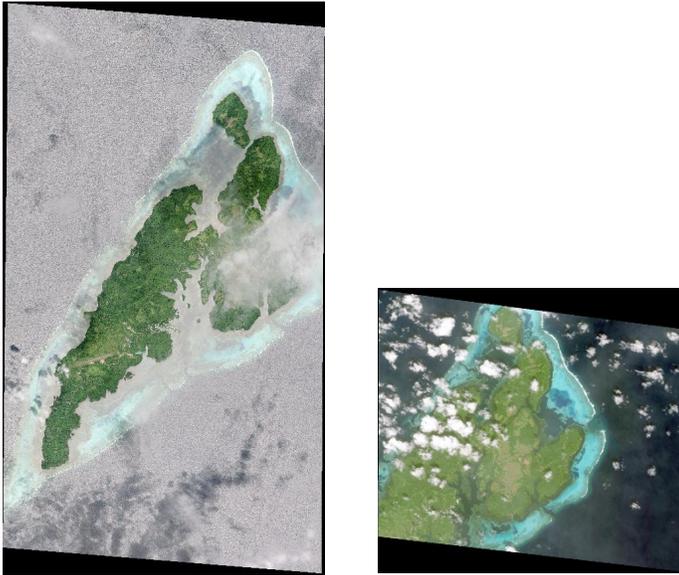
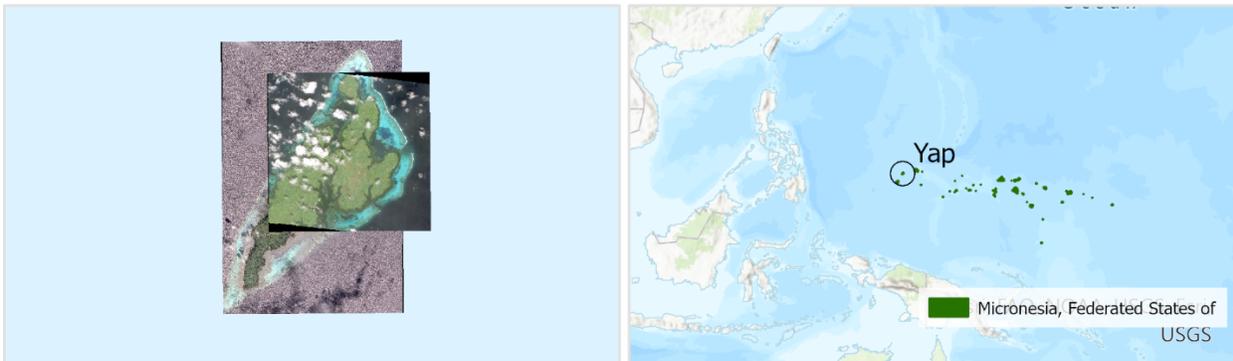
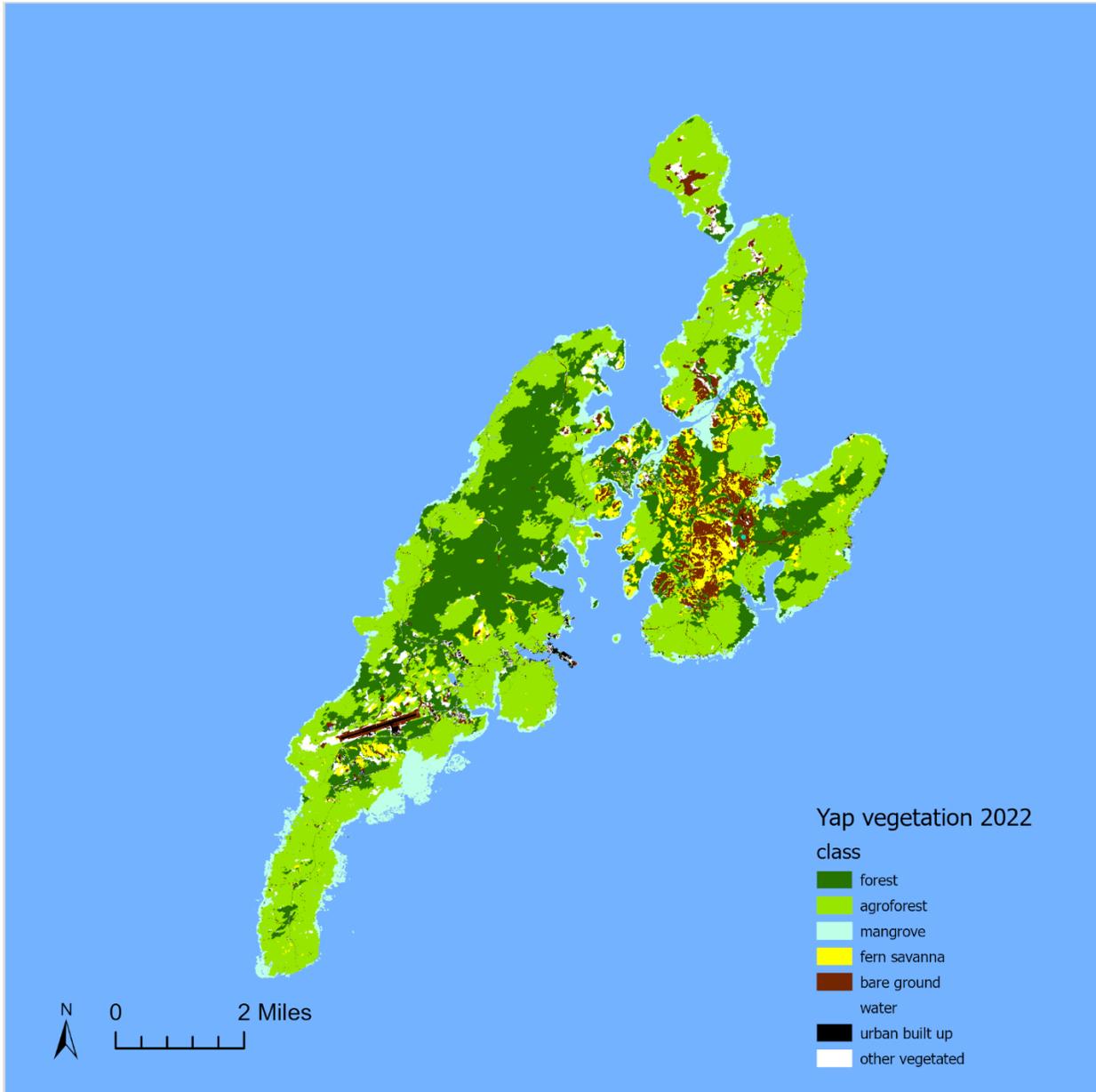


