添付資料 8

森林減少モニタリングツールの開発

Final Report

Annual and Weekly Forest Loss Detection System by using the Google Earth Engine Technology for Papua New Guinea

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Chapter 1
Introduction

1.1 General Background

The Papua New Guinea Forest Authority (PNGFA) promotes the management and wise utilization of the forest resources of Papua New Guinea as a renewable asset for the well-being of present and future generations. In order to update forest information for grasping forest situations regularly, global datasets showing dynamics in the forest, such as the deforestation data obtained from the Global Forest Change website (https://earthenginepartners.appspot.com/science-2013-global-forest), are utilized in PNGFA. Furthermore, global deforestation alert systems, such as the Global Land Analysis & Discovery (GLAD) alerts data (https://www.globalforestwatch.org/map), are going to be integrated into the forest monitoring system of PNGFA to monitor logging activities operated by developers.

Although the use of free global dataset is very convenient for monitoring vast forest areas in nationwide, there is a risk for a country to rely on such data to make its political decision because the continuous generation of the data in the future is not guaranteed. Therefore, it is necessary to develop its original systems to detect forest change for establishing a sustainable forest monitoring system. In fact, the Google Earth Engine is a cloud-based platform that provides the planetary-scale geospatial analysis with massive computational capabilities to handle various kinds of high-impact societal issues, which is including deforestation, drought, disaster, disease, food security, water management, climate monitoring, and environmental protection (Gorelick et al. 2017).

A developer established the annual and weekly forest loss detection systems utilizing Landsat-8 and Sentinel-2 imagery by utilizing Google Earth Engine. These systems might be useful even in Papua New Guinea (PNG) to assist the forest situation monitoring in the country. Hence, the work to develop annual and weekly forest loss detection by using Google Earth Engine technology is necessary to support the management and wise utilization of the forest resources of Papua New Guinea as being promoted by the PNGFA.

1.2 General Objectives

The main intention of this work is to develop the annual and weekly forest loss detection system by using the Google Earth Engine Technology for Papua New Guinea. Therefore, to obtain the goal of the primary intention, the present work concentrated on the following tasks:

1. to check the capabilities of forest loss detection systems developed in the third country for applying in Papua New Guinea,
2. to update the annual and weekly forest loss detection system for adapting to circumstances in Papua New Guinea based on the clarified issues,
3. to develop a monitoring system for selective logging concessions utilizing the Google Earth Engine technology,

4. to develop a system for monitoring logging activities inside logging concessions in Papua New Guinea using Google Earth Engine technology,
5. to prepare the documents of user manuals to instruct the users for utilizing the developed forest loss detection systems

1.3 Outline of Report

This report is organized into seven chapters. The focus of this chapter (Chapter 1) is to describe the general background of the work, purposes, and intentions for performing this work, as well as several tasks to be done by conducting the present work. Chapter 2 provides the details of the first task, which is checking the capabilities of forest loss detection systems developed in the third country for applying in Papua New Guinea. The background, objectives, outputs and results, as well as the conclusion of the task would be listed in this chapter. Chapter 3 principally discusses about the second task that is to develop a monitoring system for selective logging concessions utilizing the Google Earth Engine technology. The background, objectives, outputs and results, as well as the conclusion of the task would be listed in this chapter. Chapter 4 particularly reports the details of the third task, which is the development of a monitoring system for selective logging concessions utilizing the Google Earth Engine technology. The background, objectives, outputs and results, as well as the conclusion of the task would be listed in this chapter. Chapter 5 describes explicitly about the fourth task that is the development of a system for monitoring logging activities inside logging concessions in Papua New Guinea using Google Earth Engine technology. The background, objectives, materials and methods used, as well as the results of the task would be provided on this chapter. Chapter 6 provides the details of the fifth task, which is the preparation of the documents of user manuals to instruct the users for utilizing the developed forest loss detection systems. The background, objectives, outputs and results, as well as the conclusion of the task would be listed in this chapter. Finally, in Chapter 7, the general conclusion and remarks are given. This final chapter covers the workflow and details of methodology for each part of the developed annual and weekly forest loss detection systems.

Chapter 2
Checking capabilities of forest loss detection systems developed in the third country for applying in Papua New Guinea

2.1 Background

As an initial step to develop original systems to detect forest change for establishing a sustainable forest monitoring system in Papua New Guinea, the potential of the current forest loss detection systems by using the Google Earth Engine that was developed in the other country is necessary to be examined.

Therefore, this chapter is aimed to investigate the potential of the current annual and weekly forest loss detection systems by using the Google Earth Engine that was developed in the third country. Furthermore, issues that found on the examination process should be extracted and listed for the development of the future forest loss detection systems in Papua New Guinea.

In this chapter, the results obtained from the current forest loss detection systems developed in the third country should be compared with the available global datasets (i.e., the Global Forest Change and the GLAD Alerts Data) in the selected target areas. Moreover, the accuracy of the results should be assessed with the assumption that the forest loss data in available global datasets as the truth data.

2.2 Objectives

The objectives of this chapter are listed as follows:

1. Apply the current Annual and Weekly Forest Loss Detection scripts for two target areas in Papua New Guinea.
2. Conduct and analyze the accuracy assessments for the current Annual and Weekly Forest Loss Detection scripts.
3. List issues to be solved in order to apply the Annual and Weekly Forest Loss Detection scripts in Papua New Guinea.
4. Analyze the good examples of the index(es) by reviewing literature documents and propose threshold value for early deforestation detection.

2.3 Outputs and Results

2.3.1 Brief analysis on the good examples of the index(es) and threshold for early deforestation detection (As per August 31st, 2018)

The examples of the index(es) and threshold for early deforestation detection are listed as follows:

- Based on the “180726_Measurement_Degradation_v2.pdf” document, the integration of Spectral Mixture Analysis (SMA) and Normalized Difference Fraction Index (NDFI) could be considered as one of the direct approaches in order to assess forest degradation monitoring especially by utilizing remote sensing application.

- Regarding the SMA, this method has been proposed to overcome the mixed pixel problems found in degraded forests. Mixed pixels could be decomposed into fractions of endmembers. In degraded forests, the most common endmembers are Green Vegetation (GV), Soil, Non-Photosynthetic Vegetation (NPV), and Shade. The combination of these endmembers could be useful to exhibit confirmations that associated to forest degradation.
- As for the NDFI, this index could be obtained by combining fractions information to enhance detection of forest degradation. The NDFI values are vary from -1 to 1, but a specific NDFI interval of 0.70 to 0.85 is being used to indicate canopy change that could be associated to forest degradation. Furthermore, the temporal analysis of NDFI could leads to the detection of forest degradation, as well as forest canopy regeneration.
- For future scripts development, the integration of SMA and NDFI could be one of the promising approaches to be applied in the early deforestation detection system by using remote sensing application on the Google Earth Engine (GEE) Platform. In doing so, collecting training sites is one of the necessary components to derive SMA, for further used as inputs in generating the NDFI. Furthermore, if there is no available field data in target areas, training sites could be obtain by applying visual interpretation on Google Earth for collecting necessary training sites. As for SMA, four classes of training sites that represent each endmembers (i.e., GV, Soil, NPV, and Shade) would be necessary. However, additional informations such as specific information of the recent forest degradation sites in target areas or the most well known areas for severe forest degradation would provide a valuable understanding and a clear definition to the typical condition of forest degradation in target areas, as well as improving accuracy and reliability of the system itself.
- As for the current scripts, the Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), and Normalized Burned Ratio (NBR) were used as the approach to detect Annual and Weekly Forest Loss. This approach was adapted from the Landsat-based Forest Disturbance Alerts system listed in Hansen et al. (2016). On those scripts, a decreasing value of all indices at a given area or pixel that is greater than the threshold value would be considered as a unit of forest change. Thus, for the development of future scripts, the approach that was used by the current scripts (i.e., NDVI, NDWI, and NBR) could be compared and analyzed with the integration of SMA and NDFI so that the performance of each approach could be known, especially in applying the early deforestation detection system in the target areas.
- Regarding the threshold value that was applied in the current scripts (so-called the tIndex), it was used to identify a unit of forest change. The threshold value is an approach to objectively define the typical conditions of forest change in a given target area by advantaging a set of index. Thus, the result of Forest Loss Detection is directly relies on the value of the threshold value. In the accuracy assessments of the current scripts, two threshold values (tIndex = 0.1 and tIndex = 0.2) were tested and analyzed. Eventually, for both scripts, the tIndex = 0.2 yielded a closer Forest Loss Areas with those derived by the truth data. Therefore, the tIndex = 0.2 resulted a better accuracy as compared with those derived by the tIndex =0.1. In fact, the truth data (e.g., Global Forest Change and GLAD Alerts Data) could be used to acquire the optimum threshold value for the future scripts development by conducting trial and error experiments of threshold values for a given target area, for further increasing the accuracy of a Forest Loss Detection system.

- Another option that associated to the utilization of threshold values for detecting early deforestation is by completely omitting those threshold values rather than to set one. This option could be applied for detecting the early deforestation stages in target areas at the lowest scale, so that any decreasing values of an index or indices combinations in a given area or pixel would be considered as an early deforestation stage. However, the accuracy of this option needs to be analyzed and compared with the result of the system that applying the threshold value in order to understand their abilities for detecting early deforestation.

2.3.2 Results of accuracy assessments and list of issues to be solved of current Forest Loss Detection scripts applied in Papua New Guinea

This documentation consists of two parts that are: (1) Results of the accuracy assessments, which presents the results of the Weekly and Annual Forest Loss Detection scripts developed in the third country compared with global datasets for target areas in Papua New Guinea, and (2) List of issues to be solved, which describe a list of issues to be solved in order to apply the Forest Loss Detection scripts in Papua New Guinea.

