

WHO SPEAKS FOR THE FOREST? LOCAL KNOWLEDGE, PARTICIPATORY MAPPING AND COLLABORATIVE EVALUATION FOR GIS ANALYSIS IN THE TROPICS OF CENTRAL BALI, INDONESIA

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ABSTRACT:

This paper describes a land survey of the Bedugul area in Central Bali that was constructed using multi-temporal and multi-spectral data collected from a new class of commercially available satellites to produce detailed land cover mappings. The paper discusses the significance of the land area under investigation, including difficulties in reading land cover features in the tropics. It describes participatory field mapping efforts set in place in order to complement the reading of remote sensing assets and our attempts to represent land use features of particular interest to a local NGO. We further discuss the challenges and opportunities of representing land cover and use scenarios that satellite assets can only partially capture. We use band operations and object-based classification methods to represent change in settlement activity in the area under observation. We also describe a collaborative cloud-based analysis and evaluation pipeline that facilitates the processing of different sources of remote sensing data as well as the representation of various types of land use scenarios defined with the assistance of local knowledge

1. INTRODUCTION

God Island, Bali, is home to a population of 4,317,404 inhabitants and spans some 5,636.7 km² (Ministry of Environment and Forestry Indonesia, 2020). Situated east of Java and west of Lombok, Bali is a destination for both domestic and foreign tourists. In the center of Bali lies one particularly interesting locale, the Bedugul area, a part of the Tabanan and Buleleng Regencies. The terrain here reaches elevations ranging from 1,200 to 2,100 m. Ease of access created by the Denpasar-Singaraja highway has facilitated rapid development, increasingly dense settlements and additional public facilities and services, as well as the expansion of all kinds of touristic activities.

Bedugul consists of a basin area set in a volcanic mountain region, and the land surrounding these mountainous hills are sites intended for small-scale settlements, dryland agriculture and vegetable farming. The morphology of these undulating lands is co-defined by three volcanic lakes: Lake Buyan, Lake Bratan, and Lake Tamblingan (Figure 1). Because of its relative accessibility, fertile lands, fresh-water resources and high-land climate, the Bedugul area is considered a valuable resource for indigenous groups, local residents, developers, conservationists and tourists alike, with each group holding different interests in the area (Zen, 2019). Moreover, the forests of Bali span some 136,831 hectares across the west, middle, and east of the island. The forest management system was originally adopted from a Dutch colonial template (Widiastawa et al., 2016). Today, there are six different types of forest area management units, namely the Protected Forest Management Units of West Bali, Central Bali, and East Bali as well as the TAHURA Ngurah Rai Forest Management Unit, the Bali Natural Resources Conservation Center, and West Bali National Park (Widiastawa et al., 2016).

This background information is offered here in order to better contextualize the overall project goal, outlined in detail in section 3 below.

2. EARLY GIS ASSETS in BALI

In the past, the use of spatial data to survey Indonesia has not been particularly effective, mainly due to the lack of availability as well as the lack of diversity of appropriate data sources. The situation changed in 2012 with the introduction of data from Landsat 7 and Landsat 8/OLI (Ministry of Environment and Forestry Indonesia, 2013). However, with a spatial resolution of 30 meters per pixel, Landsat is useful for land cover interpretation at medium scale only.

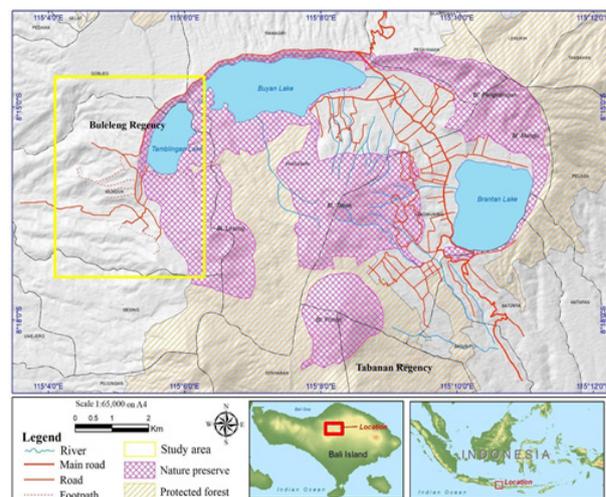


Figure 1. Overview of the study area in Central Bali.

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3. CONTESTED LAND

The Alas Merta Jati in Central Bali is contested territory as it is currently claimed as ancestral lands by the Tamblingan community (Suryawan, 2021), and at the same time has been designated as a state forest by the Indonesian government. While both entities claim to protect the forest along “sustainable” principles (Strauss, 2015), each entity interprets the responsibilities and benefits of sustainable actions in different ways.