Figure 1. WorldView-2 2022 imagery from January 20 and 7

- Satellite Imagery: 3 WorldView-2 (WV2) scenes from 2022. Eight band (1.9m) + panchromatic (0.5m). The imagery was acquired from Maxar’s DigitalGlobe under the U.S. Government’s Enhanced View Program
 - 20 January 2022 – western Yap Island, Maap, Rumong
<https://api.discover.digitalglobe.com/show?id=10300100CC1D4C00>
 - 7 January 2022 – eastern Yap Island, Gagil-Tamil, Maap
<https://api.discover.digitalglobe.com/show?id=10300100CB137A00>
- Ancillary imagery: Maxar Vivid FSM 2021
 - WorldView composite, multiple acquisition dates 2015-2021. Public license. Served via Natural Resources Conservation Service (NRCS) (accessed 28 Mar 2022)
https://nrcsgeoservices.sc.egov.usda.gov/arcgis/rest/services/ortho_imagery
- Elevation from 2018 VRICON 50cm photogrammetrically derived DSM and modeled DTM datasets
 - DTM and Height Model at 2m horizontal resolution used as model inputs
- Existing vegetation and substrate classifications and maps
 - Vegetation: Forest Action Plan (Republic of FSM 2021), Greenberg 2020, Liu & Fischer et al. 2008, Falanruw et al. 1987
- Open Street Map. Roads and Infrastructure for Yap Island. Accessed 8 Sept 2022.
<https://www.openstreetmap.org/>

The mapped area covers Yap Island, FSM, and the small islands lying within its reef. Land cover classes were adapted from Liu (2008), Falanruw et al. (1987), and the 2021 FSM Forest Action Plan (SWARS). Land cover classes include forest, agroforest, mangrove, urban built up, fern savanna other vegetated (nonforest), water 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 balanced a few considerations including classification accuracy, spatial detail and user needs.

Upon review of the initial draft, Forest service partners at Yap State Forestry requested more information on fern savanna vegetation type. Fern savanna was mapped separately from other nonforested vegetation. Reconnaissance level field verification of various land cover types and plant. April 2023 collected >200 land cover sample points, with about 150 with 3m horizontal accuracy as reported Juniper Geode GNSS receivers.



Map 2. Yap Island and WV2 Image Coverage

Class	Description	Includes
forest	tall upper canopy with woody vegetation excluding mangroves and agroforest	swamp forest, upland forest, urban canopy
agroforest	Cultivated forests, silviculture including palm plantations	Forests overlapping with mapped agroforest in historical sources, tree gardens, coconut plantations, taro patches
mangrove	tidal forested wetlands	mangrove
fern savanna	Nonforested vegetation where <i>Gleichenia linearis</i> is predominant	fern savanna
urban built up	unvegetated, paved, compacted or impervious	urban unvegetated
other vegetated	vegetated landcover excluding forest and fern savanna	cropland, grassland/savanna, urban vegetated, secondary vegetation
water	inland water	Water, intertidal mud and sand flats, eelgrass beds
bare ground	Unvegetated areas	Beach, barren land

Table 2. 2022 land cover classes description



Figure 2. Fern Savanna and forest landscapes

Methods

Overview

1. Review existing vegetation maps, identify current classification priorities
2. Via G-EGD, Obtain two recent WV2 scenes, cloud free as possible
3. Preliminary Classification: Subset, Segment, Semi-Automate
 - a. Subset with threshold classification to prepare image for eCognition. excluding coastal water and including all vegetated land area and mangrove
 - b. Multi-band segmentation of vegetated and unvegetated
 - c. Collect image training samples for iterative training of a classifier
 - d. Use training samples to train Random Trees classifier in eCognition
 - e. Classify remaining image objects
 - f. Export 2 sets of classified image objects as classified polygons
4. Synthesize single Yap Vegetation layer in ESRI Arc Pro 3.1
5. Map Revision 1: Identify and correct sources of systemic error
6. Reclassify selected forest polygons as agroforest
7. Draft map and report review
8. Collect additional field and test samples and integrating fern savanna
9. Iterate sample collection and mapping step (3-6)
10. Internal accuracy assessment

Classification priorities

Throughout the mapping process, several considerations guided the development of the draft classification scheme. One consideration was finding the clearest and most recent imagery available. The need to produce a draft map with high spatial resolution was also important, as was a map with good classification accuracy overall, and with good accuracy by vegetation class. Another goal was to develop a mapping process that was more automated than previous efforts, and that would be somewhat reproducible across other islands. Capturing vegetated nonforest areas was an additional key priority, with attention given both during preliminary model iteration, as well as draft review and editing. This was to identify candidate sites for reforestation in cleared areas, and efforts were made to include as many of those sites as possible in spite of cloud cover in the most recent imagery.