2.3.2.1 Results of the accuracy assessments

The Weekly and Annual Forest Loss Detection scripts developed in the third country were applied in two target areas (West Sepik and West New Britain Provinces) in Papua New Guinea. The results of Annual Forest Loss Detection were compared with Forest *lossyear* data obtained from Global Forest Change Version 1.5 (https://earthenginepartners.appspot.com/science-2013-global-forest/download_v1.5.html) that served as the truth data. Concurrently, the results of Weekly Forest Loss Detection were compared with GLAD Alerts data obtained from Global Forest Watch website (https://www.globalforestwatch.org/map) that utilized as the truth data. In this report, two practical accuracy indicators (i.e., Percent Error and Absolute Difference) were derived to describe the accuracy of each Forest Loss Area calculation to the known values that derived by the truth data. The Percent Error is calculated by using the following equation:

$$\text{Percent Error } (\%) = \left|\frac{(\text{experimental}) - (\text{theoretical})}{(\text{theoretical})}\right| . 100$$

By using Percent Error, a percentage close to zero means that the calculation is close to a known value, and vice versa. However, if the experimental or the theoretical value is zero, the Percent Error would not be able to describe the accuracy of a calculation. Thus, in this report, another accuracy indicator is presented, which is the Absolute Difference. The Absolute Difference is used to define the distance or difference between two values. A larger Absolute Difference means a larger difference between two values, and vice versa. The Absolute Difference is calculated by using the following equation:

$$\text{Absolute Difference} = |(\text{experimental}) - (\text{theoretical})|$$

Furthermore, the accuracy assessments results of the Annual Forest Loss Detection scripts are presented in Section 2.3.2.1.1. Meanwhile, the accuracy assessments result of the Weekly Forest Loss Detection script is described in Section 2.3.2.1.2.

2.3.2.1.1 Result of accuracy assessments of the Annual Forest Loss Detection Scripts

The Landsat 8 Annual Forest Loss Detection and Sentinel-2 Annual Forest Loss Detection scripts were used to derive Annual Forest Loss data in two target areas in Papua New Guinea. The target areas are West Sepik Province (WSP) and West New Britain Province (WNB). The investigation periods used for Annual Forest Loss Detection are during the local dry season or less-rain months, which is from July to November.

For Landsat 8 Annual Forest Loss Detection script, three Annual Forest Loss data were generated, i.e., Forest Loss in 2015 (Forest area in 2014 subtracted by Forest area in 2015), Forest Loss in 2016 (Forest area in 2015 subtracted by Forest area in 2016), and Forest Loss in 2017 (Forest area in 2016 subtracted by Forest area in 2017). Furthermore, for Sentinel-2 Annual Forest Loss Detection script, two Annual Forest Loss data were extracted, i.e., Forest Loss in 2016 (Forest area in 2015 subtracted by Forest area in 2016) and Forest Loss in 2017 (Forest area in 2016 subtracted by Forest area in 2017).

As for the Sentinel-2 Annual Forest Loss Detection script, Forest Loss in 2015 was not extracted due to there is no Sentinel-2 imageries in 2014. For both scripts, two threshold values for identifying a unit of forest change (tIndex) were tested and analyzed for the accuracy assessments purposes (i.e., tIndex = 0.1 and tIndex = 0.2). Thus, the results of accuracy assessments of the Annual Forest Loss Detection scripts are presented in the following tables and charts:

Table 2.1 Landsat 8 Annual Forest Lost Detection for West Sepik Province (tIndex 0.1)

Analysis	Weekly Forest Lost (sq. Km)	Forest lossyear data from Global Forest Change (sq. Km)	Percent Error (%)	Absolute Difference
Forest Loss in 2015 (Forest Area 2014 - Forest Area 2015)	582.28	163.97	255.11	418.31
Forest Loss in 2016 (Forest Area 2015- Forest Area 2016)	988.56	136.37	624.91	852.19
Forest Loss in 2017 (Forest Area 2016- Forest Area 2017)	2424.01	131.87	1738.18	2292.14

Table 2.2 Landsat 8 Annual Forest Lost Detection for West New Britain Province (tIndex 0.1)

Analysis	Weekly Forest Lost (sq. Km)	Forest lossyear data from Global Forest Change (sq. Km)	Percent Error (%)	Absolute Difference
Forest Loss in 2015 (Forest Area 2014 - Forest Area 2015)	1014.34	348.92	190.71	665.42
Forest Loss in 2016 (Forest Area 2015- Forest Area 2016)	416.64	98.26	324.02	318.38
Forest Loss in 2017 (Forest Area 2016- Forest Area 2017)	2919.43	73.18	3889.38	2846.25

Table 2.3 of Landsat 8 Annual Forest Lost Detection for West Sepik Province (tIndex 0.2)

Analysis	Weekly Forest Lost (sq. Km)	Forest lossyear data from Global Forest Change (sq. Km)	Percent Error (%)	Absolute Difference
Forest Loss in 2015 (Forest Area 2014 - Forest Area 2015)	202.49	163.97	23.49	38.52
Forest Loss in 2016 (Forest Area 2015- Forest Area 2016)	275.56	136.37	102.07	139.19
Forest Loss in 2017 (Forest Area 2016- Forest Area 2017)	518.53	131.87	293.21	386.66

Table 2.4 Landsat 8 Annual Forest Lost Detection for West New Britain Province (tIndex 0.2)

Analysis	Weekly Forest Lost (sq. Km)	Forest lossyear data from Global Forest Change (sq. Km)	Percent Error (%)	Absolute Difference
Forest Loss in 2015 (Forest Area 2014 - Forest Area 2015)	411.93	348.92	18.06	63.01
Forest Loss in 2016 (Forest Area 2015- Forest Area 2016)	134.21	98.26	36.59	35.95
Forest Loss in 2017 (Forest Area 2016- Forest Area 2017)	1150.76	73.18	1472.51	1077.58

Table 2.5 Sentinel-2 Annual Forest Lost Detection for West Sepik Province (tIndex 0.1)

Analysis	Weekly Forest Lost (sq. Km)	Forest lossyear data from Global Forest Change (sq. Km)	Percent Error (%)	Absolute Difference
Forest Loss in 2016 (Forest Area 2015- Forest Area 2016)	512.98	136.37	276.17	376.61
Forest Loss in 2017 (Forest Area 2016- Forest Area 2017)	483.57	131.87	266.70	351.70

Table 2.6 Sentinel-2 Annual Forest Lost Detection for West New Britain Province (tIndex 0.1)

Analysis	Weekly	Forest lossyear data from	Percent Error	Absolute

	Forest Lost (sq. Km)	Global Forest Change (sq. Km)	(%)	Difference
Forest Loss in 2016 (Forest Area 2015- Forest Area 2016)	303.24	98.26	208.61	204.98
Forest Loss in 2017 (Forest Area 2016- Forest Area 2017)	444.68	73.18	507.65	371.50

Table 2.7 Sentinel-2 Annual Forest Lost Detection for West Sepik Province (tIndex 0.2)

Analysis	Weekly Forest Lost (sq. Km)	Forest lossyear data from Global Forest Change (sq. Km)	Percent Error (%)	Absolute Difference
Forest Loss in 2016 (Forest Area 2015- Forest Area 2016)	102.84	136.37	24.59	33.53
Forest Loss in 2017 (Forest Area 2016- Forest Area 2017)	92.87	131.87	29.57	39.00

Table 2.8 Sentinel-2 Annual Forest Lost Detection for West New Britain Province (tIndex 0.2)

Analysis	Weekly Forest Lost (sq. Km)	Forest lossyear data from Global Forest Change (sq. Km)	Percent Error (%)	Absolute Difference
Forest Loss in 2016 (Forest Area 2015- Forest Area 2016)	101.99	98.26	3.80	3.73
Forest Loss in 2017 (Forest Area 2016- Forest Area 2017)	100.24	73.18	36.98	27.06

Figure 2.1 Landsat 8 Annual Forest Loss Detection Chart for West Sepik Province (tIndex 0.1)

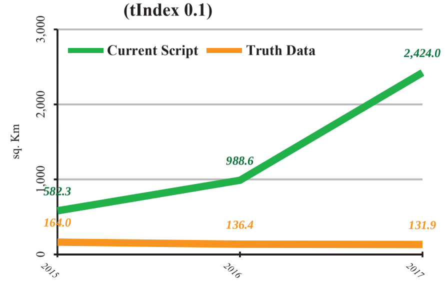


Figure 2.2 Landsat 8 Annual Forest Loss Detection Chart for West New Britain Province (tIndex 0.1)

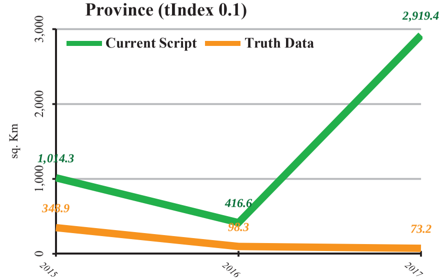


Figure 2.3 Landsat 8 Annual Forest Loss Detection Chart for West Sepik Province (tIndex 0.2)

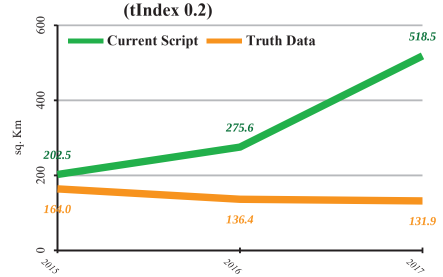


Figure 2.4 Landsat 8 Annual Forest Loss Detection Chart for West New Britain Province (tIndex 0.2)

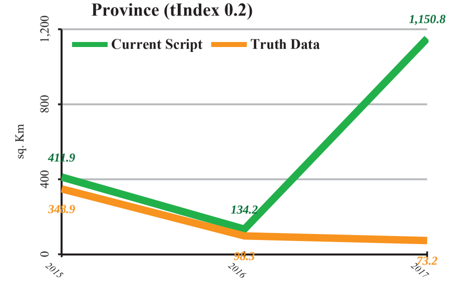


Figure 2.5 Sentinel-2 Annual Forest Loss Detection Chart for West Sepik Province (tIndex 0.1)

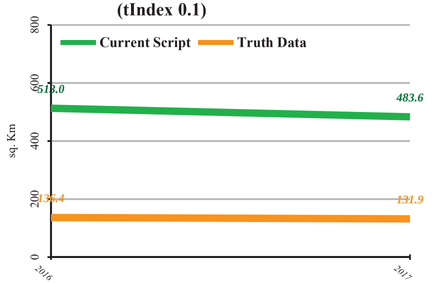


Figure 2.6 Sentinel-2 Annual Forest Loss Detection Chart for West New Britain Province (tIndex 0.1)

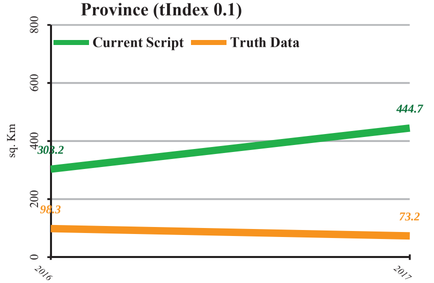


Figure 2.7 Sentinel-2 Annual Forest Loss Detection Chart for West Sepik Province (tIndex 0.2)

