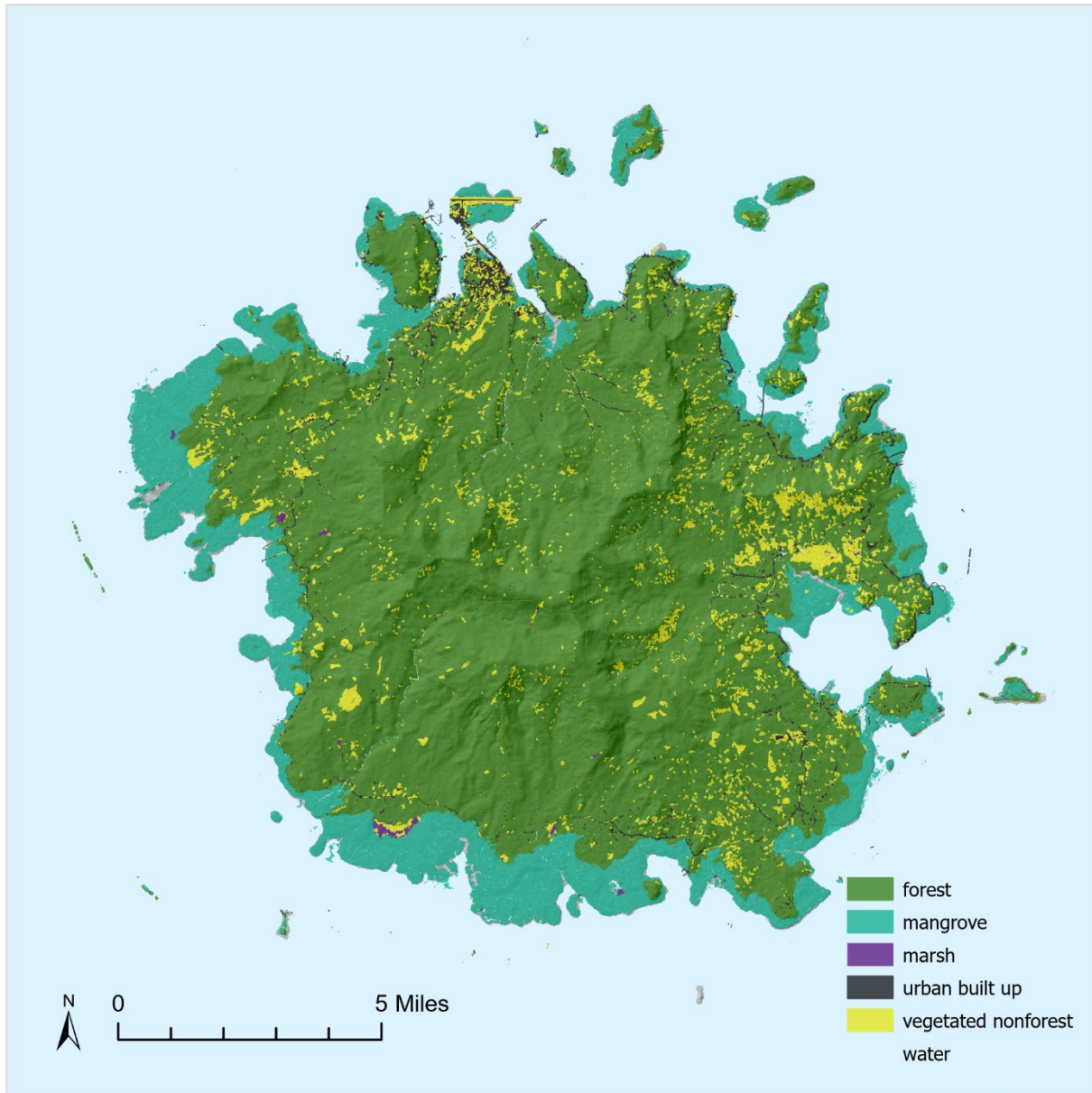




Pohnpei Island Vegetation Map 2020-2021



Pohnpei State, Federated States of Micronesia

Micha Salomon – State and Private Forestry, Region 5 – USDA Forest Service

December 2022

Map 1. Cover Image Vegetation and land cover mapped on Pohnpei Island, FSM, from 2020-2021 WorldView scenes and ancillary data. USDA Forest Service map by Micha Salomon

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Summary

Vegetation in Pohnpei 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 2020 and 2021 were classified into vegetation and land cover types. This map includes small islands in and around Pohnpei Island’s surrounding lagoon.

Table 1. 2020-21 land cover classes and acreages mapped

Class	Acre
forest	68,305
mangrove	16,155
marsh	301
urban built up	982
vegetated nonforest	2,659
water	218
total	88,620

GIS data (updated 20 Dec 2022) accompanying this report is available in ESRI Shapefile (SHP) format at https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd1079035.zip

This report can be downloaded here

https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd1079038.pdf

This mapping effort updates the Forest Service 2008 mapping data which was based on 2005 Quickbird II satellite imagery. Like this effort, the methods included image segmentation using eCognition. Classification methods were less automated in the earlier effort and classification was assisted by in situ confirmation of the more detailed land use and land cover classes. Vegetation map data published in 2008 can be found here:

https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5353761.zip

Data Sources

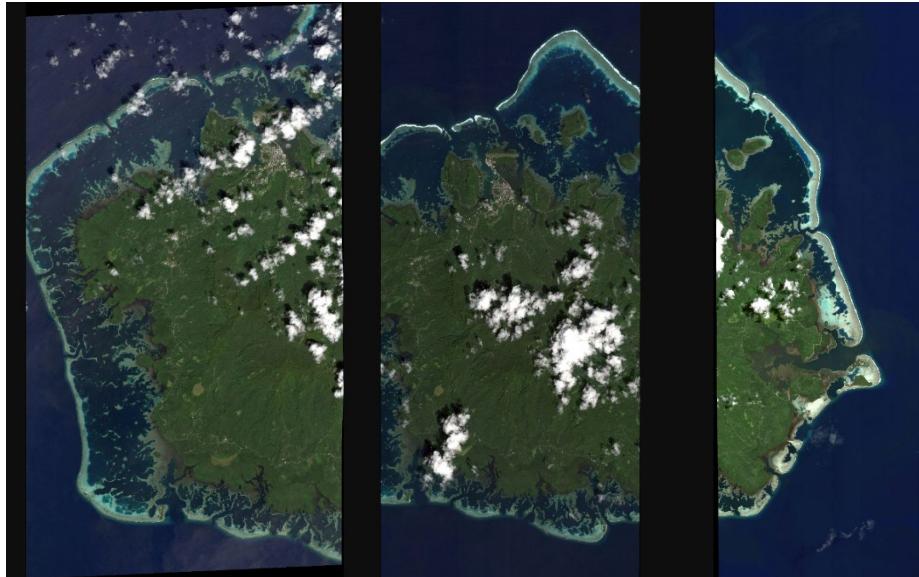
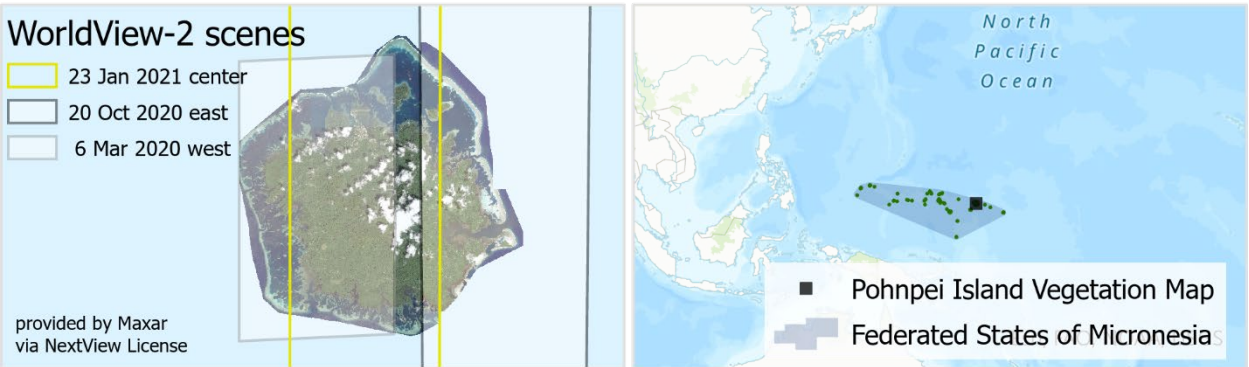


Figure 1. WorldView-2 imagery from March 2020, January 2021, October 2020

- Satellite Imagery: 3 WorldView-2 (WV2) scenes from 2020-21. Eight band (1.9m) + panchromatic (0.5m). The imagery was acquired from Maxar's DigitalGlobe under the U.S. Government's Enhanced View Program
 - 6 March 2020 – western Pohnpei Island
<https://api.discover.digitalglobe.com/show?id=10300100A18F6000>
 - 23 January 2021 – central Pohnpei Island
<https://api.discover.digitalglobe.com/show?id=10300100B41E7B00>
 - 20 October 2020 – eastern Pohnpei Island
<https://api.discover.digitalglobe.com/show?id=10300100AFA5E100>
- Ancillary imagery: Maxar Vivid FSM 2021
 - WorldView composite, multiple acquisition dates 2015-2021. Public license. Served via Natural Resources Conservation Service (NRCS) (accessed 1 Sep 2022)
https://nrcsgeoservices.sc.egov.usda.gov/arcgis/rest/services/ortho_imagery
- Elevation from ALOS via Google Earth Engine Library (accessed 1 Jun 2022)
 - Coarse digital surface model (DSM) 30m horizontal resolution
- Existing vegetation and substrate classifications and maps

- Vegetation: Forest Action Plan (Republic of FSM 2021), Greenberg 2020, Liu & Fischer et al. 2008, MacLean et al. 1986
- Open Street Map. Roads and Infrastructure for Pohnpei Island. Accessed 8 Sept 2022. <https://www.openstreetmap.org/>

The mapped area covers Pohnpei Island, FSM, and the small islands lying within its lagoon. Land cover classes were adapted from Liu (2008), MacLean et al. (1986), and the 2021 FSM Forest Action Plan (SWARS). Final land cover classes include forest, mangrove, marsh, urban built up, vegetated nonforest, water and beach. 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.



Map 2. Pohnpei Island and WV2 Image Coverage

Class	Description	Includes
forest	tall upper canopy with woody vegetation excluding mangroves	agroforest, swamp forest, palm forest, Oahs palm forest (<i>Metroxylon amicarum</i>), upland forest, urban canopy
mangrove	tidal forested wetlands	mangrove
marsh	frequently to perennially flooded nontidal wetlands with emergent nonforest vegetation or shallow flooded substrate	marsh
urban built up	unvegetated, paved, compacted or impervious	urban unvegetated, barren land
vegetated nonforest	vegetated landcover that is not forest	cropland, grassland/savanna, urban vegetated, secondary vegetation
water	inland water	water
beach ¹	Unvegetated nearshore	beach, unvegetated intertidal

Table 2. 2020-21 land cover classes description

¹ Post hoc annual reclassification from 'urban built up', not tidally controlled

Methods

Overview

1. Review existing vegetation maps, identify current classification priorities
2. Via G-EGD, Obtain three recent WV2 scenes, cloud free as possible
3. Preliminary Classification: Subset, Segment, Semi-Automate
 - a. Subset: prepare image for eCognition segmentation by excluding water, clouds and including all vegetated areas
 - b. Segment images to differentiate forest, mangrove, and vegetated nonforest
 - c. Collect image training samples for iterative training of a classifier
 - d. Collect image test samples for accuracy assessments
 - e. Use training samples to train Random Trees classifier in eCognition
 - f. Classify remaining image objects
 - g. Export 3 sets of classified image objects as classified polygons
4. Synthesize single Pohnpei Vegetation layer in ESRI Arc Pro 10.7
5. Map Revision 1: Identify and correct sources of systemic error
6. Draft map & report review
7. Collect additional test samples for final accuracy assessment
8. Map Revision 2: Incorporate review comments, address error

Classification priorities

Throughout the mapping process, several considerations guided the development of the final classification scheme. One consideration was finding the clearest and most recent imagery available. The need to produce a final 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 final 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. One last note is that, in contrast with previous mapping efforts, ground confirmation of image samples and mapping was not possible due to travel restrictions

Source imagery

Obtaining timely imagery with limited cloud cover over Pohnpei Island continues to pose a challenge, particularly along the high volcanic ridges at the center of the island. Three WV2 scenes with relatively limited cloud cover from 2020 and 2021 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.