This project has multiple goals. First, we want to improve the state of GIS based land cover analysis in Bali in general. Second, we are invested in procedures that can operate with constrained resources, where such constraints can be of economic or computational nature. Third, want to include needs and interests in land cover representation that are usually not included. To that end, we are working together with a local Non-Governmental Organization (WISNU, 2022) representing the Tamblingan community of Central Bali to assess the ways in which different priorities impact the use of GIS assets as well as the conception of land cover categories and their representation.

3.1 Data sources

Informed by the history of land use debates and of satellite imaging in Bali, we make use of the current surge of commercial satellite assets that offer unprecedented access to daily acquisition of new imagery. Our data collection relies on a combination of high-resolution satellite imagery from PlanetScope (PS) provided by Planet Labs (PS, 2022), ESA’s Sentinel2 (Sentinel2, 2012) and field level data collection provided by inhabitants of the area.



Figure 2. Still image from video collected by informant (GPS coordinates Lat -8.256662, Lon 115.079644). The videos are used to clarify the actual conditions on the ground.

PS offers a spatial resolution of 3.7m/pixel across all its bands while Sentinel2 has a maximum resolution of 10m/pixel for bands at central wavelengths 490nm, 665nm, 842nm and resolutions of 20 and 60m for the other bands. However, PS in the recent past only offered 4 channels, specifically Blue (455 - 515 nm), Green (500 - 590 nm), Red (590 - 670 nm), and Near-Infrared (780 - 860 nm) versus Sentinel2’s 13 channels. Importantly, PS assets are updated daily while Sentinel2 has an effective revisit frequency of 5 days (Raza et al. 2020).

3.2 Data collection and verification

Our first data collection step follows standard practices. We study the composite’s PS satellite data in conjunction with Google Earth imagery (GE, 2022) to identify a first round of land cover features. However, we then include elements of participatory mapping (Cochrane, 2020) to verify questionable sites. Local informants, remunerated for their contributions, collect short video recordings of the actual situation on the ground, and upload these verification datasets to a shared server for review by the research team (Figure 2).

4. CONCEPTUAL CHALLENGES

The single most significant issue we encounter in this project is the fact that local knowledge and local interests are not represented in GIS maps nor in the land cover categories that constitute formal categories in GIS representation in Indonesia.

Moreover, while spectral reflectance can identify an object in an idealized scenario, some factors such as dynamic land use scenarios are not discernible. Any attempt to automate land cover classification must take these limitations into account. Algorithmic classification based on the collection of training data samples (ROI sets) can address some of these conditions if the training samples are carefully selected and validated. However, it is imperative that knowledge in satellite imagery be combined with information regarding conditions on the ground. Even then, one must contend with visual confusion from heterogeneous land use scenarios (Zen, 2019). The next sections describe some of these conditions.

4.1 Complex land cover conditions

A major limitation to satellite observations in the tropics is the high frequency of cloudy days that make observations in the visual bands impossible. Weeks can pass between times when low cloud coverage allows for views of a given location, despite daily image asset updates.

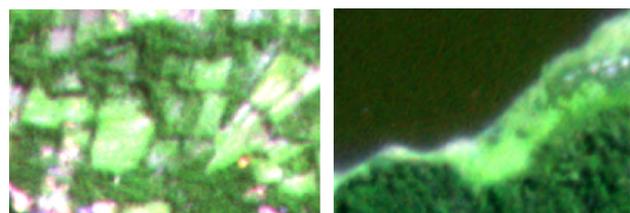


Figure 3. PS satellite images of rice paddies (left) and grasslands (right) displayed in true color (RGB 321). Small grassland patches appear very similar to rice paddies in spectral and textural information.

Due to the warm and humid climate, agricultural plots can contain crop plants or appear barren in short succession. And the lushness of the island renders the land as an ocean of green tones, many of which are lumped together by the limited spectral perception of the most accessible commercial satellite assets. The

well-known Balinese rice paddies are a case in point, as figures 3, 4, 5 and 6 illustrate.

In addition to the limited spectral information, the spatial resolution constraints make differentiation between settlement and grasslands difficult. Figure 6 shows examples of settlement and grassland areas. The orange arrow on the left points to a settlement and the red arrow on the right points to grassland lying directly next to a large body of water.