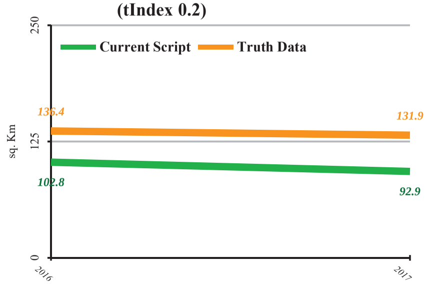
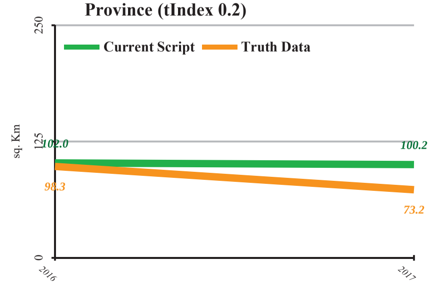


Figure 2.8 Sentinel-2 Annual Forest Loss Detection Chart for West New Britain Province (tIndex 0.2)



For Landsat 8 Annual Forest Loss Detection script, both threshold values (tIndex = 0.1 and tIndex = 0.2) yielded higher Annual Forest Loss Areas as compared to those derived by the truth data, for both target areas (WSP and WNB Provinces) during all investigation periods. Overall, the tIndex = 0.2 yielded a closer Annual Forest Loss Areas with the truth data as compared to those derived by the tIndex = 0.1. Furthermore, relatively small portions of cloud cover were appeared in the greenest-pixel imageries in 2014, 2015, and 2016, for both target areas. Nevertheless, relatively medium portions of cloud cover were appeared in the greenest pixel image in 2017, especially in WNB Province. Therefore, the Annual Forest Loss Areas in 2017 yielded the highest difference with the truth data.

As for the accuracy indicators of Landsat 8 Annual Forest Loss Detection script, the lowest Percent Error (best accuracy) is 23.49% and 18.06%, for Annual Forest Loss in 2015 in WSP and WNB using tIndex = 0.2, respectively. Moreover, the highest Percent Error (worst accuracy) is 1738.18% and 3889.38%, for Annual Forest Loss in 2017 in WSP and WNB using tIndex = 0.1, respectively. As for the Absolute Difference, the lowest value (best accuracy) is 38.52 and 35.95, for Annual Forest Loss in 2015 in WSP and Annual Forest Loss in 2016 in WNB using tIndex = 0.2, respectively. Moreover, the highest Absolute Difference (worst

accuracy) is 2292.14 and 2846.25, for Annual Forest Loss in 2017 in WSP and WNB using tIndex = 0.1, respectively.

For Sentinel-2 Annual Forest Loss Detection script, both threshold values (tIndex = 0.1 and tIndex = 0.2) yielded higher Annual Forest Loss Areas as compared to those derived by the truth data, for both target areas (WSP and WNB Provinces) during all investigation periods, except for that derived by tIndex = 0.2 in WSP Province as shown in Figure 2.7. Overall, the tIndex = 0.2 yielded a closer Annual Forest Loss Areas with the truth data as compared to those derived by the tIndex = 0.1. Furthermore, for both target areas, significant amount of cloud cover were appeared in the greenest-pixel image in 2015 mainly due to the fact that in this year the Sentinel-2 has just been launched so that the quantity of image archive data was limited. However, the cloud cover condition for both target areas in 2016 was getting better so that relatively medium portions of cloud cover were appeared during this investigation period. Furthermore, relatively small portions of cloud cover were appeared in the greenest-pixel image in 2017 for both target areas.

Thus, for Sentinel-2 Annual Forest Loss Detection script, the lowest Percent Error (best accuracy) is 24.59% and 3.80%, for Annual Forest Loss in 2016 in WSP and WNB using tIndex = 0.2, respectively. Moreover, the highest Percent Error (worst accuracy) is 276.17% and 507.65%, for Annual Forest Loss in 2016 in WSP and Annual Forest Loss in 2017 in WNB using tIndex = 0.1, respectively. As for the Absolute Difference, the lowest value (best accuracy) is 33.53 and 3.73, for Annual Forest Loss in 2016 in WSP and WNB using tIndex = 0.2, respectively. Moreover, the highest Absolute Difference (worst accuracy) is 376.61 and 371.50, for Annual Forest Loss in 2016 in WSP and Annual Forest Loss in 2017 in WNB using tIndex = 0.1, respectively.

In conclusion, the Annual Forest Loss Areas for both target areas (WSP and WNB Provinces) generated by the current scripts were likely to fit with those derived by the truth data by using a larger tIndex. Therefore, the tIndex = 0.2 yielded a better accuracy as compared to those derived by the tIndex = 0.1 both for Landsat 8 Annual Forest Loss Detection and Sentinel-2 Annual Forest Loss Detection script.

2.3.2.1.2 Result of accuracy assessments of the Weekly Forest Loss Detection Script

The Sentinel-2 Weekly Forest Loss Detection script was used to derive Weekly Forest Loss data in two target areas in Papua New Guinea, i.e., West Sepik Province (WSP) and West New Britain Province (WNB). The investigation periods used for Weekly Forest Loss Detection were started from July 2017 to June 2018. The Start Date and End Date of Reference and Target image for each analysis are listed in the Table of Weekly Forest Loss Detection. Furthermore, two threshold values for identifying a unit of forest change (tIndex) were tested and analyzed for the accuracy assessments purposes (i.e., tIndex = 0.1 and tIndex = 0.2). Thus, the results of accuracy assessments of the Weekly Forest Loss Detection script are presented in the following tables and charts:

Table 2.9 Sentinel-2 Weekly Forest Lost Detection for West Sepik Province (tCloud 10; tIndex 0.1)

Reference Image	Target Image	Weekly Forest	GLAD Alert	Percent Error	Absolute

Start Date	End Date	Start Date	End Date	Lost (sq. Km)	Weekly Forest Lost (sq. Km)	(%)	Difference
2017/6/25	2017/7/2	2017/7/2	2017/7/9	37.62	44.20	14.89	6.58
2017/7/2	2017/7/9	2017/7/9	2017/7/16	0.00	44.67	100.00	44.67
2017/7/9	2017/7/16	2017/7/16	2017/7/23	1655.86	16.89	9703.79	1638.97
2017/7/16	2017/7/23	2017/7/23	2017/7/30	0.00	0.85	100.00	0.85
2017/7/23	2017/7/30	2017/7/30	2017/8/6	0.00	13.18	100.00	13.18
2017/7/30	2017/8/6	2017/8/6	2017/8/13	189.35	19.93	850.08	169.42
2017/8/6	2017/8/13	2017/8/13	2017/8/20	0.00	16.83	100.00	16.83
2017/8/13	2017/8/20	2017/8/20	2017/8/27	0.00	14.93	100.00	14.93
2017/8/20	2017/8/27	2017/8/27	2017/9/3	400.12	70.61	466.66	329.51
2017/8/27	2017/9/3	2017/9/3	2017/9/10	726.17	62.63	1059.46	663.54
2017/9/3	2017/9/10	2017/9/10	2017/9/17	138.06	23.33	491.77	114.73
2017/9/10	2017/9/17	2017/9/17	2017/9/24	527.97	51.87	917.87	476.10
2017/9/17	2017/9/24	2017/9/24	2017/10/1	0.00	1.73	100.00	1.73
2017/9/24	2017/10/1	2017/10/1	2017/10/8	34.13	32.78	4.12	1.35
2017/10/1	2017/10/8	2017/10/8	2017/10/15	653.30	1.92	33926.04	651.38
2017/10/8	2017/10/15	2017/10/15	2017/10/22	0.00	16.80	100.00	16.80
2017/10/15	2017/10/22	2017/10/22	2017/10/29	714.25	2.92	24360.62	711.33
2017/10/22	2017/10/29	2017/10/29	2017/11/5	690.83	3.13	21971.25	687.70
2017/10/29	2017/11/5	2017/11/5	2017/11/12	0.00	30.49	100.00	30.49
2017/11/5	2017/11/12	2017/11/12	2017/11/19	39.46	12.61	212.93	26.85
2017/11/12	2017/11/19	2017/11/19	2017/11/26	1074.73	0.00	N/A	1074.73
2017/11/19	2017/11/26	2017/11/26	2017/12/3	0.00	1.68	100.00	1.68
2017/11/26	2017/12/3	2017/12/3	2017/12/10	429.48	9.45	4444.76	420.03
2017/12/3	2017/12/10	2017/12/10	2017/12/17	152.50	0.11	138536.36	152.39
2017/12/10	2017/12/17	2017/12/17	2017/12/24	0.00	21.93	100.00	21.93
2017/12/17	2017/12/24	2017/12/24	2017/12/31	442.58	21.93	1918.15	420.65
2017/12/24	2017/12/31	2017/12/31	2018/1/7	90.62	0.11	82281.82	90.51
2017/12/31	2018/1/7	2018/1/7	2018/1/14	0.45	6.63	93.21	6.18
2018/1/7	2018/1/14	2018/1/14	2018/1/21	64.63	0.12	53758.33	64.51
2018/1/14	2018/1/21	2018/1/21	2018/1/28	0.19	1.27	85.04	1.08
2018/1/21	2018/1/28	2018/1/28	2018/2/4	191.32	2.76	6831.88	188.56
2018/1/28	2018/2/4	2018/2/4	2018/2/11	154.69	21.19	630.01	133.50
2018/2/4	2018/2/11	2018/2/11	2018/2/18	22.80	25.93	12.07	3.13
2018/2/11	2018/2/18	2018/2/18	2018/2/25	0.00	1.88	100.00	1.88
2018/2/18	2018/2/25	2018/2/25	2018/3/4	73.26	8.38	774.22	64.88
2018/2/25	2018/3/4	2018/3/4	2018/3/11	2.19	0.54	305.56	1.65
2018/3/4	2018/3/11	2018/3/11	2018/3/18	65.80	3.38	1846.75	62.42
2018/3/11	2018/3/18	2018/3/18	2018/3/25	53.07	28.45	86.54	24.62