Source imagery

Obtaining timely imagery with limited cloud cover and haziness over Yap Island continues to pose a challenge. Two WV2 scenes with relatively limited cloud cover from 2022 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. A 2021

VIVID composite was also used for interpretation, and filling in classification gaps in 2022 imagery due to cloud cover and/or haze.

Preliminary classification

Preliminary classification involved the development of several algorithms, mostly implemented in eCognition Developer 10.2. eCognition is a software tool centered around object-based image analysis (OBIA). This means that rather than classifying individual pixels, OBIA classifies groups of contiguous pixels, called 'image objects'. Image objects are also sometimes referred to as 'image segments', or simply 'segments' because a process called segmentation can be used to create image objects.

The overall purpose of preliminary classification was to create two separate but uniform classified draft outputs that were consistent with each other, and that could be combined into one synthesized vegetation map. Key steps were image segmentation into image objects, followed by classification of those segments using a trained machine learning classifier which will be described in greater detail below. Collection of training sample data was conducted in both eCognition and ESRI ArcGIS Pro.

Original downloads for each image strip consisted of multiple tiles for each of the two WV2 scenes. Custom import settings were created in eCognition to allow the import of multiple downloaded 8 band tiles into a single eCognition scene. Each of the three tiled scene was prepared in this way in preparation for the following subsetting step.

Band Indices and Subsetting

Prior to segmentation, several steps were implemented to prepare the data by reducing it to a particular subset. The first subset omits large areas of cloud and coastal water while carefully including very small vegetated islands including atoll forests among the outer reefs of Yap Island. The same algorithm also includes nearshore mangrove islets in very small stands less than 12m² (6 pixels) in area. The purpose of this step is not to classify per se, but to prepare the dataset for the next step in the analysis, image segmentation.

To define these preliminary areas to be excluded and included, a series of thresholding and scaling algorithms were applied. Band indices were created for this and later steps. The indices are labeled NDWI, FDI, NDBRe, NDVI, NDI_ReN1, and NDI_RRe are calculated as follows:

1. $NDWI = \text{green} - \text{near infrared 1} / \text{green} + \text{near infrared 1}$
2. $FDI = \text{near infrared 2} - \text{red edge} - \text{blue}$
3. $NDBRe = \text{blue} - \text{red edge} / \text{blue} + \text{red edge}$
4. $NDVI = \text{near infrared 1} - \text{red} / \text{near infrared 1} + \text{red}$
5. $NDI_ReN1 = \text{red edge} - \text{near infrared 1} / \text{red edge} + \text{near infrared 1}$
6. $NDI_RRe = \text{red} - \text{red edge} / \text{red} + \text{red edge}$

Multi threshold classification was performed on the NDWI and NDVI layers above to separate coastal water, vegetation and unvegetated areas. By removing most offshore coastal water, the input to the next step was intentionally limited mostly to areas of terrestrial vegetation. The outputs of this step are an omitted coastal water class, and a vegetated and unvegetated portions that are segmented separately in the next step.

Segmentation

eCognition's multi-resolution segmentation algorithm creates image objects from groups of pixels that are similar to their neighbors, but different from neighboring objects. The parameters for multi-resolution segmentation were developed through trial and error over several iterations. With the scale parameters, the aim was to create image objects at a spatial scale of a few objects per, for example, an apparent agricultural plot or a building.

The goal of the segmentation step is for different land cover types to be well differentiated into polygon-like image objects. In general, single image objects should not cover multiple land cover classes. Also, each patch of a distinct land cover type should be delineated as one or more image objects. Figure 3 shows a portion of an image before and after segmentation.



Figure 3. Image segmentation

Two iterations of eCognition's signature multi-resolution segmentation algorithm were implemented, one for the 'vegetated' subset, and the other for the unvegetated. Segmentation for vegetated areas used the following parameters: scale 26, Shape 0.2, Compactness 0.3, and using Blue_(weight=1), Green₍₃₎, NDBRe₍₁₎, NDI_ReN1₍₁₎, NDRRe₍₁₎, NIR 1₍₁₎ and two more derived bands: IDM₍₁₎ and sEnt₍₁₎. The latter 2 layers were derived from texture rasters called GLCMs of the panchromatic band ([GEE implementation](#)). The parameters, including 'Layer weights' are shown in the figure below.