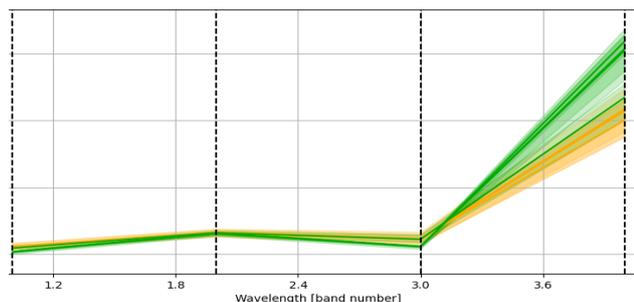


Figure 4. Spectral signature plot of grasslands (green) and rice paddies (orange). Bands 1, 2, and 3 (R, G, B) are almost indistinguishable when grassland and rice paddies are plotted. Only band 4 (IR) offers some information to differentiate the categories.

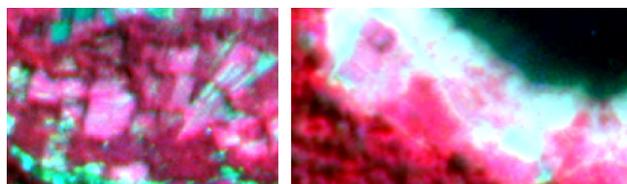


Figure 5. Composite false color (RGB 432) comparison of water with grass (right) and rice paddies (left).

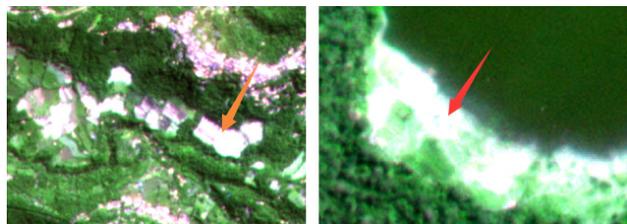


Figure 6. Settlement (left) and grasslands directly adjacent to a body of water (right) on true color (RGB 321).

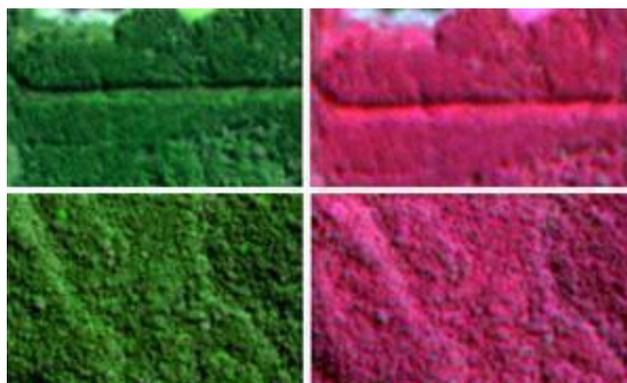


Figure 7. Examples of mixed forest (bottom left: true color, bottom right: false color) and homogenous forest (top left: true color, top right: false color).

Homogenous forests dominated by a single species can serve as indicators of agricultural production or, more importantly, sites of untouched original forest areas. Usually, these homogeneous sites are interspersed amongst areas of mixed forest full of a variety of tropical forest species with similar spectral and textural signatures. Homogeneous forests are dominated by *Liquidambar excelsa* (Noronha) Oken (family: Altingiaceae), hence we must rely on the spectral signature of that single plant species to differentiate mixed from homogenous forests (Figure 7).

Representing instances of small-scale tropical agroforestry, the intentional integration of trees, shrubs and plants into farming systems, is similarly onerous. Agroforestry covers in principle a large collection of crops (from tomatoes to oranges trees, flowers and bananas) cultivated using a variety of methods and intensities and is a subset of general agriculture. The major issues to contend with include the informal spatial arrangements typical of small-scale production as well the lack of spectral differentiation between agroforestry products and the surrounding forested areas as the flower garden below illustrates (Figure 8).



Figure 8. Hortensia flower garden (Lat -8.266422, Lon 115.087146) with hortensia, coffee plants, banana and orange trees, PS asset, May 2021).

While our study produces the most detailed land cover map of Central Bali to date, we are still only able to include a subset of all possible types of land cover due to the complex land use situations on the ground and the limitations of the satellite sensor systems observing them from above.

5. APPROACH

Taking these limitations into account, we set our focus on the land cover categories listed in Table 1 both are relevant to our goals and achievable using our analysis methods. We expect the collection to change as the project progresses, specifically as we learn how to include additional elements of agroforestry.

#	english	bahasa	legend
1	lake	danau	
2	settlement	pemukiman	
3	shrub land	semak belukar	
4	grass land	padang rumput	
5	homogenous forest	hutan homogen	
6	agriculture1	ladang/tegalan1	
7	agriculture2	ladang/tegalan2	
8	open land	lahan terbuka	
9	clove plantation	kebun cengkik	
10	mixed forest	hutan campur	
11	rice field	sawah	
12	mixed garden	kebun campuran	

Table 1. Overview of land use categories. Agriculture1 represents an agricultural area with crops. Agriculture2 represents the same area before or after crop growth.