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 three 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 three 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.

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 Pohnpei Island. The same algorithm also includes nearshore mangrove islets in very small stands less than 4m across. 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. The algorithms used the blue, red edge, and near infrared bands, as well as combinations of those bands to mask out the areas of densest cloud cover and of coastal water (Figure 2). Formulas for band indices, here labeled FDI and NDBRe, are as follows

1. FDI (= near infrared 2 - red edge - blue)
2. NDBRe (= blue - red edge/blue + red edge)

By removing coastal water and clouds, the input to the next step was intentionally limited mostly to areas of terrestrial vegetation. Preliminary classification is a coarse data reduction step, meant to improve the output of segmentation. It improves the segmentation output by excluding most coastal water and thick clouds from consideration, while including small patches of vegetation that may be surrounded by water. After developing the subsetting algorithm, the image segmentation results were improved relative to earlier iterations.

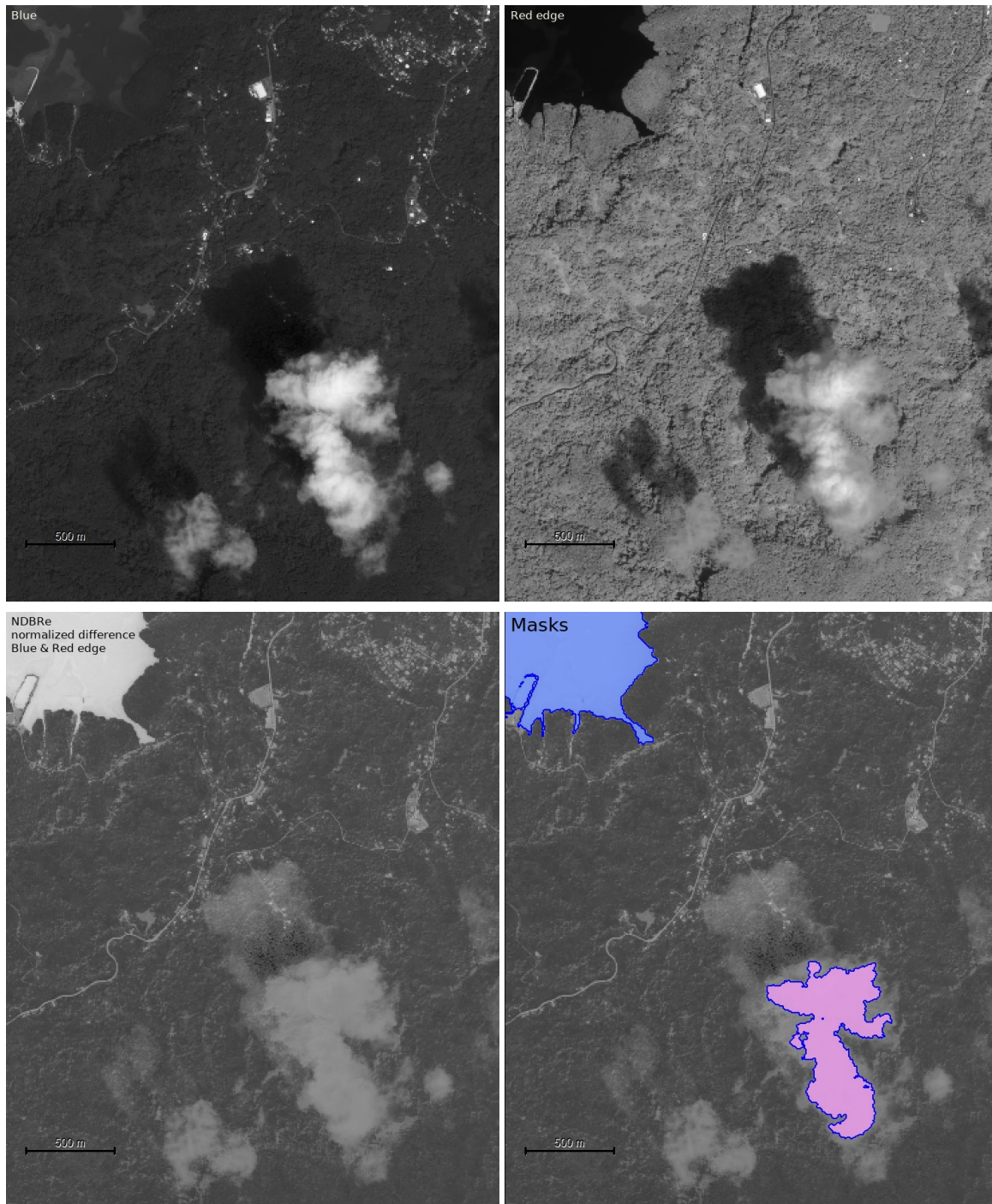
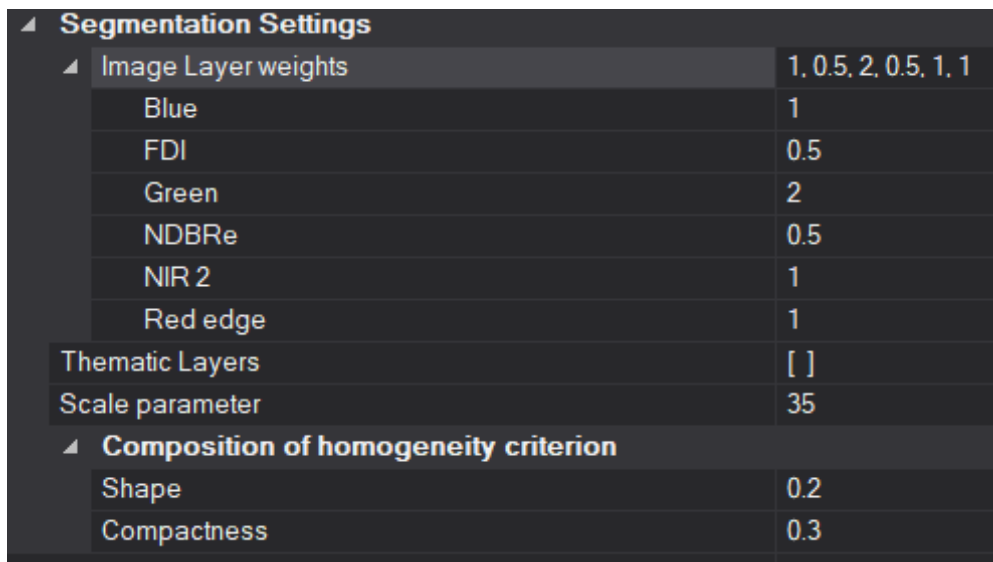