Segmentation Settings	
Image Layer weights	1, 3, 1, 1, 1, 1, 1, 1
Blue	1
Green	3
NDBRe	1
NDI_ReN1	1
NDI_RRe	1
NIR 1	1
YapW_IDM22	1
YapW_sEnt22	1
Thematic Layers	[]
Scale parameter	26

Segmentation Settings	
Image Layer weights	1, 1, 2, 2, 1, 2, 1, 1, 1
Blue	1
Coastal blue	1
FDI	2
NDBRe	2
NDI_ReN1	1
NDI_RRe	2
NIR 1	1
YapE_IDM22	1
YapE_sEnt22	1
Thematic Layers	[]
Scale parameter	10
Composition of homogeneity criterion	
Shape	0.1
Compactness	0.3

Figure 4. Segmentation parameters for vegetated and unvegetated portions

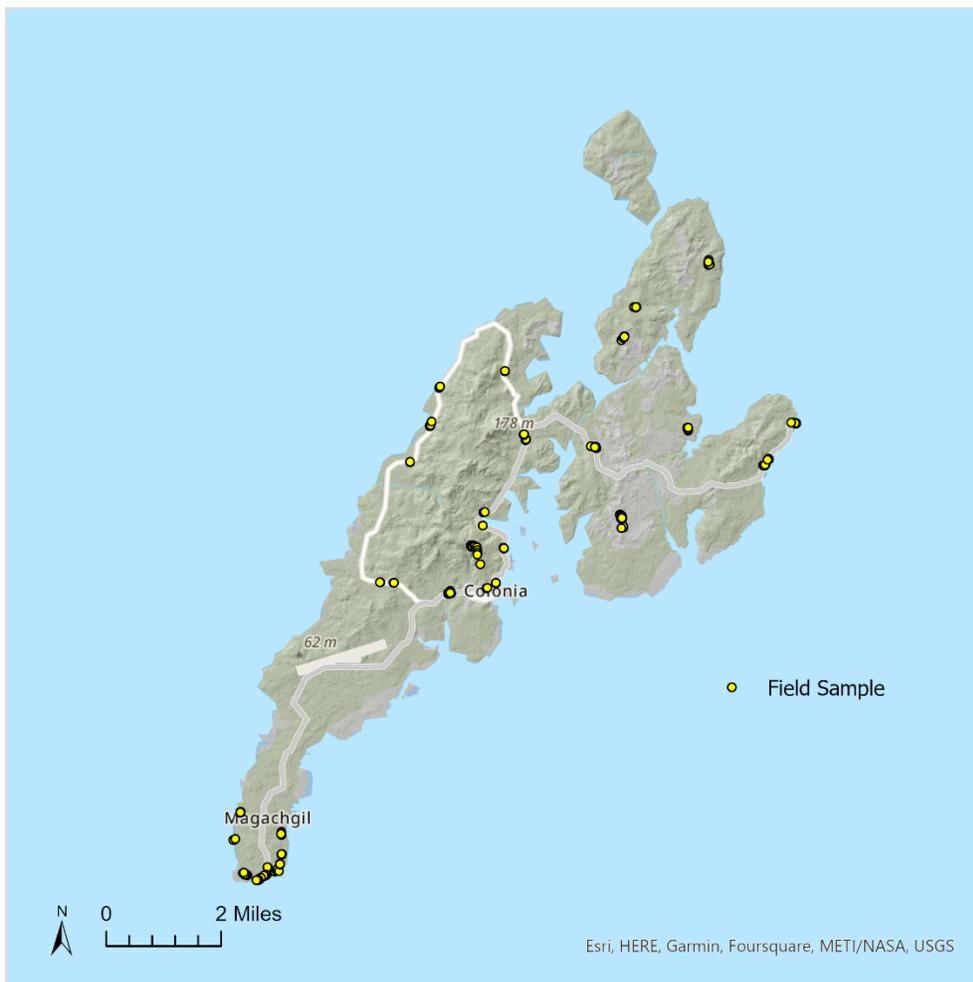
Segmentation for unvegetated areas used the following parameters: scale 10, Shape 0.1, Compactness 0.3, and using Coastal blue₍₁₎, Blue₍₁₎, FDI₍₂₎, NDBRe₍₂₎, NDI_ReN1₍₁₎ NDRRe₍₂₎, NIR 1₍₁₎ and two more derived bands: IDM₍₁₎ and sEnt₍₁₎.

Once they are created and refined, the image objects can then use a different set of criteria to train and apply a classifier. In this case, eCognition’s implementation of a Random Trees classifier was used. Training the classifier also requires independently classified samples. The next few steps describe how samples were collected and classified, and used to train the classifier.

Sample collection

Independently of the previous steps, different types of sample points were identified and collected for the study area. Samples were mostly collected using ESRI ArcGIS Pro 10.8 with pansharpened imagery via visual interpretation. Training sample points were collected for the purposes of preliminary classification. Test sample points were collected for accuracy assessments that were used to improve the classifier.

In April of 2023, field samples were also collected using a GNSS receiver to record location. For image samples where the location was cloudy or in shade, a reference or 'true' classification from an alternate clearer image was added when possible and used in accuracy assessments as appropriate.



Map 3. Field sample locations

For the Yap west image strip (Jan 20), 985 image training sample points were collected and classified. For Yap east (Jan 7) 597 points were ultimately used, 29 of them spatially overlapping with corresponding Yap west points. In addition to several hundred randomly located points, the sampling process included spending 10 minutes locating and mapping samples for each of the Sample Classes shown in Table 3 below. Clouds and shadows are reclassified in later steps. More detailed classifications were also included in the training data that were not included in the 'Class'. Included in earlier iterations were subclasses of 'other vegetated nonforest' including 'urban cultivated', 'marsh' and 'secondary vegetation'. Note that agroforest was not classified from this model directly, they are a subset of forest calculated in a subsequent step.

Class or Image Sample Class

forest

mangrove

bare ground

urban built up

fern savanna

urban cultivated (**other vegetated**)

secondary vegetation (**other vegetated**)

marsh (**other vegetated**)

water

shadow

cloud

Table 3: Image sample classes

Pan-sharpened imagery, false-color infrared views, 2021 WorldView composites (VIVID) and band combination rasters were used to visually assign classes to each sample. Historical vegetation maps were also used for reference. Rich MacKenzie, Katie Friday, Phil Cannon, and Julian Dendy assisted with some image interpretation.