Our analytical approach relies on a hybrid of algorithm-based classification in conjunction with human feedback, combining the information from state-of-the-art GIS land cover classification techniques described below with human expertise in response to falsely positive or negative identified categories produced by classifiers during testing. The human expert, in consultation with informants on the ground, acts as the control function that adds site specific knowledge, and even land use memories. These insights enter updated ROI datasets and are then ingested into classification operations in an iterative process.

6. LIMITS OF SATELLITE IMAGERY

The extent to which water resources are able to emanate from and through land forms one of the most significant features of our study area, and one that satellite imagery can only indirectly capture. Recent research has described how near-infrared, thermal infrared and passive microwave bands can be used to detect evapotranspiration, crop moisture and precipitation in support of water management in Bali (Aryastana, 2020).

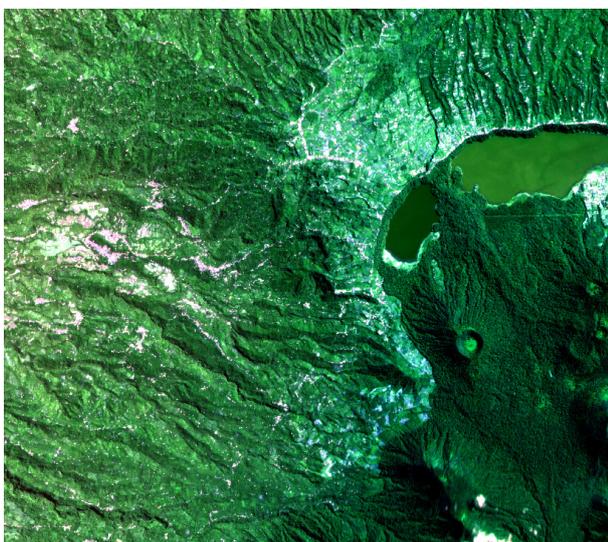


Figure 9. Study area in May 2021 (PS image).



Figure 10. Significant waterways in the study area, superimposed in red on the image of Figure 9.

However, the location of streaming surface waters in the tropics remains largely hidden to earth orbiting satellites. Towering trees

and dense foliage render the extent and expanse of the various brooks, streams and rivers invisible from above (Figure 9).

Figure 10 shows the image from Figure 9 superimposed with a comprehensive hydrology map of the area. The hydrology information was produced by the Geospatial Information Agency Indonesia (Ina-Geoportal, 2022). Given that about 30% of Bali's water is sourced from this area (Zen, 2019), the inclusion of water resources into land use discussions is meaningful as it makes the significance and extent of water resources in the area visually salient, an aspect of information representation that is particularly important where the use of limited water resources is a point of contention, as is the case in Central Bali.

7. IMPLEMENTATION

In order to support the challenging data interpretation work and enable a testing framework for international collaboration, we have developed a cloud-based GIS environment (COCKTAIL, 2022) that combines elements of established open source libraries QGIS, GDAL, OTB and SAGA such that we can design processing pipelines across these various widely-used GIS systems and run this software cocktail remotely, securely and reliably in the cloud under conditions that are not always guaranteed in the contexts of emerging economies. This environment allows our research team to work in their respective time zones and to explore different approaches to the data analysis and classification approaches within a shared analytic framework.

Cocktail offers modules to access Sentinel2 data sets directly from the Copernicus Open Access Hub (ESA, 2022), and can process data collected from Landsat and Planet Labs as well. In our case, we combine the use of freely available Sentinel2 data with commercial imagery from PS that offers higher spatial resolution. Cocktail contains modules to quickly determine GIS features of interest to our research, including the Normalized Difference Built-up Index (NDBI) as well as the Normalized Difference Vegetation Index (NDVI), and apply these features directly onto raster imagery. Cocktail can be used for object-based classification via Random Forest, Support Vector Machine and Neural Networks with the support of annotated training data of labelled areas of interest. Moreover, textural information can be added as an additional layer of information to the classifiers. Our cloud-based classification pipelines allow us to perform all permutations of hyperparameter combinations possible, and to keep track of the results in a sharable environment.

In our case, the training sets for object-based classification contain dozens of examples from each of the 12 land cover classes (Table 1). While these classification approaches produce detailed results, they are costly to generate due to the effort required to build the training datasets in the first place. That makes the band-operations described above attractive, particularly for the generation of quick overview results. The band operation results on the Sentinel2 imagery provide first order insights toward what can likely be detected in greater detail in the corresponding analysis of the PS assets.