2018/3/18	2018/3/25	2018/3/25	2018/4/1	32.89	38.71	15.03	5.82
2018/3/25	2018/4/1	2018/4/1	2018/4/8	18.56	59.84	68.98	41.28
2018/4/1	2018/4/8	2018/4/8	2018/4/15	61.31	41.16	48.96	20.15
2018/4/8	2018/4/15	2018/4/15	2018/4/22	8.31	8.93	6.94	0.62
2018/4/15	2018/4/22	2018/4/22	2018/4/29	146.23	4.84	2921.28	141.39
2018/4/22	2018/4/29	2018/4/29	2018/5/6	138.87	4.87	2751.54	134.00
2018/4/29	2018/5/6	2018/5/6	2018/5/13	88.02	108.86	19.14	20.84
2018/5/6	2018/5/13	2018/5/13	2018/5/20	193.99	36.58	430.32	157.41
2018/5/13	2018/5/20	2018/5/20	2018/5/27	85.93	27.38	213.84	58.55
2018/5/20	2018/5/27	2018/5/27	2018/6/3	66.12	9.05	630.61	57.07
2018/5/27	2018/6/3	2018/6/3	2018/6/10	305.47	293.55	4.06	11.92
2018/6/3	2018/6/10	2018/6/10	2018/6/17	0.14	299.36	99.95	299.22
2018/6/10	2018/6/17	2018/6/17	2018/6/24	387.19	55.83	593.52	331.36
2018/6/17	2018/6/24	2018/6/24	2018/7/1	255.06	103.53	146.36	151.53

Table 2.10 Sentinel-2 Weekly Forest Lost Detection for West New Britain Province (tCloud 10; tIndex 0.1)

Reference Image		Target Image		Weekly Forest Lost (sq. Km)	GLAD Alert Weekly Forest Lost (sq. Km)	Percent Error (%)	Absolute Difference
Start Date	End Date	Start Date	End Date				
2017/6/25	2017/7/2	2017/7/2	2017/7/9	0.00	0.00	N/A	0.00
2017/7/2	2017/7/9	2017/7/9	2017/7/16	2916.72	0.08	3645800.00	2916.64
2017/7/9	2017/7/16	2017/7/16	2017/7/23	20.54	0.00	N/A	20.54
2017/7/16	2017/7/23	2017/7/23	2017/7/30	33.23	0.00	N/A	33.23
2017/7/23	2017/7/30	2017/7/30	2017/8/6	2475.83	0.00	N/A	2475.83
2017/7/30	2017/8/6	2017/8/6	2017/8/13	110.98	44.59	148.89	66.39
2017/8/6	2017/8/13	2017/8/13	2017/8/20	2190.26	13.60	16004.85	2176.66
2017/8/13	2017/8/20	2017/8/20	2017/8/27	64.77	4.56	1320.39	60.21
2017/8/20	2017/8/27	2017/8/27	2017/9/3	1.75	38.99	95.51	37.24

2017/8/27	2017/9/3	2017/9/3	2017/9/10	10.95	6.30	73.81	4.65
2017/9/3	2017/9/10	2017/9/10	2017/9/17	0.03	1.67	98.20	1.64
2017/9/10	2017/9/17	2017/9/17	2017/9/24	17.11	1.12	1427.68	15.99
2017/9/17	2017/9/24	2017/9/24	2017/10/1	24.37	8.28	194.32	16.09
2017/9/24	2017/10/1	2017/10/1	2017/10/8	27.09	1.02	2555.88	26.07
2017/10/1	2017/10/8	2017/10/8	2017/10/15	62.39	0.00	N/A	62.39
2017/10/8	2017/10/15	2017/10/15	2017/10/22	14.95	5.03	197.22	9.92
2017/10/15	2017/10/22	2017/10/22	2017/10/29	2.12	1.52	39.47	0.6
2017/10/22	2017/10/29	2017/10/29	2017/11/5	10.39	5.58	86.20	4.81
2017/10/29	2017/11/5	2017/11/5	2017/11/12	116.75	0.36	32330.56	116.39
2017/11/5	2017/11/12	2017/11/12	2017/11/19	0.00	12.78	100.00	12.78
2017/11/12	2017/11/19	2017/11/19	2017/11/26	25.23	12.70	98.66	12.53
2017/11/19	2017/11/26	2017/11/26	2017/12/3	137.27	34.53	297.54	102.74
2017/11/26	2017/12/3	2017/12/3	2017/12/10	2.86	0.00	N/A	2.86
2017/12/3	2017/12/10	2017/12/10	2017/12/17	92.23	0.00	N/A	92.23
2017/12/10	2017/12/17	2017/12/17	2017/12/24	25.63	0.00	N/A	25.63
2017/12/17	2017/12/24	2017/12/24	2017/12/31	2.65	0.00	N/A	2.65
2017/12/24	2017/12/31	2017/12/31	2018/1/7	106.87	2.39	4371.55	104.48
2017/12/31	2018/1/7	2018/1/7	2018/1/14	2.44	0.01	24300.00	2.43
2018/1/7	2018/1/14	2018/1/14	2018/1/21	1.51	0.01	15000.00	1.5
2018/1/14	2018/1/21	2018/1/21	2018/1/28	59.80	17.22	247.27	42.58
2018/1/21	2018/1/28	2018/1/28	2018/2/4	1.45	1.59	8.81	0.14
2018/1/28	2018/2/4	2018/2/4	2018/2/11	17.83	100.27	82.22	82.44
2018/2/4	2018/2/11	2018/2/11	2018/2/18	147.65	13.12	1025.38	134.53
2018/2/11	2018/2/18	2018/2/18	2018/2/25	2.00	79.38	97.48	77.38
2018/2/18	2018/2/25	2018/2/25	2018/3/4	1.03	0.07	1371.43	0.96
2018/2/25	2018/3/4	2018/3/4	2018/3/11	10.15	0.31	3174.19	9.84

2018/3/4	2018/3/11	2018/3/11	2018/3/18	25.32	0.31	8067.74	25.01
2018/3/11	2018/3/18	2018/3/18	2018/3/25	145.30	0.00	N/A	145.30
2018/3/18	2018/3/25	2018/3/25	2018/4/1	116.91	69.60	67.97	47.31
2018/3/25	2018/4/1	2018/4/1	2018/4/8	18.66	7.85	137.71	10.81
2018/4/1	2018/4/8	2018/4/8	2018/4/15	31.30	15.65	100.00	15.65
2018/4/8	2018/4/15	2018/4/15	2018/4/22	0.13	21.29	99.39	21.16
2018/4/15	2018/4/22	2018/4/22	2018/4/29	8.69	0.64	1257.81	8.05
2018/4/22	2018/4/29	2018/4/29	2018/5/6	20.15	1.13	1683.19	19.02
2018/4/29	2018/5/6	2018/5/6	2018/5/13	24.56	14.02	75.18	10.54
2018/5/6	2018/5/13	2018/5/13	2018/5/20	3.86	43.97	91.22	40.11
2018/5/13	2018/5/20	2018/5/20	2018/5/27	1.56	19.00	91.79	17.44
2018/5/20	2018/5/27	2018/5/27	2018/6/3	0.68	87.57	99.22	86.89
2018/5/27	2018/6/3	2018/6/3	2018/6/10	1.72	18.51	90.71	16.79
2018/6/3	2018/6/10	2018/6/10	2018/6/17	5.00	50.62	90.12	45.62
2018/6/10	2018/6/17	2018/6/17	2018/6/24	4.12	0.01	41100.00	4.11
2018/6/17	2018/6/24	2018/6/24	2018/7/1	94.52	0.00	N/A	94.52

Table 2.11 Sentinel-2 Weekly Forest Lost Detection for West Sepik Province (tCloud 10; tIndex 0.2)

Reference Image		Target Image		Weekly Forest Lost (sq. Km)	GLAD Alert Weekly Forest Lost (sq. Km)	Percent Error (%)	Absolute Difference
Start Date	End Date	Start Date	End Date				
2017/6/25	2017/7/2	2017/7/2	2017/7/9	7.60	44.20	82.81	36.60
2017/7/2	2017/7/9	2017/7/9	2017/7/16	0.00	44.67	100.00	44.67
2017/7/9	2017/7/16	2017/7/16	2017/7/23	556.57	16.89	3195.26	539.68
2017/7/16	2017/7/23	2017/7/23	2017/7/30	0.00	0.85	100.00	0.85
2017/7/23	2017/7/30	2017/7/30	2017/8/6	0.00	13.18	100.00	13.18
2017/7/30	2017/8/6	2017/8/6	2017/8/13	45.21	19.93	126.84	25.28
2017/8/6	2017/8/13	2017/8/13	2017/8/20	0.00	16.83	100.00	16.83

2017/8/13	2017/8/20	2017/8/20	2017/8/27	0.00	14.93	100.00	14.93
2017/8/20	2017/8/27	2017/8/27	2017/9/3	111.33	70.61	57.67	40.72
2017/8/27	2017/9/3	2017/9/3	2017/9/10	186.47	62.63	197.73	123.84
2017/9/3	2017/9/10	2017/9/10	2017/9/17	39.98	23.33	71.37	16.65
2017/9/10	2017/9/17	2017/9/17	2017/9/24	149.65	51.87	188.51	97.78
2017/9/17	2017/9/24	2017/9/24	2017/10/1	0.00	1.73	100.00	1.73
2017/9/24	2017/10/1	2017/10/1	2017/10/8	5.49	32.78	83.25	27.29
2017/10/1	2017/10/8	2017/10/8	2017/10/15	178.95	1.92	9220.31	177.03
2017/10/8	2017/10/15	2017/10/15	2017/10/22	0.00	16.80	100.00	16.80
2017/10/15	2017/10/22	2017/10/22	2017/10/29	219.69	2.92	7423.63	216.77
2017/10/22	2017/10/29	2017/10/29	2017/11/5	206.95	3.13	6511.82	203.82
2017/10/29	2017/11/5	2017/11/5	2017/11/12	0.00	30.49	100.00	30.49
2017/11/5	2017/11/12	2017/11/12	2017/11/19	7.99	12.61	36.64	4.62
2017/11/12	2017/11/19	2017/11/19	2017/11/26	260.34	0.00	N/A	260.34
2017/11/19	2017/11/26	2017/11/26	2017/12/3	0.00	1.68	100.00	1.68
2017/11/26	2017/12/3	2017/12/3	2017/12/10	93.12	9.45	885.40	83.67
2017/12/3	2017/12/10	2017/12/10	2017/12/17	34.54	0.11	31300.00	34.43
2017/12/10	2017/12/17	2017/12/17	2017/12/24	0.00	21.93	100.00	21.93
2017/12/17	2017/12/24	2017/12/24	2017/12/31	102.85	21.93	368.99	80.92
2017/12/24	2017/12/31	2017/12/31	2018/1/7	21.89	0.11	19800.00	21.78
2017/12/31	2018/1/7	2018/1/7	2018/1/14	0.06	6.63	99.10	6.57
2018/1/7	2018/1/14	2018/1/14	2018/1/21	8.00	0.12	6566.67	7.88
2018/1/14	2018/1/21	2018/1/21	2018/1/28	0.01	1.27	99.21	1.26
2018/1/21	2018/1/28	2018/1/28	2018/2/4	29.54	2.76	970.29	26.78
2018/1/28	2018/2/4	2018/2/4	2018/2/11	28.01	21.19	32.18	6.82
2018/2/4	2018/2/11	2018/2/11	2018/2/18	3.45	25.93	86.69	22.48
2018/2/11	2018/2/18	2018/2/18	2018/2/25	0.00	1.88	100.00	1.88