Figure 2. Bands and band combinations used to mask clouds and coastal water

Segmentation

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 4 shows a portion of an image before and after 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.

Two main stages of the algorithm were quadtree segmentation at 200 Scale on the Blue, Green, and NIR 2 bands, followed by eCognition's signature multi-resolution segmentation algorithm implemented at scale 35, Shape 0.2, Compactness 0.3, and using Blue_(weight=1), FDI_(0.5), Green₍₂₎, NDBRe_(0.5), NIR 2₍₁₎ and Red edge₍₁₎ as weighted image layers. The parameters, including 'Layer weights' are shown in the figure below.



Segmentation Settings	
Image Layer weights	1, 0.5, 2, 0.5, 1, 1
Blue	1
FDI	0.5
Green	2
NDBRe	0.5
NIR 2	1
Red edge	1
Thematic Layers	[]
Scale parameter	35
Composition of homogeneity criterion	
Shape	0.2
Compactness	0.3

Figure 3. Parameters of multi-resolution segmentation on 8 band WV2 scene

Figure 4 shows a portion of the final segments produced. No segmentation is perfect, but in this example there good separation of urban areas and nonforested areas, with some 'oversegmenting' of shadows and treed areas.

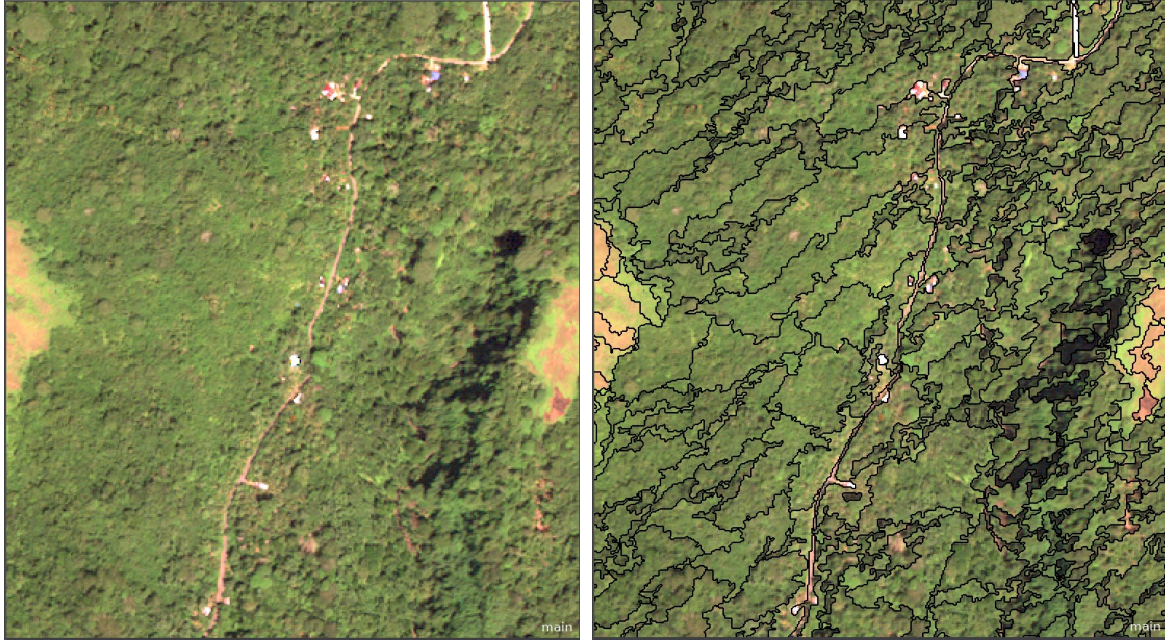


Figure 4. Image segmentation

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, image sample points were identified from each source image via visual interpretation. Samples were mostly collected using ESRI ArcGIS Pro 10.8 with pansharpened imagery. Training sample points were collected for the purposes of preliminary classification. Test sample points were collected for interim accuracy assessments that were used to improve the model. Additional test samples were also used in the final accuracy assessment.

Initially, two levels of classification detail were collected. In the final vegetation map, the lower level of classification detail, labeled ‘Class0’, was ultimately used. 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.

Pohnpei central, west and east image strips had a total of 1566, 1395 and 994 collected and interpreted image training sample points, respectively. Also Independently, 1074 test

samples were collected and classified at two levels of detail across the three images. In addition to several hundred randomly located points, the sampling process included spending 30 minutes for each of the 15 unique and detailed ‘Class_name’ attributes. The 15 detailed ‘Class_name’ types are shown in Table 3 below. Ultimately this vegetation map uses a less detailed classification scheme, more similar to the ‘Class0’ groupings listed in the left column of Table 3. Final classes used in the vegetation map excluded clouds, shadows and coastal water.