Some field verification was undertaken in April 2023. Survey 123 was used in conjunction with a Juniper Geode GNSS receiver to collect high precision field survey points to assist and improve vegetation mapping. Field data was collected from points distributed around the island, but especially in the vicinity of forestry project sites. Geolocated field samples and photos are available in ArcGIS Online for Forest Service and partners working in Yap.

For the final accuracy assessment, independent test points were randomly selected and classified. A combination of randomly located points and points located by class stratification were used in the accuracy assessment. Class stratified points were identified from reference imagery for each unique class for about 7 minutes per class.

Random trees classifier applied to image objects

Point training samples representing the various classes were then assigned to spatially intersecting image segments, classifying that subset of segments as image object samples. Those sample segments were used to train a Random Trees classifier in eCognition. For each of the two datasets, the point training samples transferred their classification to a spatially intersecting subset of the eCognition image objects. A few dozen additional image object samples were also classified and added to the training sample pool in eCognition prior to training the classifier. Several hundred image samples were used to train each of the two instances of eCognition’s ‘Random Trees’ classifier.

Parameters of the eCognition Classifier were developed iteratively. The draft parameters of the classifier are shown in Figure 6. The classifier operates on several statistical aggregate features of image objects: the mean of indices NDBRe, NDWI, ND_RRe and FDI; WV2 bands Green, Yellow, Red, Blue, Red edge and NIR 2. Additional parameters used included the GLCM indices, a distance from shoreline index (DS22), and mean of a Height Model (HM18) and Terrain Model (TM18) generated from the VRICON surface rasters.

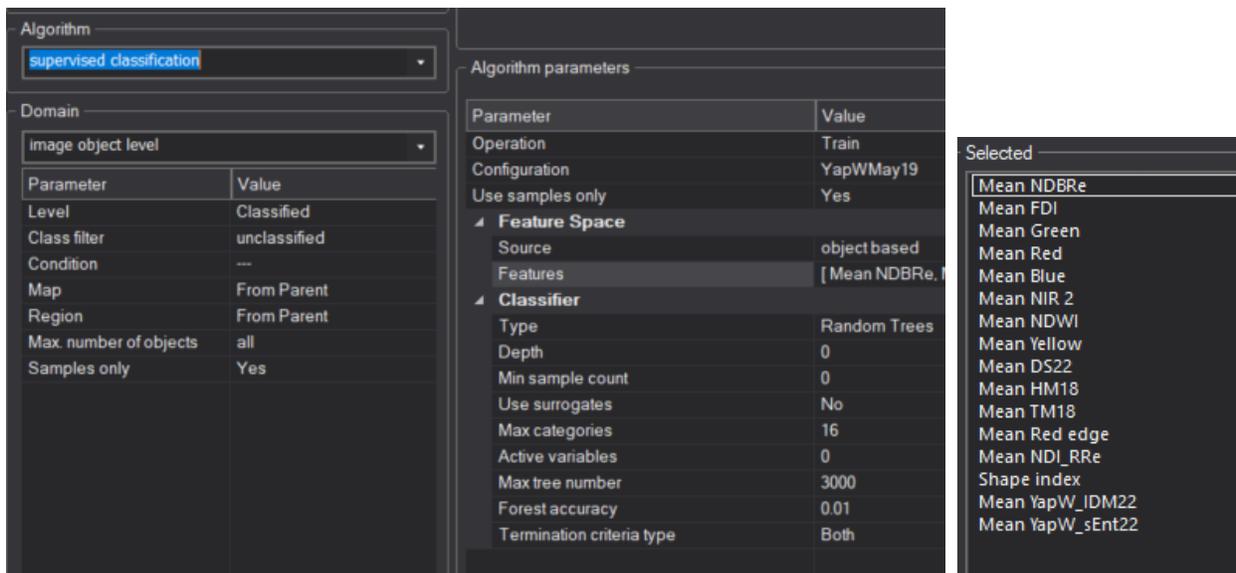


Figure 5. Settings for eCognition Random Trees classifier

The output of this preliminary classification step is two datasets. Namely, one set of classified image objects from each of the two images.

Synthesis and revision of vegetation map from two classified images

A single vegetation map layer was synthesized using the two outputs from the previous classification step. Image objects with preliminary modeled classifications were exported from eCognition as vector datasets. In ArcMap, the two spatially overlapping datasets were combined into a single vegetation map without overlaps. Quality checks are ongoing with the draft, and field visits onsite in April 2023 were used to refine the final map. Overlapping areas of the two input datasets were compared with each other, satellite imagery and ancillary data to determine interim classifications. Additional systematic rule-, size- and location-based edits were performed on the draft vegetation map in preparation for delivery.

Sources of systemic error in image classification included

1. portions of the image under thin cloud cover
2. portions of the imagery shaded by clouds

Manual corrections were conducted for systemic classification errors associated with areas of partial or thin cloud cover. Polygons corresponding to cloudy portions of the images were examined and corrected by using the vector boundaries of existing image segments. Very small polygons of all classes that were less than 12 square meters, excepting small mangrove islands were eliminated by merging with adjacent larger polygons. 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 1987 or 2006 Forest Service vegetation maps, modified to better spatially align with more recent image datasets, for example VIVID 2021.