To be clear, our goal is not to innovate on the construction of any single classifier - we are using the algorithms as provided by a trusted open-source remote sensing library (ORFEO, 2022). Rather, our goal is to make the best use of the many pathways along which any classification can occur, in order to easily find statistically viable solutions so that we may then make an

informed selection from those candidates' solutions that also pass human visual inspection.

8. EVALUATION

With the assistance of batch processes enabled using the Cocktail environment outlined above, we scanned the space of combinations of three prominent GIS classifiers (Support Vector Machines, Random Forest and Neural Networks) and hyperparameters that result in the best combination of f1-scores across all selected land cover categories. We use the f-score, a measure of classification quality that combines precision and recall into a single metric, as our indicator of a classifier's performance in our experiments. While a high f-score average is required, it is not sufficient to ensure an actually useable output. Multiple and different types of errors are not adequately captured by the metric. The paragraphs below describe some of these errors.

#	Image	Settings	Classifier	mean f1 score	min f1 score	max f1 score
1	06_12_2020	kernel=linear, c=1.0	SVM	0.71	0.20	0.88
2	06_12_2020	kernel=linear, c=0.3	SVM	0.69	0.19	0.81
3	06_12_2020	kernel=sigmoid, c=1.0	SVM	0.61	0.15	0.69
4	06_12_2020	kernel=sigmoid, c=0.3	SVM	0.59	0.13	0.64
5	06_12_2020	300trees, nodesize =3	RF	0.69	0.53	0.72
6	06_12_2020	300trees, nodesize =5	RF	0.68	0.49	0.69
7	06_12_2020	1000trees, nodesize =3	RF	0.69	0.61	0.80
8	06-12-2020	1000trees, nodesize =5	RF	0.72	0.69	0.76
9	05_01_2017	kernel=linear, c =1.0	SVM	0.65	0.18	0.73
10	05_01_2017	kernel=linear, c=0.3	SVM	0.63	0.13	0.71
11	05_01_2017	kernel=sigmoid, c=1.0	SVM	0.62	0.14	0.68
12	05_01_2017	kernel=sigmoid, c=0.3	SVM	0.59	0.14	0.65
13	05_01_2017	300trees, node size =3	RF	0.58	0.51	0.69
14	05_01_2017	300trees, node size =5	RF	0.63	0.52	0.70
15	05_01_2017	1000trees, node size =3	RF	0.65	0.52	0.71
16	05_01_2017	1000trees, node size =5	RF	0.67	0.51	0.72

Table 2. Some of the SVM (Support Vector Machine) and RF (Random Forest) experiments performed with Cocktail

In the mostly flat Buyan area (Figure 11), the dominant land cover categories are 'settlement', 'mixed garden' and 'agriculture'. The category 'rice paddy' (in turquoise) represents a false positive result and should not appear in this area, as evidenced by the satellite image (left) and confirmed by a local expert.

The term 'open land' refers to an area without settlement or a specific use, and this term sometimes serves as catch-all phrase for all kinds of under-specified and temporary land use scenarios. For example, one area near a mixed forest was visited by our local informant, who reported back that the land was being used temporarily as a camping site. Additionally, among the open areas around mixed forests located on the upper part of

Tamblingan forest (Figure 12), dominant categories to describe them include "open land" and "mixed forest".

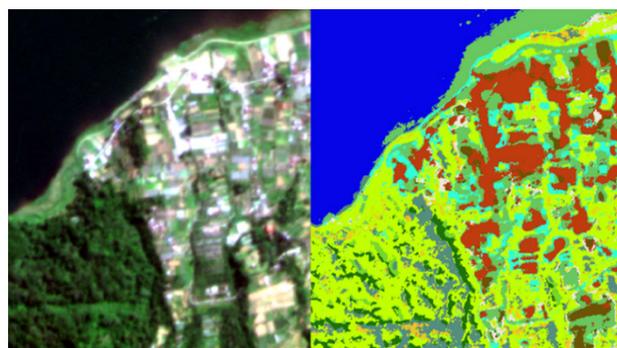


Figure 11. Comparison between satellite asset (left) and SVM classification (right) from experiment #1.