‘Class0’	‘Class_name’ subcategory
forest	agroforest, swamp forest, palm forest, palm forest ivory nut, upland forest, forest shadow
mangrove	mangrove
marsh	marsh
urban built up	bare ground, urban built up
vegetated nonforest	urban cultivated (lawn), secondary vegetation
water	Water, coastal water (mask)
cloud	Cloud

Table 3: Interim classes used in sampling and classification

Pan-sharpened imagery, false-color infrared views, 2016-2020 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, Aaron Kamoske, Kain Kutz and Michael Jordan also provided assistance in defining and assigning classes, interpreting land cover, and identifying vegetation types.

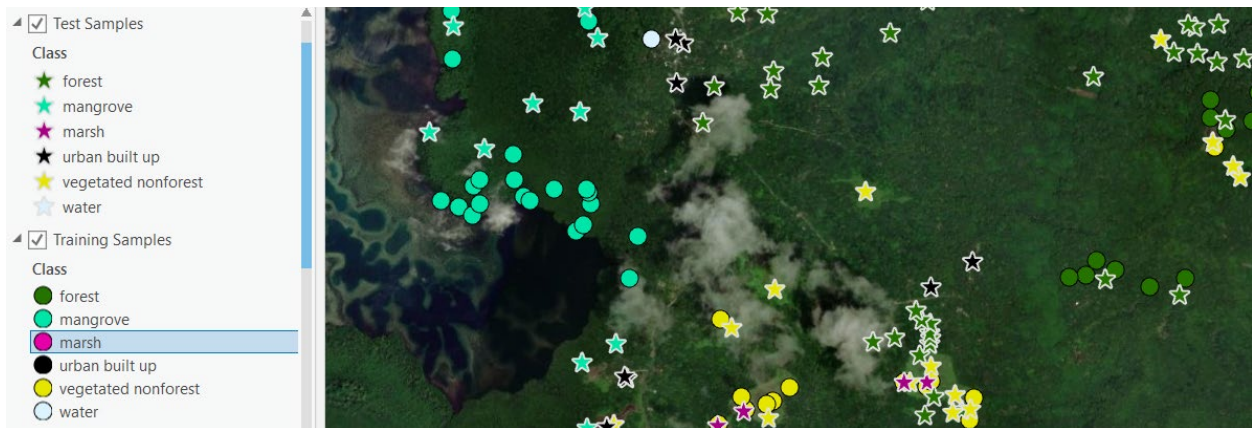


Figure 5. Image sample collection showing training and test samples at ‘Class0’ detail

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 three 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. About 1000 image samples were used to train each of the three instances of eCognition’s ‘Random Trees’ classifier. Initially, training and classification were implemented on both the detailed ‘Class_name’ category, and the less detailed, ‘rolled-up’ ‘Class0’ category.

Several iterations of the segmentation and classification algorithms were run for each of the three images, at first iterations included the more detailed ‘Class_name’ attribute. Later iterations would settle on the less detailed ‘Class0’ attribute to train the classifier and classify the image objects for each source image. Iterations of this automated approach ultimately provided an overall user’s map accuracy of greater than 80%.

Parameters of the eCognition Classifier were developed iteratively. The final 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 and FDI; WV2 bands Green, Red, Blue, Red edge and NIR 2. To help differentiate mangrove from other forest types, mean elevation was used. For the same purpose, the geometric characteristic ‘shared Border to coastal water’ parameter were used as well. ‘Area of image object’ and ‘distance to cloud’ parameters were included to assist in separating ‘cloud’ classification from ‘urban built up’ in very bright areas of the image.

Parameter	Value
Operation	Train
Configuration	PohE_SupClass_RandTrees3_Aug19
Use samples only	Yes
▲ Feature Space	
Source	object based
Features	[Mean NDBRe, Mean FDI, Mean Green
▲ Classifier	
Type	Random Trees
Depth	0
Min sample count	0
Use surrogates	No
Max categories	16
Active variables	0
Max tree number	3000
Forest accuracy	0.01
Termination criteria type	Both

Selected
Mean NDBRe
Mean FDI
Mean Green
Mean Red
Mean Blue
Mean Red edge
Mean DEM
Mean NIR 2
Distance to cloud
Area
Border to coastal water (mask)

Figure 6. Settings for eCognition Random Trees classifier

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

Synthesis and revision of vegetation map from three classified images

A single vegetation map layer was synthesized using the three outputs from the previous classification step. Image objects with preliminary modeled classifications were exported from eCognition as vector datasets. In ArcMap, the three spatially overlapping datasets were combined into a single vegetation map without overlaps. Throughout the process, geometry and classification accuracy checks were conducted, with changes implemented where appropriate. Existing image segments were used for redefining polygon boundaries whenever possible. During the review process classification changes were tracked. Overlapping areas of the three input datasets were compared with each other, satellite imagery and ancillary data to determine final classification. 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 and/or steep relief
3. misclassification of 'urban built up' as cloud
4. overclassification of 'water' and 'marsh' in areas of low reflectance

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 3.4 square meters, excepting small mangrove islands were eliminated by merging with adjacent larger polygons. Polygons classified as

mangroves within the ring road of the main island were reclassified as forest. In this step, default or 'matrix' land cover was classified as forest where obscured by cloud cover. Land cover polygons were dissolved by class into single part polygons to reduce the number of output features.

Expert review and second revision

Program leads, experts and partners reviewed the draft vegetation map and methods report. Following the review, additional changes and corrections were made to the vegetation map based on reviewer comments.

Additional inspection and correction of the mangrove - forest edge was conducted around the perimeters of Pohnpei Island and the nearby small islands. Where 'mangrove' or 'forest' classification along this edge was judged to be in error, polygons derived from previously created image segments were used to change the geometry where correction was needed.