Draft map and report review

Multiple levels of internal review were conducted prior to production and distribution of draft report and data to partners in March 2023. Partner review from Yap State Forestry led to integration of 'fern savanna' class into final map. The field visit enabled the mapper's capacity to identify this vegetation type in imagery.

Collect additional field and test samples for draft accuracy assessment

Table 3 shows classes that were used for image samples. Classes used in the map are marked in bold. 454 independent test samples were used in the final accuracy assessment, locations

of test samples was partially pure random and partly stratified by class. Five to seven minutes were spent identifying points for each of the final classes listed in table 3.

Iterate Sample Collection and Mapping Steps

The final parameters for the models are described in the steps above. Many additional image training points and several new parameters were integrated into the training algorithm. Reference and final classifications were assisted by field visits. Image interpretation and classification also included review of ancillary imagery and surface models.

Accuracy Assessment

Test samples derived from unobscured areas in the three WV2 images were compared with the classification in the vegetation map. 130 samples were randomly located throughout the study area, and half were stratified by class and location. Stratification by class was achieved by a minimum of 5 minutes collection time given to collect image samples of each separate class. Classes included several forest and vegetation types that would later be lumped together in the draft map. A total of 454 test samples were compared showing an overall classification accuracy of 86%. The reported accuracies combine agroforest and forest.

Reference (Test Samples)	Agro/ forest	mangrove	fern savanna	other veg	bare ground	urb built	water	total correct	total	User Acc.
Map Class										
Agro/forest	214	3	9	8	1	0	1	236	236	90.1%
mangrove	0	47	1	0	0	0	3	51	51	92.2%
fern savanna	0	0	33	2	3	0	0	38	38	86.8%
other vegetation	5	0	5	14	1	3	0	28	28	50.0%
bare ground	0	0	2	5	32	5	0	44	44	72.7%
urban built up	2	0	0	1	2	28	0	33	33	84.8%
water	0	1	0	0	0	0	23	24	24	95.8%
total	221	51	50	30	39	36	27	391	454	
Producer's accuracy	96.8%	92.2%	66.0%	46.7%	82.1%	77.8%	85.2%			86.1%

Table 4. Accuracy assessment

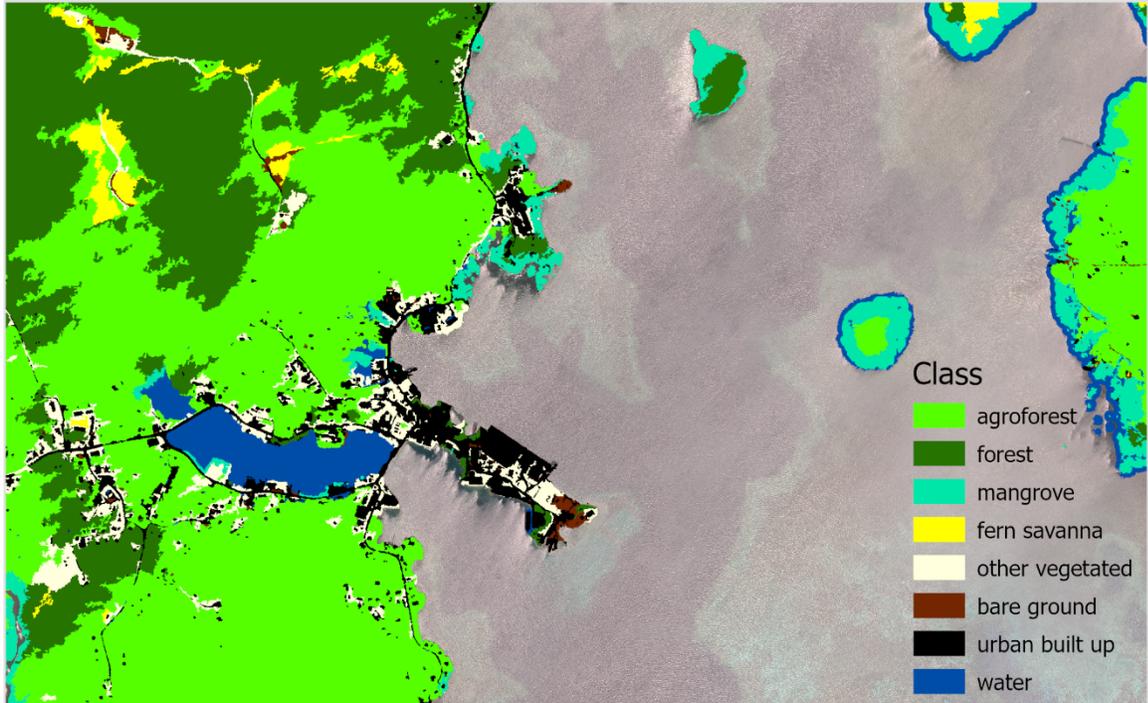
Results

Acres and relative percentages for each land cover class were calculated. Including mangroves, the 24,000 acre island of Yap is 85% forested and 96% vegetated. Nonforest landcover is mostly located at lower elevations near the ring road and other major roads, especially in the east. Most urban built up area is in and around Colonia, the Yap State capital.