2018/2/18	2018/2/25	2018/2/25	2018/3/4	8.02	8.38	4.30	0.36
2018/2/25	2018/3/4	2018/3/4	2018/3/11	0.11	0.54	79.63	0.43
2018/3/4	2018/3/11	2018/3/11	2018/3/18	7.23	3.38	113.91	3.85
2018/3/11	2018/3/18	2018/3/18	2018/3/25	8.00	28.45	71.88	20.45
2018/3/18	2018/3/25	2018/3/25	2018/4/1	5.56	38.71	85.64	33.15
2018/3/25	2018/4/1	2018/4/1	2018/4/8	1.77	59.84	97.04	58.07
2018/4/1	2018/4/8	2018/4/8	2018/4/15	10.19	41.16	75.24	30.97
2018/4/8	2018/4/15	2018/4/15	2018/4/22	0.83	8.93	90.71	8.1
2018/4/15	2018/4/22	2018/4/22	2018/4/29	20.05	4.84	314.26	15.21
2018/4/22	2018/4/29	2018/4/29	2018/5/6	20.81	4.87	327.31	15.94
2018/4/29	2018/5/6	2018/5/6	2018/5/13	16.99	108.86	84.39	91.87
2018/5/6	2018/5/13	2018/5/13	2018/5/20	30.77	36.58	15.88	5.81
2018/5/13	2018/5/20	2018/5/20	2018/5/27	10.43	27.38	61.91	16.95
2018/5/20	2018/5/27	2018/5/27	2018/6/3	12.13	9.05	34.03	3.08
2018/5/27	2018/6/3	2018/6/3	2018/6/10	52.24	293.55	82.20	241.31
2018/6/3	2018/6/10	2018/6/10	2018/6/17	0.01	299.36	100.00	299.35
2018/6/10	2018/6/17	2018/6/17	2018/6/24	68.06	55.83	21.91	12.23
2018/6/17	2018/6/24	2018/6/24	2018/7/1	44.68	103.53	56.84	58.85

Table 2.12 Sentinel-2 Weekly Forest Lost Detection for West New Britain Province (tCloud 10; tIndex 0.2)

Reference Image		Target Image		Weekly Forest Lost (sq. Km)	GLAD Alert Weekly Forest Lost (sq. Km)	Percent Error (%)	Absolute Difference
Start Date	End Date	Start Date	End Date				
2017/6/25	2017/7/2	2017/7/2	2017/7/9	0.00	0.00	N/A	0.00
2017/7/2	2017/7/9	2017/7/9	2017/7/16	1063.10	0.08	1328775.00	1063.02
2017/7/9	2017/7/16	2017/7/16	2017/7/23	3.34	0.00	N/A	3.34
2017/7/16	2017/7/23	2017/7/23	2017/7/30	6.89	0.00	N/A	6.89
2017/7/23	2017/7/30	2017/7/30	2017/8/6	645.08	0.00	N/A	645.08

2017/7/30	2017/8/6	2017/8/6	2017/8/13	27.41	44.59	38.53	17.18
2017/8/6	2017/8/13	2017/8/13	2017/8/20	644.79	13.60	4641.10	631.19
2017/8/13	2017/8/20	2017/8/20	2017/8/27	14.88	4.56	226.32	10.32
2017/8/20	2017/8/27	2017/8/27	2017/9/3	0.21	38.99	99.46	38.78
2017/8/27	2017/9/3	2017/9/3	2017/9/10	1.49	6.30	76.35	4.81
2017/9/3	2017/9/10	2017/9/10	2017/9/17	0.01	1.67	99.40	1.66
2017/9/10	2017/9/17	2017/9/17	2017/9/24	1.38	1.12	23.21	0.26
2017/9/17	2017/9/24	2017/9/24	2017/10/1	5.43	8.28	34.42	2.85
2017/9/24	2017/10/1	2017/10/1	2017/10/8	8.81	1.02	763.73	7.79
2017/10/1	2017/10/8	2017/10/8	2017/10/15	25.71	0.00	N/A	25.71
2017/10/8	2017/10/15	2017/10/15	2017/10/22	4.35	5.03	13.52	0.68
2017/10/15	2017/10/22	2017/10/22	2017/10/29	0.91	1.52	40.13	0.61
2017/10/22	2017/10/29	2017/10/29	2017/11/5	2.52	5.58	54.84	3.06
2017/10/29	2017/11/5	2017/11/5	2017/11/12	31.05	0.36	8525.00	30.69
2017/11/5	2017/11/12	2017/11/12	2017/11/19	0.00	12.78	100.00	12.78
2017/11/12	2017/11/19	2017/11/19	2017/11/26	3.93	12.70	69.06	8.77
2017/11/19	2017/11/26	2017/11/26	2017/12/3	29.49	34.53	14.60	5.04
2017/11/26	2017/12/3	2017/12/3	2017/12/10	0.78	0.00	N/A	0.78
2017/12/3	2017/12/10	2017/12/10	2017/12/17	16.44	0.00	N/A	16.44
2017/12/10	2017/12/17	2017/12/17	2017/12/24	4.18	0.00	N/A	4.18
2017/12/17	2017/12/24	2017/12/24	2017/12/31	0.47	0.00	N/A	0.47
2017/12/24	2017/12/31	2017/12/31	2018/1/7	22.85	2.39	856.07	20.46
2017/12/31	2018/1/7	2018/1/7	2018/1/14	0.46	0.01	4500.00	0.45
2018/1/7	2018/1/14	2018/1/14	2018/1/21	0.48	0.01	4700.00	0.47
2018/1/14	2018/1/21	2018/1/21	2018/1/28	11.63	17.22	32.46	5.59
2018/1/21	2018/1/28	2018/1/28	2018/2/4	0.24	1.59	84.91	1.35
2018/1/28	2018/2/4	2018/2/4	2018/2/11	2.69	100.27	97.32	97.58

2018/2/4	2018/2/11	2018/2/11	2018/2/18	45.60	13.12	247.56	32.48
2018/2/11	2018/2/18	2018/2/18	2018/2/25	0.42	79.38	99.47	78.96
2018/2/18	2018/2/25	2018/2/25	2018/3/4	0.08	0.07	14.29	0.01
2018/2/25	2018/3/4	2018/3/4	2018/3/11	3.17	0.31	922.58	2.86
2018/3/4	2018/3/11	2018/3/11	2018/3/18	6.82	0.31	2100.00	6.51
2018/3/11	2018/3/18	2018/3/18	2018/3/25	32.75	0.00	N/A	32.75
2018/3/18	2018/3/25	2018/3/25	2018/4/1	25.01	69.60	64.07	44.59
2018/3/25	2018/4/1	2018/4/1	2018/4/8	4.37	7.85	44.33	3.48
2018/4/1	2018/4/8	2018/4/8	2018/4/15	6.33	15.65	59.55	9.32
2018/4/8	2018/4/15	2018/4/15	2018/4/22	0.02	21.29	99.91	21.27
2018/4/15	2018/4/22	2018/4/22	2018/4/29	1.65	0.64	157.81	1.01
2018/4/22	2018/4/29	2018/4/29	2018/5/6	5.05	1.13	346.90	3.92
2018/4/29	2018/5/6	2018/5/6	2018/5/13	5.22	14.02	62.77	8.8
2018/5/6	2018/5/13	2018/5/13	2018/5/20	0.76	43.97	98.27	43.21
2018/5/13	2018/5/20	2018/5/20	2018/5/27	0.34	19.00	98.21	18.66
2018/5/20	2018/5/27	2018/5/27	2018/6/3	0.20	87.57	99.77	87.37
2018/5/27	2018/6/3	2018/6/3	2018/6/10	0.37	18.51	98.00	18.14
2018/6/3	2018/6/10	2018/6/10	2018/6/17	1.03	50.62	97.97	49.59
2018/6/10	2018/6/17	2018/6/17	2018/6/24	1.27	0.01	12600.00	1.26
2018/6/17	2018/6/24	2018/6/24	2018/7/1	15.07	0.00	N/A	15.07

Figure 2.9a Sentinel-2 Weekly Forest Loss Detection Chart for West Sepik Province
(tCloud 10; tIndex 0.1)

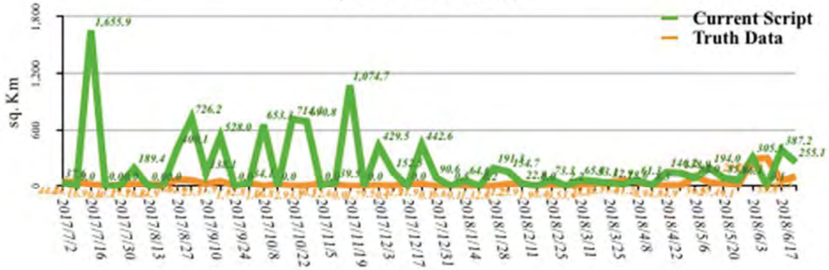


Figure 2.9b Sentinel-2 Weekly Forest Loss Detection Chart for West Sepik Province
(tCloud 10; tIndex 0.1; Zoomed in at Max. 450 sq.Km)