A second round of review and changes was conducted in cloud-obscured areas. Specific areas of vegetated nonforest were extracted from pre-2020 imagery and appended to the vegetation map, replacing areas classified as 'forest' by default. Sites covered by clouds in the three source images were identified. Relative to the early subsetting stage, a more restrictive cloud masking algorithm was created in Google Earth Engine, which identified areas where cloud free imagery was still lacking. At these sites, polygons identified as 'vegetated nonforest' were derived from subsets of older but less cloudy 4-band WorldView VIVID composites. Arc Pro's Raster Functions were used to conduct unsupervised classification directly on an ESRI ImageServer service. Polygons were exported over small areas from the Raster Function to extract additional nonforest polygons that were then appended to the vegetation map. Maps 4 and 5 on the following pages both contain examples where additional 'vegetated nonforest' polygons were appended in this way.

Lastly, due to a preponderance of commission errors, small 'marsh' and 'water' polygons (< 0.25 acre / 1000 sq. m.) adjacent to urban polygons were reclassified as 'urban built up'. Final classes for the product were reduced to the six classes listed in Table 1.

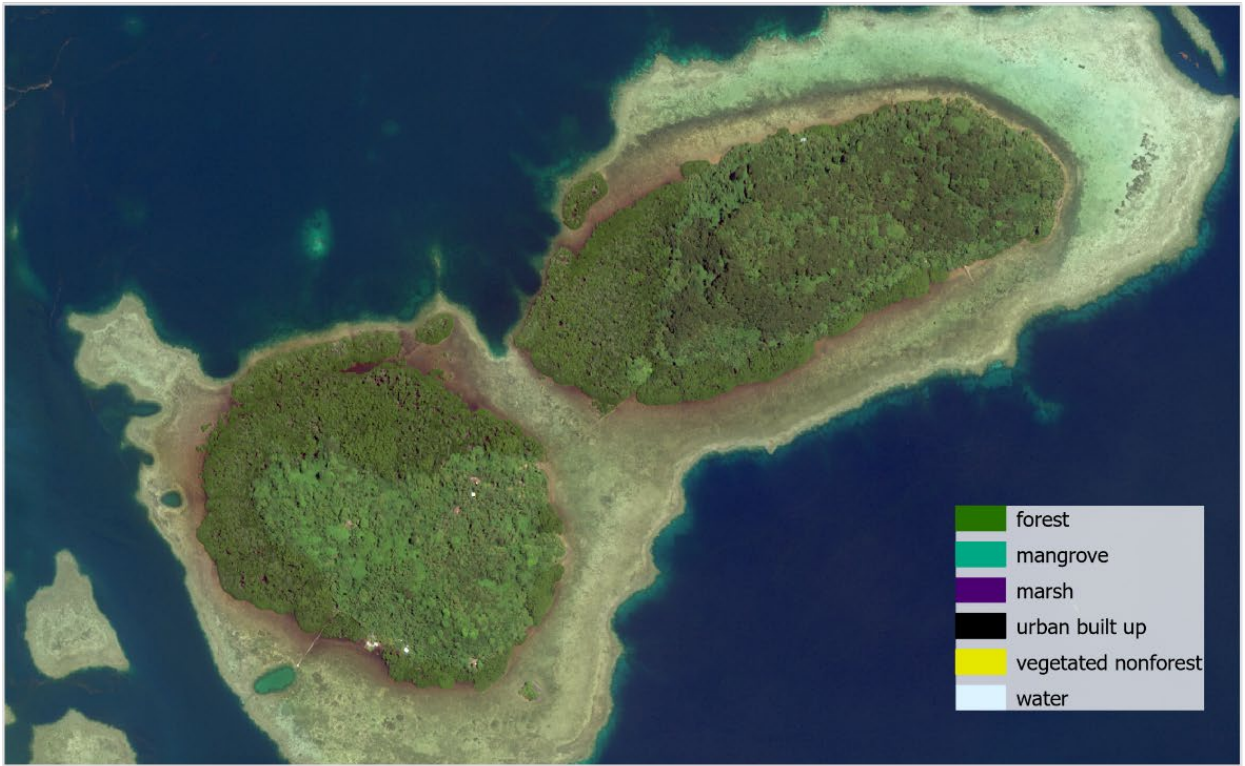
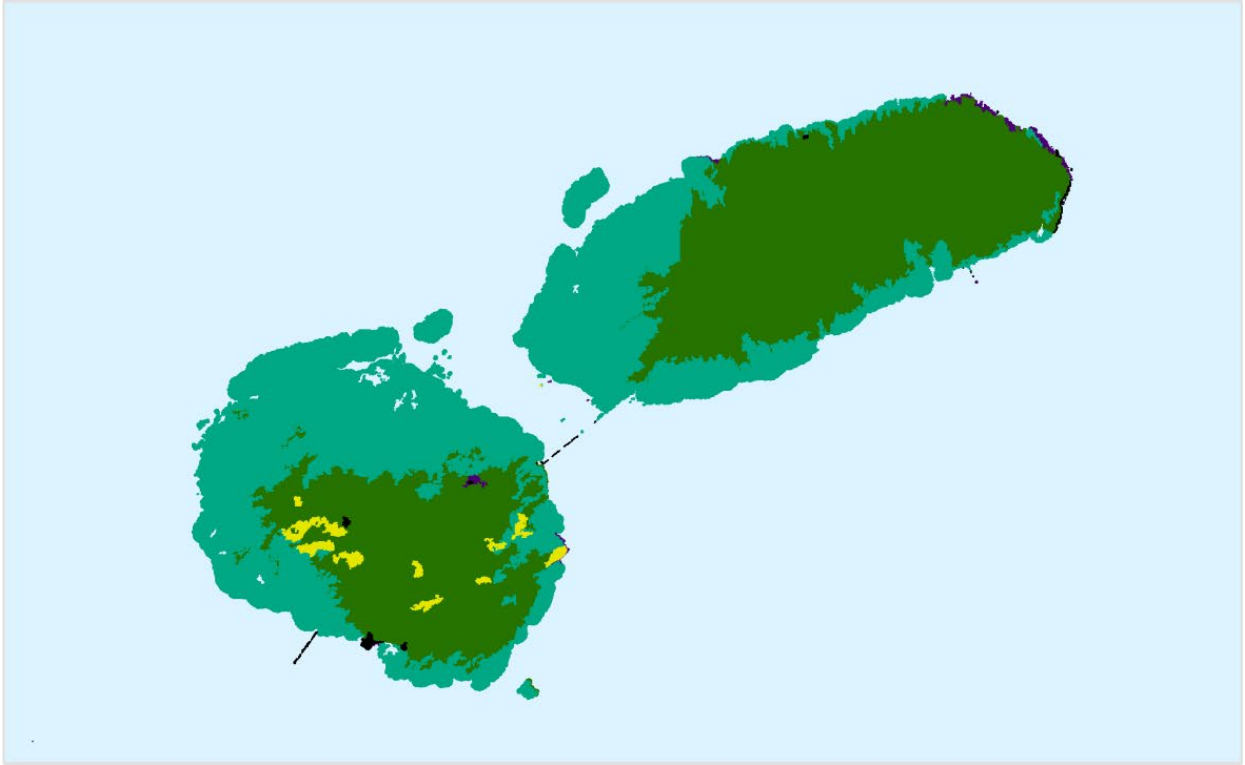
Results