Class	Acres	Percent	Description	Includes
forest	7,736	32%	tall upper canopy with woody vegetation excluding mangroves	swamp forest, upland forest, urban canopy
agroforest	10,571	44%	Managed for silvi/agriculture. Used for food, ecosystem services such as shade, erosion control, storm surge mitigation etc. (Falanruw 1987)	agroforest, tree plantations, orchards
mangrove	1,920	8%	forested wetlands in tidal and anoxic landscapes	mangrove
fern savanna	1,551	7%	Nonforested vegetation where <i>Gleichenia linearis</i> is predominant	fern savanna
other vegetated	1,054	4%	vegetated landcover that is not forest	cropland, marsh, urban vegetated, secondary vegetation
bare ground	735	3%	unvegetated areas, imagery is below NDWI and NDVI thresholds	beach, rock face, bare ground, unpaved road
urban built up	299	1%	unvegetated, paved, compacted or impervious	urban unvegetated, roof
total	23,866			

Table 5. Yap Island land cover acreage and relative cover 2022

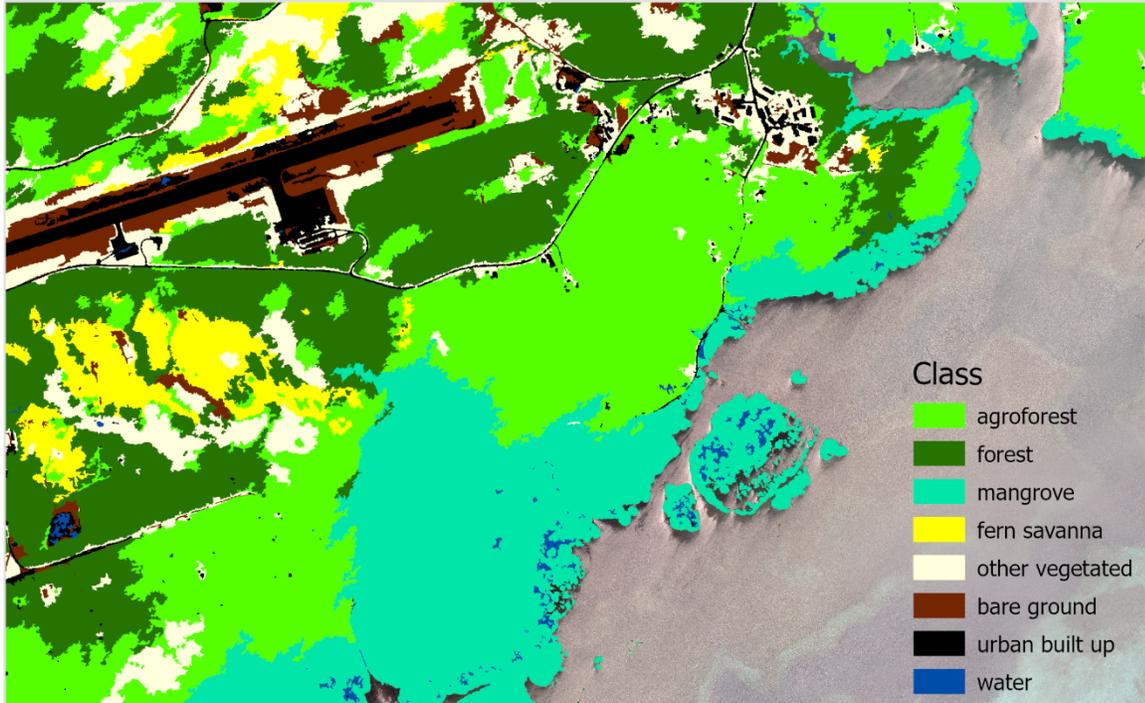
Maps on the following pages show several views of the dataset in comparison with the WV2 source imagery.