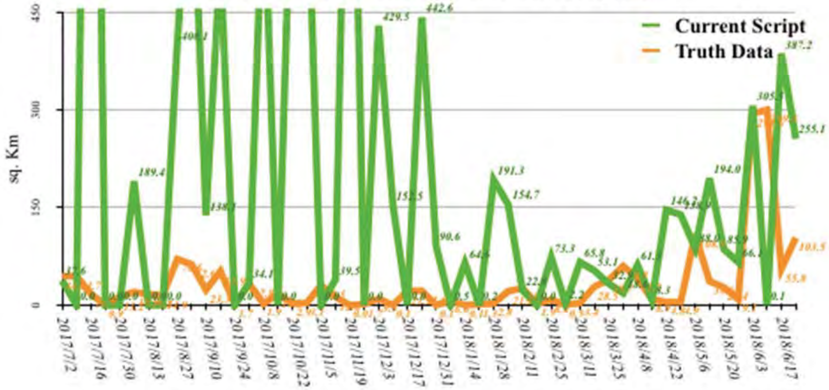


Figure 2.10a Sentinel-2 Weekly Forest Loss Detection Chart
for West New Britain Province (tCloud 10; tIndex 0.1)

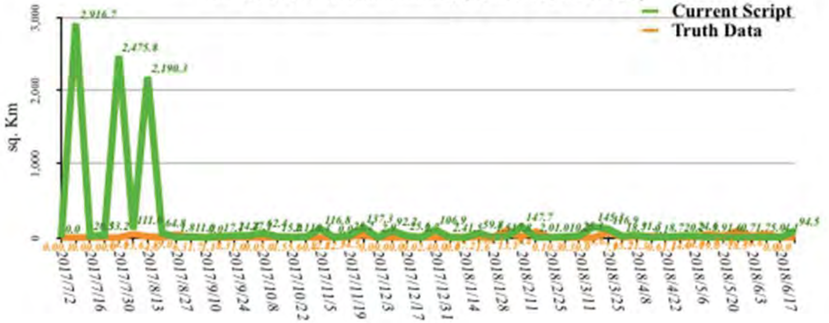


Figure 2.10b Sentinel-2 Weekly Forest Loss Detection Chart
for West New Britain Province
(tCloud 10; tIndex 0.1; Zoomed in at Max. 150 sq.Km)

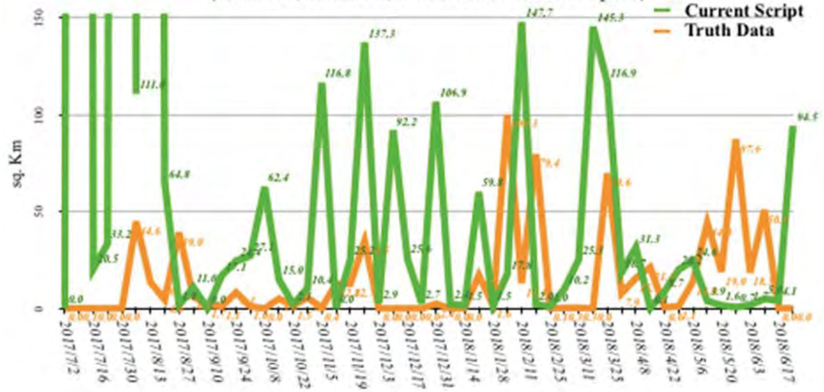


Figure 2.11a Sentinel-2 Weekly Forest Loss Detection Chart for West Sepik Province
(tCloud 10; tIndex 0.2)

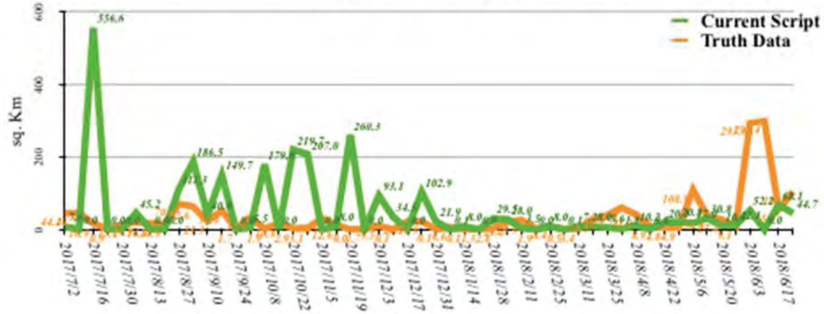


Figure 2.11b Sentinel-2 Weekly Forest Loss Detection Chart for West Sepik Province
(tCloud 10; tIndex 0.2; Zoomed in at Max. 200 sq.Km)

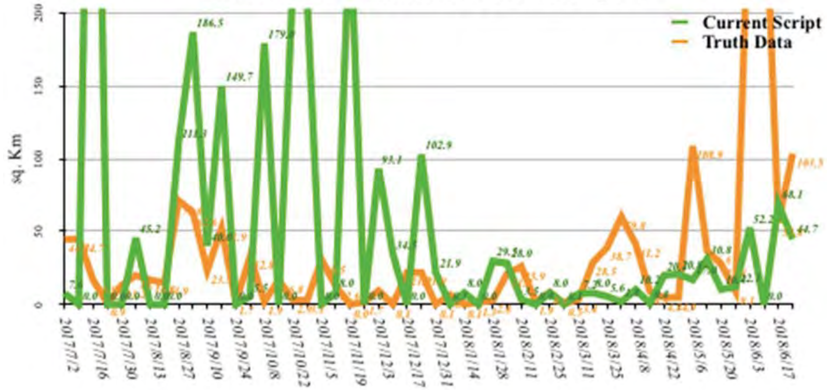


Figure 2.12a Sentinel-2 Weekly Forest Loss Detection Chart for West New Britain Province (tCloud 10; tIndex 0.2)

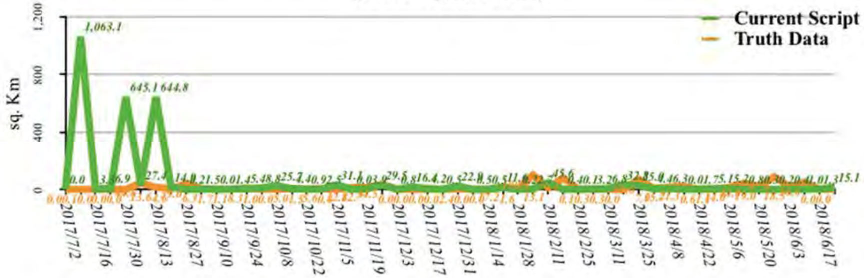
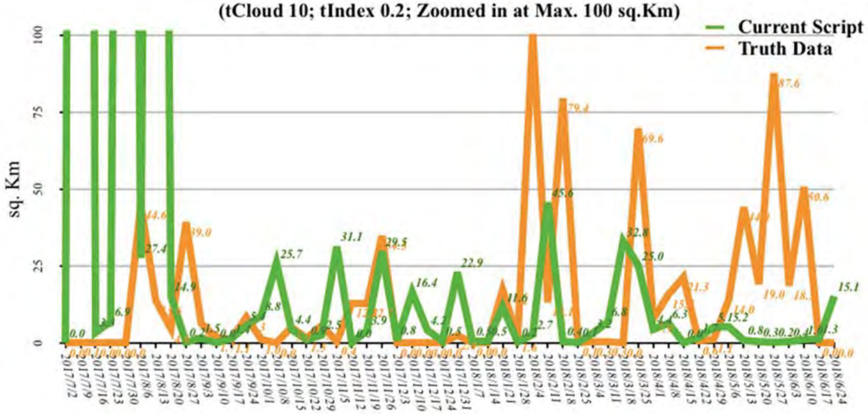


Figure 2.12b Sentinel-2 Weekly Forest Loss Detection Chart for West New Britain Province (tCloud 10; tIndex 0.2; Zoomed in at Max. 100 sq.Km)



For Sentinel-2 Weekly Forest Loss Detection script that using tIndex = 0.1 in WSP Province, the difference of Weekly Forest Loss Areas between current script and the truth data were significantly high from July 2017 to December 2017. However, the differences were significantly decreased from January 2018 to June 2018 so that the trend of Weekly Forest Loss Areas between current script and the truth data became similar. Overall, the Weekly Forest Loss Areas of current scripts were higher than those derived by the truth data.

Furthermore, for Sentinel-2 Weekly Forest Loss Detection script that using tIndex = 0.1 in WSP Province, the lowest Percent Error (best accuracy) is 4.06%, for Weekly Forest Loss in 2018/06/03 to 2018/6/10. Moreover, the highest Percent Error (worst accuracy) is 138536.36%, for Weekly Forest Loss in 2017/12/10 to 2017/12/17. As for the Absolute Difference, the lowest value (best accuracy) is 0.62, for Weekly Forest Loss in 2018/04/15 to 2018/04/22. Moreover, the highest Absolute Difference (worst accuracy) is 1638.97, for Weekly Forest Loss in 2017/07/16 to 2017/07/23.

As for Sentinel-2 Weekly Forest Loss Detection script that using tIndex = 0.1 in WNB Province, the difference of Weekly Forest Loss Areas between current script and the truth data were significantly high from July 2017 to August 2017. However, the differences were significantly decreased from September 2017 to June 2018 so that the trend of Weekly Forest Loss Areas between current script and the truth data became nearly similar. Overall, the Weekly Forest Loss Areas of current scripts were higher than those derived by the truth data.

Moreover, for Sentinel-2 Weekly Forest Loss Detection script that using tIndex = 0.1 in WNB Province, the lowest Percent Error (best accuracy) is 8.81%, for Weekly Forest Loss in 2018/01/28 to 2018/2/04. Furthermore, the highest Percent Error (worst accuracy) is 3645800.00%, for Weekly Forest Loss in 2017/07/09 to 2017/07/16. As for the Absolute Difference, the lowest value (best accuracy) is 0.00, for Weekly Forest Loss in 2017/07/02 to 2017/07/09. Moreover, the highest Absolute Difference (worst accuracy) is 2916.64, for Weekly Forest Loss in 2017/07/09 to 2017/07/16.

For Sentinel-2 Weekly Forest Loss Detection script that using tIndex = 0.2 in WSP Province, the difference of Weekly Forest Loss Areas between current script and the truth data were significantly decreased compared with those derived by using tIndex = 0.1. However, similar to those derived by using tIndex = 0.1, the difference of Weekly Forest Loss Areas between current script and the truth data are relatively high from July 2017 to December 2017. However, the differences were decreased from January 2018 to June 2018 so that the trend of Weekly Forest Loss Areas between current script and the truth data became nearly similar. Overall, the Weekly Forest Loss Areas that derived by the current script were higher for 2017 and lower for 2018, as compared to those derived by the truth data.