Acres and relative percentages for each land cover class were calculated. Including mangroves, the 90,000 acre island of Pohnpei is over 95% forested and over 98% 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 Kolonia, the Pohnpei State capital.

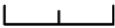
Class	Acres	Percent	Description	Includes
forest	68,856	77.7%	tall upper canopy with woody vegetation excluding mangroves	agroforest, atoll forest, swamp forest, palm forest, upland forest, urban canopy
mangrove	15,261	17.2%	tidal forested wetlands	mangrove
marsh	225	0.3%	perennially flooded wetlands with emergent nonforest vegetation	marsh
urban built up	1,106	1.1%	unvegetated, paved, compacted or impervious	urban unvegetated, barren land, beach
vegetated nonforest	3,016	3.4%	vegetated landcover that is not forest	cropland, grassland/savanna, urban vegetated, secondary vegetation
water	206	0.2%	inland water	water
total	88,596			

Table 4. Pohnpei Island land cover acreage and relative cover 2020-21

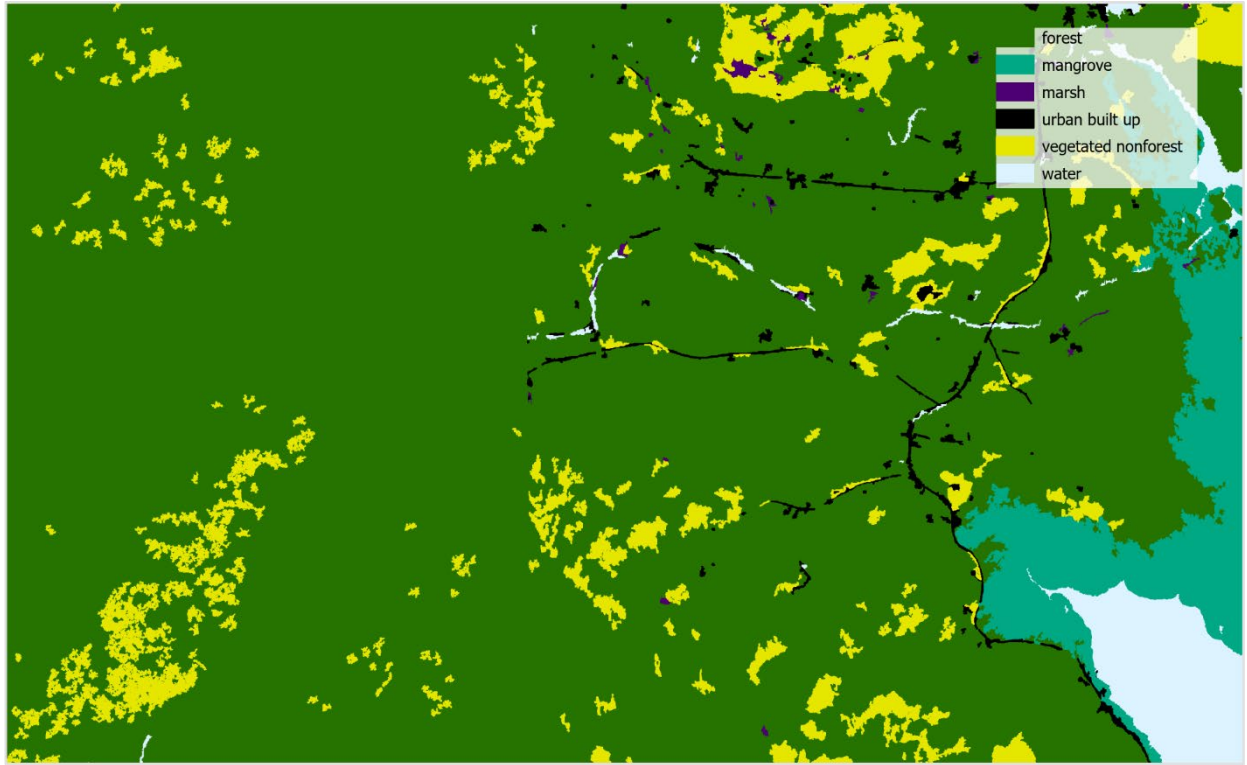
Maps on the following pages show several views of the dataset in comparison with the WV2 source imagery.