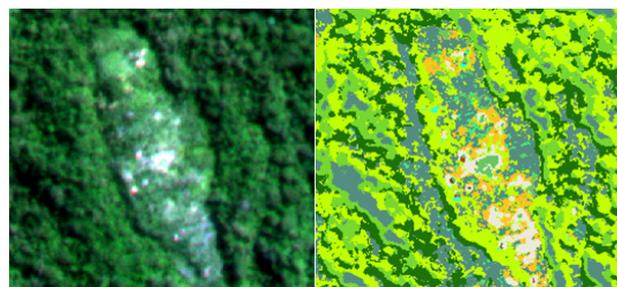


Figure 12. Comparison between 2020 satellite image (left) and the SVM classification result (right) from experiment #1.

Agricultural plots can be represented in a variety of forms. The category agriculture covers a large collection of crops cultivated using a variety of methods. Moreover, the category agriculture can be defined using similar spectral information as bare soil, causing further overlaps with the category of open land. These various sources of interpretive confusion are not only the result of limitations on the available satellite imagery, rather they reflect unstable land use conditions on the ground. Categorization tends to reduce these varied use dimensions to a single item for the sake of clarity and at the cost of a loss of nuance.

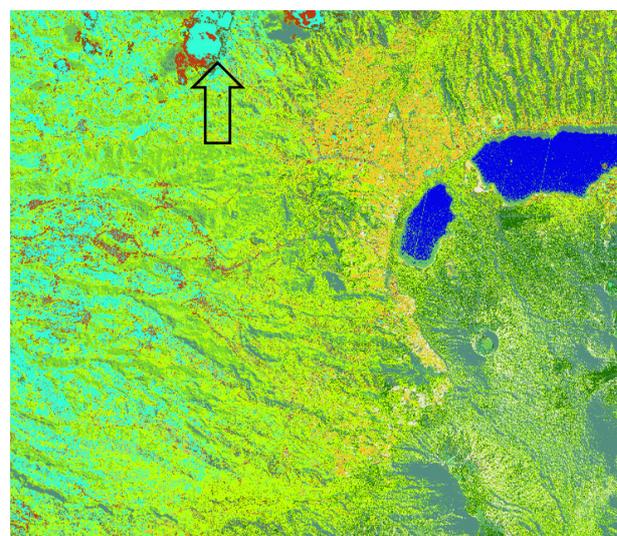


Figure 13. Best result from 2017 (#9). Top center cluster of presumed rice paddies and settlements (black arrow) are interpretation errors; The original satellite image shows cloud cover over that part of the terrain.

Nonetheless, several of our classification results are statistically and visually convincing. We can recognize from figures 13 (2017), 14 and 15 (2020) that there has in fact been noticeable change in settlement activity in some areas. Particularly in the vicinity of lake Buyan along the main road ways and within the rice paddies on the eastern side of the study area (inside the black ovals in Figure 14, details in Figure 15) there have been obvious increases in settlement expansion and density. These observations, produced by SVM and RF classifiers, are largely confirmed in Figures 16a/b, which show a Sentinel RGB image from May 2021, with the Normalized Difference Built-up Index (NDBI) difference between the years 2017 and 2021 superimposed onto it. The red area indicates change if growth exceeds 80%. The built-up area at the edge of lake Tamblingan in the yellow ellipse, representing a complex mix of grasslands and shallow waters, produced spurious results.

Observations regarding growth of settlements among these sensitive areas allow for a more candid assessment of the territorial claims of competing stakeholders. Providing reproducible documentation of land use changes and in particular settlement growth can support spatial planning efforts (Sulistiyawan, 2018) and provide conflicting positions for candid discussions on the various ways in which settlement construction and deforestation, tourism and sustainability are interlinked (Austin 2019).

9. DISCUSSION

PS assets are now recognized as emerging key resources for Earth imaging and analysis. However, some key aspects of these image assets have been understood as lacking in comparison to traditional satellite datasets.

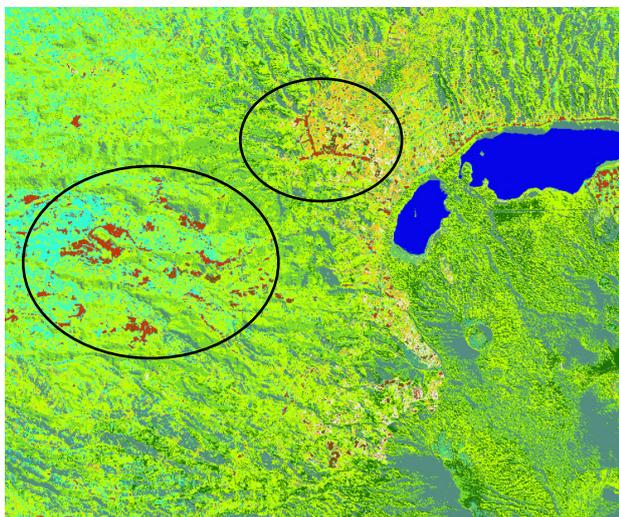


Figure 14. Best classification result from the year 2020 (#1)

For example, Frazier observes that the geometric and radiometric quality of PS assets does not match ‘analysis ready’ datasets (Frazier, 2021). As the authors observe, these limitations can be overcome, but they require access to services from PS that are subject to a licensing agreement and are thus of limited use to resource constrained research communities, including within many organizations in emerging economies.