Thus, for Sentinel-2 Weekly Forest Loss Detection script that using tIndex = 0.2 in WSP Province, the lowest Percent Error (best accuracy) is 4.30%, for Weekly Forest Loss in 2018/02/25 to 2018/3/04. Moreover, the highest Percent Error (worst accuracy) is 31300.00%, for Weekly Forest Loss in 2017/12/10 to 2017/12/17. As for the Absolute Difference, the lowest value (best accuracy) is 0.36, for Weekly Forest Loss in 2018/02/25 to 2018/3/04. Moreover, the highest Absolute Difference (worst accuracy) is 539.68, for Weekly Forest Loss in 2017/07/16 to 2017/07/23.

Finally, for Sentinel-2 Weekly Forest Loss Detection script that using tIndex = 0.2 in WNB Province, the difference of Weekly Forest Loss Areas between current script and the truth data were significantly decreased compared with those derived by using tIndex = 0.1. However, similar to those derived by using tIndex = 0.1, the difference of Weekly Forest Loss Areas between current script and the truth data are relatively high from July 2017 to August 2017. However, the differences were decreased from September 2017 to June 2018 so that the trend of Weekly Forest Loss Areas between current script and the truth data became nearly similar. Overall, the Weekly Forest Loss Areas that derived by the current scripts were higher for 2017 and lower for 2018, as compared to those derived by the truth data.

Furthermore, for Sentinel-2 Weekly Forest Loss Detection script that using tIndex = 0.2 in WNB Province, the lowest Percent Error (best accuracy) is 13.52%, for Weekly Forest Loss in 2017/10/15 to 2017/10/22. Moreover, the highest Percent Error (worst accuracy) is 1328775.00%, for Weekly Forest Loss in 2017/07/09 to 2017/07/16. As for the Absolute Difference, the lowest value (best accuracy) is 0.00, for

Weekly Forest Loss in 2017/07/02 to 2017/07/09. Moreover, the highest Absolute Difference (worst accuracy) is 1063.02, for Weekly Forest Loss in 2017/07/09 to 2017/07/16.

To conclude, the Weekly Forest Loss Areas for both target areas (WSP and WNB Provinces) derived by the current script were likely to fit with those derived by the truth data by using a larger tIndex. Thus, the tIndex = 0.2 yielded a better accuracy as compared to those derived by the tIndex = 0.1 for Sentinel-2 Weekly Forest Loss Detection script.

2.3.2.2 List of issues to be solved

The issues to be solved are listed as follows:

- The current scripts are using the greenest-pixel method to generate cloud-free image for analysis, but cloud contaminations are remain occurred for several analysis periods both in Annual and Weekly Forest Detection scripts, for both target areas (WSP and WNB Provinces). Thus, for the future scripts development, the greenest-pixel method should be changed to another method (e.g., median image method) or modified for generating a better quality of cloud-free image to be used for Forest Loss Detection in Papua New Guinea.
- There are over estimations (or a very high) Annual and Weekly Forest Loss Areas derived by the current scripts. These could be happened due to the very different conditions of cloud cover within the *Reference* and *Target* imageries. For instance, for the Weekly Forest Loss Detection script, there are significantly cloud-free weekly image collections for a week, but in the following week the cloud-cover condition of weekly image collections are very bad, or vice versa.
- For Annual Forest Loss Detection, the satellite imageries in Papua New Guinea are mostly contaminated by cloud cover, even though in the period of local dry season (August to October) for both satellites (Landsat 8 and Sentinel-2). Furthermore, the cloud-cover condition for satellite imageries in the local rainy season are worse as compared to those in the local dry season. Thus, for Annual Forest Loss Detection purposes, the investigation period is adjusted to cover one-month prior and after the local dry season, which is July to November.
- In the current Weekly Forest Loss Detection script developed for the third country, the Weekly Forest Loss Areas would always be calculated even though there is no cloud-free image collections in the archive (using a cloud filtering function to obtain cloud-free image by looking for image collections up to 10 weeks prior to the actual observation). For future scripts development in Papua New Guinea, the cloud filtering function could be modified so that if the image collections are having a very bad cloud contamination (i.e., as listed in the image metadata), no result (N/A) would be shown and the calculation would be terminated in order to avoid over estimation of Weekly Forest Loss Areas.
- In the accuracy assessments, two threshold values (tIndex = 0.1 and tIndex = 0.2) were tested. For both scripts, the tIndex = 0.2 yielded better accuracies with the truth data. In order to increase the accuracy of both scripts, the truth data could be use to find the optimum threshold value for the future scripts development by conducting trial and error experiments of threshold value for a given target area.

- Instead of applying threshold value to define a unit of Forest Loss on a script, omitting the threshold value could be an option to detect the early deforestation stages in target areas. Thus, any decreasing values of an index or indices combinations in a pixel would be consider as an early deforestation stage.
- For the future scripts development, the integration between Spectral Mixture Analysis (SMA) and Normalized Difference Fraction Index (NDFI) could be applied. However, to derive SMA, training sites are necessary. Due to the lack of field data in target areas, training sites could be obtain by applying visual interpretation on Google Earth for collecting training sites in Papua New Guinea.
- Regarding the provincial boundary of target areas (WSP and WNB Provinces), the file size of provincial boundary shapefiles that obtained from the Papua New Guinea Forest Authority or PNGFA (both the official and the simple versions of shapefiles) are too large and too many details of nodes so that exceeding the computational memory of Google Earth Engine and resulting errors. Thus, creating a simplified polygon (e.g., by using the "BEND_SIMPLIFY" function in ArcMap that keep the main shape of a polygon and removes extra nodes bends in the boundary) could significantly reduced the computational memory of Google Earth Engine.
- For obtaining an efficient computation of the future script development, the aggregation of Forest Loss Area accumulation per grid could be considered. However, the size of each grid should also be considered. A 500 x 500 meter grid might yielded a very different Forest Loss Areas as compared to those derived by per-pixel calculations. Thus, a 3x3 pixel (90 x 90 meter grid for Landsat 8, and 30 x 30 meter grid for Sentinel-2) or 5x5 pixel (150 x 150 meter grid for Landsat 8, and 50 x 50 meter grid for Sentinel-2) could be applied.

2.4 Conclusion

The present chapter has been successfully investigated the potential of the current annual and weekly forest loss detection systems by using the Google Earth Engine that was developed in the third country, as well as extracted and listed issues that found on the examination process for the development of the future forest loss detection systems in Papua New Guinea. The conclusion of this chapter is listed as follows:

a. Landsat8-based Annual Forest Loss in 2015, 2016 and 2017 for WSP and WNB Provinces were obtained.
b. Sentinel2-based Annual Forest Loss in 2016 and 2017 for WSP and WNB Provinces were obtained.
c. Sentinel2-based Weekly Forest Loss from July 2017 to June 2018 for WSP and WNB Provinces were obtained.
d. Annual and Weekly Forest Loss Data were obtained from Global Forest Change and GLAD Alerts to be used as the truth data.
e. Accuracy assessments for the current Annual and Weekly Forest Loss Detection scripts have been done.
f. The tIndex = 0.2 yielded a better accuracy as compared to those derived by the tIndex = 0.1 both for Annual and Weekly Forest Loss Detection scripts.
g. The issues found in the examination process have been listed for future scripts development.

h. The integration of SMA and NDFI could be applied for future scripts development, and could also be compared with the approach used by the current scripts.
i. The truth data could be used to find the optimum threshold value for future scripts development by conducting trial and error experiments.

Chapter 3
Update the annual and weekly forest loss detection system for adapting to circumstances in Papua New Guinea based on the clarified issues

3.1 Background

The capabilities of the current scripts (i.e., the annual and weekly forest loss detection system utilizing Landsat-8 and Sentinel-2 imagery developed for the other country) have been checked and analyzed to identify forest loss detection in two target areas in Papua New Guinea. In this chapter, the annual and weekly forest loss detection system is subject to be updated to adapt circumstances in Papua New Guinea based on the clarified issues encountered in the assessment process of the current scripts. Therefore, the main focus of this chapter is to detect deforestations in Papua New Guinea by using remote sensing application on the Google Earth Engine platform as early as and as accurate as possible.

The key issue that needs to be solved is to apply the proper method to exclude areas that are not suitable for forest loss analysis purposes such that the cloud/haze-contaminated areas. By omitting those areas from the analysis, the result of accuracy assessment should be free from an error associated with cloud/haze effects.

Furthermore, the method used in the forest monitoring system is considered to be updated in order to obtain a better and improved result for detecting deforestation in Papua New Guinea. The performance of utilizing the integration of Spectral Mixture Analysis (SMA) and Normalized Difference Fraction Index (NDFI) would be tested and analyzed in the updated forest loss detection system. Moreover, the optimum threshold value to detect deforestation would be assessed by conducting trial and error experiment with the truth data obtained from the Global Forest Change (https://earthenginepartners.appspot.com/science-2013-global-forest/download_v1.5.html) and GLAD Alerts (https://www.globalforestwatch.org/map) Data.

Concurrently, the greenest and lower/least greenest image would also be generated to investigate their capability in detecting deforestation. On the other hand, to be more effective and confident to update the current script further, research and review on the best use of index(es), methods, and threshold value from the currently available forest monitoring system in the world would be done in parallel (i.e., at the early stage).

3.2 Objectives

The objectives of this chapter are listed as follows:

1. to conduct research and review on the best use of index(es), methods, and threshold value from the currently available forest monitoring system in the world,
2. to apply the proper method to exclude areas that are not suitable for analysis purposes such that the cloud/haze-contaminated areas, for the updated Annual and Weekly Forest Loss Detection scripts in Papua New Guinea,

3. to test and analyze the performance of utilizing the integration of Spectral Mixture Analysis (SMA) and Normalized Difference Fraction Index (NDFI) for the updated Annual and Weekly Forest Loss Detection scripts in Papua New Guinea,
4. to test and analyze the capability of applying greenest and lower/least greenest image in detecting deforestation for the updated Annual and Weekly Forest Loss Detection scripts in Papua New Guinea.
5. to perform a trial and error experiment with the truth data to obtain the optimum threshold value to detect deforestation for the updated Annual and Weekly Forest Loss Detection scripts in Papua New Guinea.