provided by Maxar
via NextView License


0 1,000 Feet


Map 3. Comparison with WV2 islet land cover

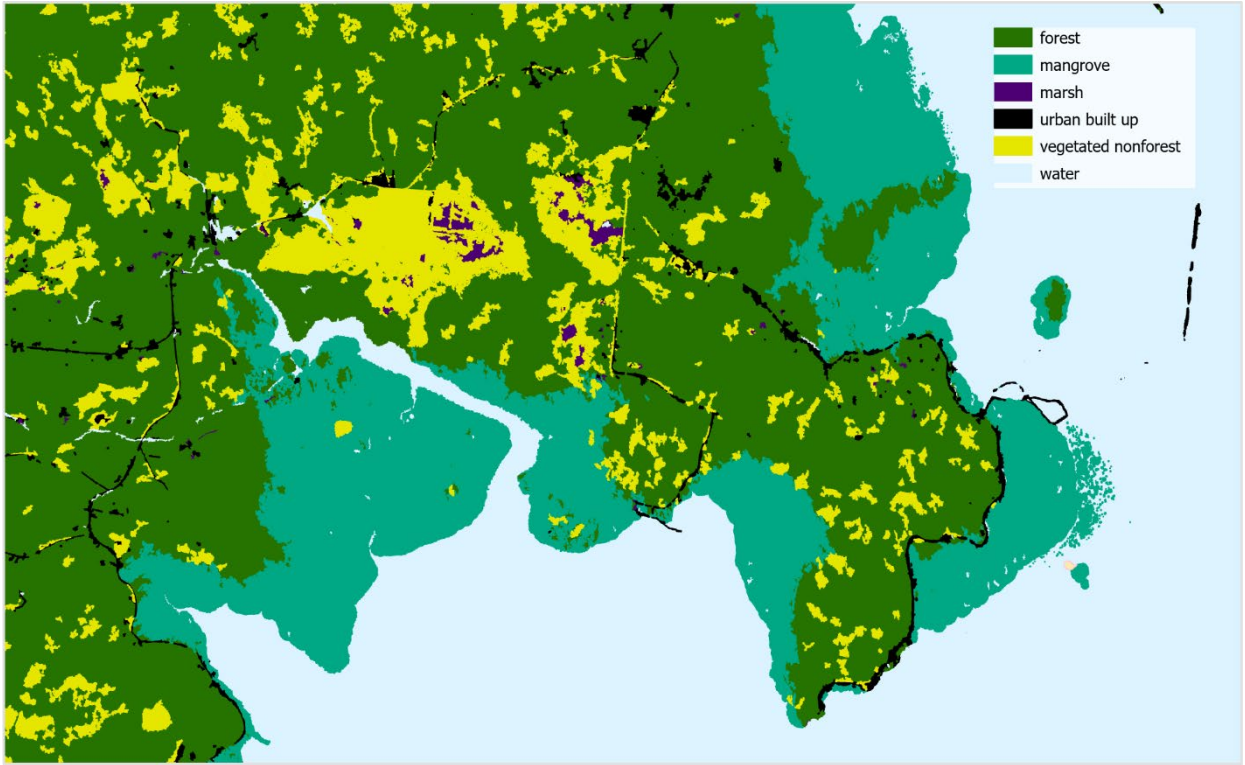


Micronesia Imagery Service provided by USDA-FPAC. Images provided by © 2021 Maxar Intelligence.

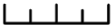
provided by Maxar via NextView License

0 1,000 Feet


Map 4. Comparison with WV2 2016-2021 VIVID Composite



provided by Maxar
via NextView License

0 1,000,000 Feet


Map 5. Comparison with WV2 classification despite cloud cover

Table 5 compares the classification between this vegetation map and two historical vegetation maps. The MacLean et al. 1986 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 2005 satellite imagery and field confirmation through 2008.

In 2022, extensive efforts were made to include all atoll forests, and also very small mangrove stands that may be sites of recruitment, and where coastal waters may have changed to mangrove forest. Differences in mapping and classification methods among the three maps explain some of the increase in mangrove area in 2022 results. Nevertheless, the progradation of mangroves along outer shorelines, and the expansion of islet stands can be observed consistently around most of the study area.

Discrepancies in area exist among agricultural and successional vegetation types. In situ confirmation of vegetation and land use/land cover types is especially recommended to further classify 'agroforest' and other important managed, significant, successional, invasive and/or endemic vegetation types. 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).

2020-2022	1986		2005 - 2008		Comparison		
	MacLean et al.	acres	Liu et al.	acres	1986	2005	2021
Salomon forest	Agroforest	32,506	Agroforest	14,608	59,019	67,677	68,856
	Palm Forest	2,034	Palm Forest	4,526			
	Palm Forest Ivory Nut (Metroxylon Amicarum)	916					
	Swamp Forest	693	Swamp Forest	244			
	Atoll/Beach Forest	31					
	Upland Broadleaf Forest	22,840	Upland Forest	48,299			
	Montane Cloud Forest	156					
mangrove	Mangrove Forest	13,282	Mangrove Forest	13,982	13,282	13,982	15,261
vegetated nonforest	Savanna /Grassland	3,440		14,038	5,123	3,016	
			Cropland				29
			Savanna				2,440
	Urban Cultivated	440					
Secondary Vegetation	10,598	Secondary Vegetation	2,214				
marsh	Freshwater Marsh	280	Marsh	330	452	330	225
	Montane Perched Freshwater Marsh	48					
	Saline Marsh	124					
urban built up			Barren	14	1,086	985	1,016
	Developed /Disturbed	1,086	Urban Builtup	972			
water	Water	28	Water	80		80	206
			Background	57			
	total	88,061		88,235			88,580

Table 5. Comparison with circa 1986 and 2005-2008 acreages

Accuracy Assessment

Test samples derived from unobscured areas in the three WV2 images were compared with the classification in the vegetation map. Half of samples were randomly located, and half were stratified by class and location. Stratification by class was achieved by a minimum of 15 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 final map. Stratification by class was also achieved by opportunistically gathering samples from less. A total of 1281 samples were compared showing an overall classification accuracy of 88%.

Reference (Test Samples)	forest	mangrove	marsh	urban built up	vegetated nonforest	water	total correct	total	User's accuracy
Map Class									
forest	583	12	18	28	45	2		688	84.7%
mangrove	12	253	3	3	1	3		275	92.0%
marsh	0	0	21	0	3	1		25	84.0%
urban built up	3	0	0	72	5	0		80	90.0%
vegetated nonforest	0	0	4	5	178	0		187	95.2%
water	0	0	1	0	0	25		26	96.2%
total	598	265	47	108	232	31	1132	1281	
Producer's accuracy	97.5%	95.5%	44.7%	66.7%	76.7%	80.6%			88.4%

Table 6. Internal accuracy assessment

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