As mentioned above, we have observed that the 4 channels previously made available through the use of PS are at times unable to offer sufficient information to parse complex land cover encountered in the tropics. The newly introduced

SuperDove satellite fleet covering 8 spectral channels will likely be able to alleviate this problem to some degree (Superdove, 2022). With an almost identical spatial resolution (3.7 m - 4.2 m, depending on altitude) [7] as the previous PS constellation, *SuperDove*’s 8-channels include the categories Coastal Blue (443nm), Blue (480nm), Green 1 (531nm), Green (565nm), Red (665nm), Yellow (610nm), Red Edge (705nm) and NIR (865nm), where Yellow and Green1 have no equivalent in Sentinel2.

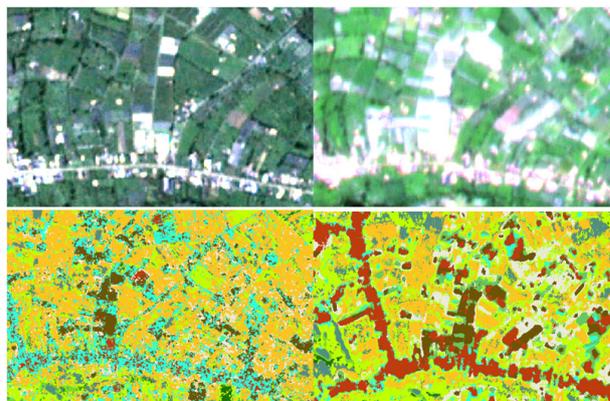


Figure 15. Detail. Change in settlement development between 2017 (top and bottom left) to 2020 (top and bottom right) based on PS datasets and experiment #1.

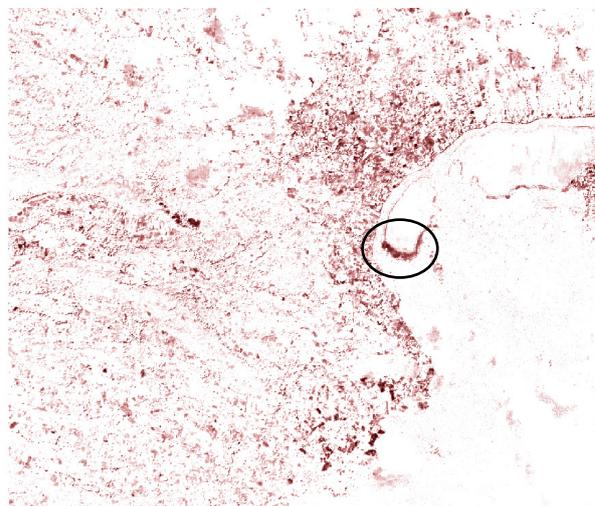


Figure 16a. Simple band operations for quick overviews. Change in the Normalized Built-up Index (NDBI) between 2017 and 2021.

We base this cautious optimism on the evaluation of an early 8-channel PS asset to which we applied our object-based SVM classifier from the ORFEO library. As Figure 17 below shows, the new image asset provides the classifier with additional information it may use to discern the two types of forests of interest in much finer detail, but it creates false positive results for rice paddies south of Lake Buyan (within the black ellipse). This suggests that there might be some spectral differences between the 4-channel data and the new 8-channel data of the *Superdove* constellation. Certainly, the training sets produced for the 4-band data will have to be updated for the new *Superdove* assets.

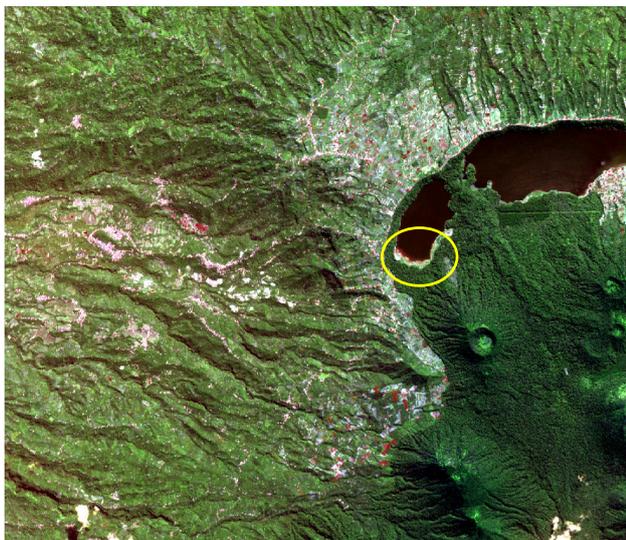


Figure 16b. Figure 16a, superimposed on 2021 Sentinel image from July 26th, 2021. The areas in red have at least 80% increase in settlement activity with respect to the 2017 NDBI result.