provided by Maxar
via NextView License

0 1,000 Feet

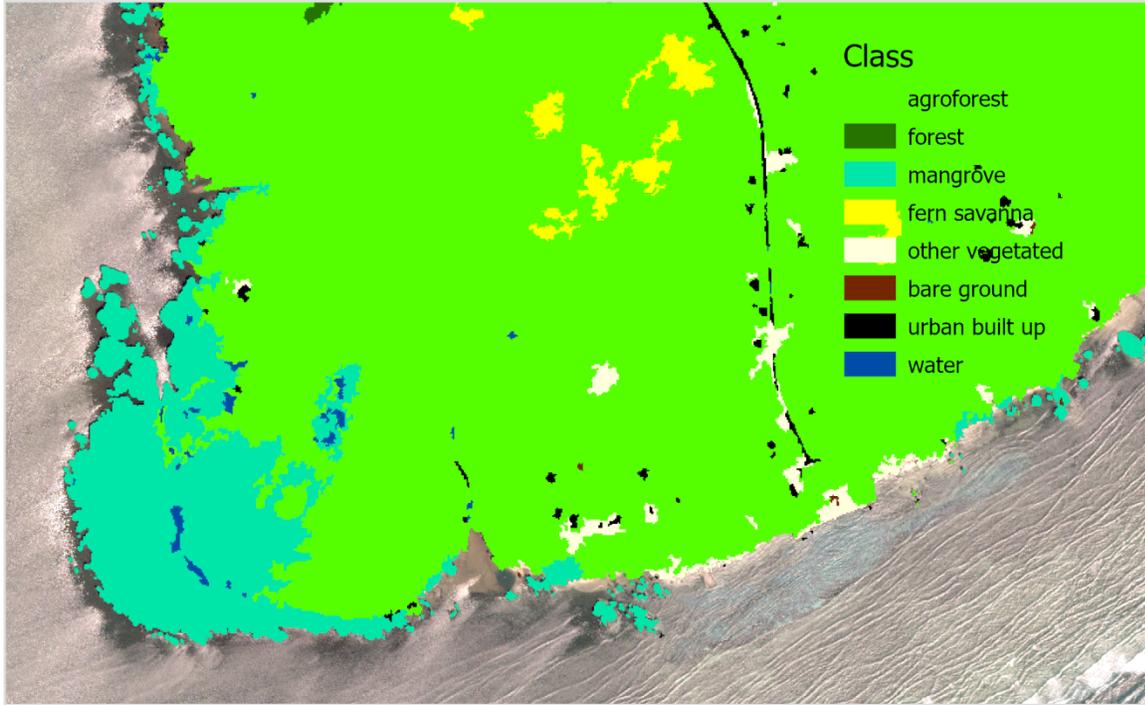
Map 4. Colonia inlet



provided by Maxar
via NextView License

0 1,000 Feet

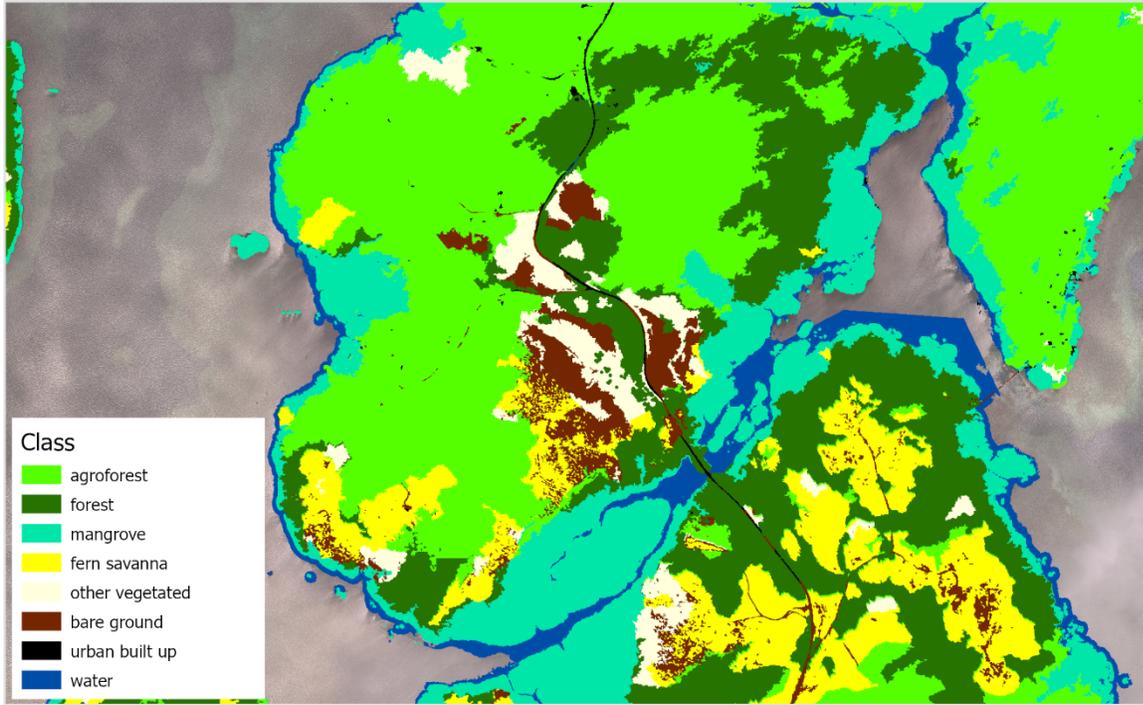

Map 5. Airport and Mangroves near Yunuf



provided by Maxar
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0 1,000 Feet

Map 6. Gilmaan, South Yap



Micronesta Imagery Service provided by USDA-PPAC. Images provided by © 2021 Maxar Intelligence.

provided by Maxar via NextView License

0 1,000 Feet

Map 7. Ma'ap and North Gagil Tamil

Table 6 compares the classification between this vegetation map and two historical vegetation maps. The Falanruw et al. 1987 mapping effort uses manual mapping methods at a smaller scale, combined with botanical expertise, aerial photo interpretation and extensive field confirmation. Previous mapping efforts conducted by Liu were based on 2003-2005 satellite imagery.

Differences in mapping and classification methods among the three maps explain some of the increase in forested area in 2022-23 results excluding mangroves. For more homogenous classes, additional analysis which builds upon verification and refinement of this map might be pursued. For example, using a binary classification and machine learning to classify *Merremia*, a fast growing vine, in Kosrae, FSM (Salomon et al. 2021)

2022-2023 Salomon	1987 Falanruw et al.		2003 - 2005 Liu et al.		1987	2003	2022
		Acres		Acres			
Agroforest	Agroforest	5,785	Agroforest	6,736	6,175	6,736	10,571
	Coconut plantation	390					
forest	Upland Forest	6,254	Upland Forest	7,718	6,638	7,780	7,736
	Swamp Forest	384	Swamp Forest	62			
mangrove	Mangrove Forest	2,807	Mangrove Forest	2,631	2,807	2,631	1,920
fern savanna	Savanna/Grassland	4,736	Savanna/Shrub	4,088	4,736	4,088	1,551
other vegetated	Cropland	108	Cropland	14	1,854	1,604	1,054
			Urban Cultivated	298			
	Secondary Vegetation	1,356	Secondary Vegetation	983			
	Marsh	390	Marsh	309			
urban built up	Urban land	753	Urban Builtup	720		720	299
bare ground			Barren	184			735
	total	22,963		23,743			23,866

Table 6. Comparison with circa 1987 and 2003 acreages

References

Region 5 State and Private Forestry publications

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