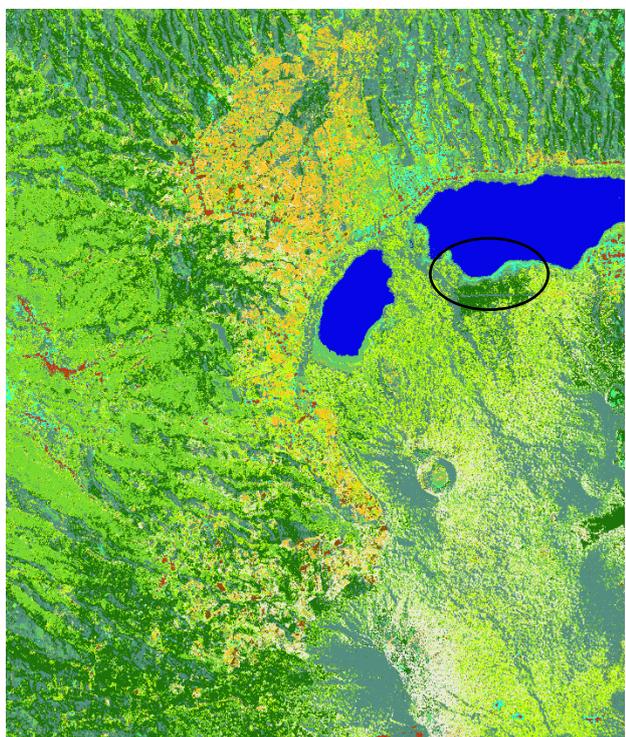


Figure 17. SVM on PS Superdove image, May 2nd, 2022.

Yet spectral and spatial resolution, as well as revisit frequency are not the only requirements for making satellite imagery actionable assets. Attention to location specific details and careful analysis are equally important. Not every area in the world will receive equal attention in the quest for responsible forest management and observation, as other authors have already pointed out (Rothe, 2017).

Figure 18 shows how our study area is represented in the highly regarded *Global Forest Watch* that offers “near real time information about where and how forests are changing around the world” (GlobalForestWatch, 2022). Here, it becomes clear that near real time updates do not necessarily translate into deeper insights. The classification results offered by Global Forest

Watch offer no useful insights onto our study area. Real time data must be coupled with careful interpretation; image asset interpretation severely lags behind the acquisition of the data, and in some cases, it is not performed at all.

It is possible that yet better classification algorithms (Tong, 2020) will make some of our efforts redundant in the future. However, we believe that there will remain areas of uncertainty and confusion that need to be addressed using an added portion of human expertise and care. We see our work as a contribution to an A.I.-facilitated local knowledge in-the-loop GIS future that is sensitized to resource-constrained environments. If nothing else, our work should improve the quality and reliability of land cover analysis in Bali.

Our collaboration with the NGO WISNU remains in its early stages, and the results presented here must be recognized as preliminary. What we can say at this point is that no single remote sensing source can capture all the interests and needs that the agency seeks to collect. For example, while certain agroforestry assets such as clove gardens are discernible using PS imagery, at this time other components such as flower gardens are not, and are thus likely to remain undetectable to current commercial satellite observation. Other researchers have resorted to UAVs to address some of these limitations on remote sensing (Vilar, 2020), and this project might have to consider a similar approach.



Figure 18. Global Forest Watch’s low-resolution view of land use and forest change in the study area (March 2022). <https://tinyurl.com/GFWatch-Tamblingan>.

The time intensive sense-making effort inherent to this project reminds us that the representation of complex land use conditions across time is not something that remote sensing in conjunction with AI analysis can solve without human assistance. Careful asset creation and science communication remain integral elements of the sense making process, and the communication effort must not only carry a message of unprecedented opportunities but also of limitations, even under state-of-the-art resource observation (Böhlen, 2014). Despite these limitations, the mapping of remote sensing opportunities has the potential to build a shared framework for assessing environmental impacts, and new ways to speak for the forest in the tropics.

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