3.3 Outputs and Results

3.3.1 Brief analysis on the best use of index(es), methods, and threshold values from the currently available forest monitoring systems (As per September 21st, 2018)

3.3.1.1 Brief analysis regarding cloud/haze elimination methods

- In order to overcome the key issue for the updated annual and weekly forest loss detection system, the proper cloud/haze elimination method needs to be applied to exclude areas that is not suitable for forest loss analysis purposes, such that areas with cloud/haze-contaminations.
- The current annual and weekly forest loss detection system is utilizing the greenest-pixel method to derive cloud-free image by advantaging Normalized Difference Vegetation Index (NDVI) values of an image collection to obtain the highest NDVI value on each pixel that is assumed as the cloud-free pixel.
- Hansen et al. (2016) was separately identified cloud cover, haze, water and shadow and those data was used to create a pool of viable land observations which are put through the full radiometric normalization by using the so-called dark-object subtraction (DOS) as the primary correction and the anisotropy adjustment as the secondary correction.
- The “Landsat-8 Mosaic and Cloudless Mosaic to Calculate Ratio of Cloudless Coverage” script is utilizing Landsat cloud-scoring method that is available on the Google Earth Engine (GEE) platform to mask cloudy pixels by advantaging spectral information on the BLUE, GREEN, RED, NIR, SWIR1, SWIR2, and Temperature bands. Currently, this Landsat cloud-scoring algorithm, both for single image (so-called the simple cloud score algorithm) and for an image collection (so-called the simple composite algorithm), has been updated and authorized by GEE and could be use in the updated Landsat-8 annual forest loss detection system to overcome the key issue.
- As for the Sentinel-2, instead of using the greenest-pixel method, there are two other cloud/haze elimination methods that could be applied in the updated annual and weekly forest loss detection system. The first cloud/haze elimination method (i.e., the QA band method) is using the cloud and cirrus flags derived from Sentinel-2 QA band to mask cloudy pixels over an image collection. The detail instruction of

using this method is attached in the example script repository in GEE code editor. The second cloud/haze elimination method (i.e., the cloud and shadow masking method) is advantaging the spectral information on BLUE and WATER VAPOR bands to mask cloudy pixels and utilizing the combination of MEAN SOLAR AZIMUTH ANGLE and MEAN SOLAR ZENITH ANGLE information on the metadata to mask the potential shadow areas. The algorithm of applying this method is available in the official GEE Developers Group. Thus, these cloud/haze elimination methods could be use in the updated Sentinel-2 annual and weekly forest loss detection system to overcome the key issue.

3.3.1.2 Brief analysis regarding forest loss analysis methods

- In Hansen et al. (2016), the combination of NDVI, Normalized Difference Water Index (NDWI), and Normalized Burn Ratio (NBR) were mainly used to derive time-series metric. Metrics are statistical measures derived from a multi-temporal stack of good quality Landsat observations. Furthermore, they applied the time-series metrics to bagged decision-tree algorithms for separating forest disturbance and non-forest disturbance. They also used expert image interpretation and LIDAR data for generating training and validation data. Unfortunately, they did not clearly published the threshold values or rules of the bagged decision-tree algorithms in details. Therefore, reproducing the exactly similar method as partially described in Hansen et al. (2016) could lead to uncertainties.
- The current annual and weekly forest loss detection system is using the combination of NDVI, NDWI, and NBR to analyze forest loss between the given reference and target images. Thus, a decreasing value of those three indices at a given area or pixel that is greater than the given threshold value would be considered as forest loss. This method was adapted and simplified from the forest loss analysis method derived by Hansen et al. (2016).
- Souza et al. (2003) developed the Spectral Mixture Analysis (SMA) to map classes of degraded forest. The fraction images (vegetation, non-photosynthetic vegetation (NPV), soil, and shade) derived from the spectral mixture models were classified into intact forest, degraded forest, forest regeneration, and logged forest area using a decision-tree classifier. Furthermore, Souza et al. (2005) introduced a new spectral index, so-called the Normalized Difference Fraction Index (NDFI), for enhanced detection of forest canopy damage caused by selective logging activities and associated forest fires. The NDFI synthesizes information from several component fraction images derived from the spectral mixture models (i.e., the SMA).
- The integration of SMA and NDFI method is widely used by various forest monitoring systems. The CLASlite was developed by Carnegie Institute for Science was used the Monte Carlo SMA for detecting deforestation and forest degradation, and was initially applied in Brazil and quickly expanded across Latin America, Africa, Asia and other regions. In the Republic of Cameroon, the integration of SMA and NDFI was used to detect and map forest degradation that was associated with selective logging activities. Furthermore, forest degradation associated with selective logging activities and forest fires were also mapped in Bolivia by advantaging the integration of SMA and NDFI.

3.3.1.3 Brief analysis regarding the integration of SMA and NDFI method

- There are several ways to derive fraction images by using SMA, one of most convenience ways is by using the predetermined endmember spectral library. In GEE, the SMA method is authorized under the spectral transformation algorithms, and so-called the spectral unmixing method. This method "unmix" each pixel with the given predetermined spectral endmember, by computing the pseudo-inverse and multiplying it through each pixel.
- Small (2004) proposed the standard global endmember from the Landsat n-dimensional spectral space. These predetermined spectral endmember library could be use to derive the necessary fraction images as the input for generating the NDFI image. This predetermined spectral endmember library is applied to BLUE, GREEN, RED, NIR, SWIR1, and SWIR2 bands of a Landsat-8 image. Although the spectral endmember library was initially derived for Landsat sensors, this method would also be applied to the similar bands for Sentinel-2 images in the updated annual and weekly forest loss detection system.
- In the updated annual and weekly forest loss detection system, five fraction images (vegetation, NPV, soil, shade, and cloud) would be generated. The vegetation, NPV, soil, and shade fraction images would be use to derive the NDFI image. Furthermore, the cloud fraction image would be used for an additional cloud masking for the NDFI image (Souza et al. 2013).
- Theoretically, the NDFI values range from 1 to -1, however, Souza et al. (2005) proposed a detail thresholding scheme for classifying the NDFI values. High NDFI values (NDFI >0.75) represents forest areas that were not subject to canopy damage due to selective logging and/or burning, medium NDFI values (0<NDFI<0.75) are associated with forest canopy damage due to selective logging and forest burning, and areas with negative NDFI values are mostly associated with areas that were subject to clear-cutting. These NDFI values thresholding scheme would be use to mask deforestation in the updated annual and weekly forest loss detection system.

3.3.1.4 Brief analysis regarding greenest and least-greenest method

- In the updated annual forest loss detection system, both derived by the Landsat-8 and the Sentinel-2, the greenest and least-greenest image for each year would be generated and analyzed for their capability in detecting deforestation. Therefore, the NDVI would be utilize as an index to define the level of greenest or least-greenest for a given pixel.
- The greenest image is defined as an image with the highest NDVI value on each pixel over an image collection for the earlier period of the year (i.e., in the rainy season for Papua New Guinea). In this period, it was assumed that there are no or limited deforestation-related activities due to the unfavorable weather condition, so that the green vegetation cover tends to increase. Thus, by looking at the climate data for each area of interest (AOI) in Papua New Guinea , the duration rainy season is set for January to May.

- The least-greenest image is defined as an image with the lowest NDVI value on each pixel over an image collection for the later period of the year (i.e., in the dry season for Papua New Guinea). In this period, it was assumed that the deforestation-related activities are common due to the favorable weather condition, so that the green vegetation cover tends to decrease. Thus, by looking at the climate data for each AOI in Papua New Guinea , the duration dry season is set for June to December.
- The greenest image is subtracted by the least-greenest image to obtain the accumulation of tree-cover loss for each year. Thus, the greenest, least-greenest, and the tree-cover loss accumulation images could be compared each other to obtain the forest loss dynamic on each AOI for each year.

3.3.1.5 Brief analysis regarding the optimum threshold value

- In the updated annual and weekly forest loss detection system, threshold value is being used to define a unit of forest loss by using the given forest loss analysis method. Thus, the optimum threshold value plays an important role for increasing the accuracy and reliability of the system.
- The optimum threshold value for a forest loss detection script is defined as a threshold value that produces the lowest difference of forest loss areas as compared to those derived by the truth data (i.e., the Global Forest Change for annual forest loss detection and the GLAD Alerts Data for annual forest loss detection).
- Three threshold values with a fraction of one digit after the comma (i.e., tIndex = 0.1; tIndex = 0.2; and tIndex = 0.3) would be tested and analyzed on each AOI for each script. Thus, a threshold value that yields the least mean absolute difference for a given investigation period with the truth data would be considered as the optimum threshold value for the given script.

3.3.2 Details of the updated annual and weekly forest loss detection system for Papua New Guinea

3.3.2.1 Regarding the "Landsat-8 Annual Forest Loss Detection for Papua New Guinea (Version 2018.09.17)" script

3.3.2.1.1 The main structure of the script

This script is intended to detect the annual forest loss areas for two area of interests (AOIs) in Papua New Guinea by using Landsat-8 images. The script is divided into eight parts, which are: *(1) Input Commands, (2) Parameters Collections, (3) Parameters for Investigation Periods, (4) Cloud-free Functions, (5) Image Collections, (6) Forest Loss Analysis, (7) Compare Greenest and Least Greenest,* and *(8) Parameters for Export Images.*

Part 1 consists of all input commands (14 in total) that should be defined by the user in order to run the script. These commands include the duration of investigation periods for the reference and target images, the total amount of target images to be used for the forest loss analysis, the AOI selection, the option of methods to be used for cloud/haze elimination purposes, the option to show the cloud-free to the GEE Map, the option of methods to be used for forest loss analysis purposes, the definition of threshold value, the option to show the loss-image to the GEE Map, the option to generate greenest, least-greenest and tree-cover loss accumulation images, and options to export the loss-images to user's Asset and/or Google Drive. In the end of this part, there is an information of the additional feature to calculate forest loss areas by using the dedicated loss-area calculation script. The script for calculating forest loss areas is being separated from the forest loss detection script to obtain a better performance (i.e., GEE memory usage and computation time) on each script.

Part 2 comprises the collection of general parameters that being used in the script. These parameters include the definition of image collections, date formatting for the investigation period, conditional functions for the selected AOI, conditional functions for the selected method for forest loss analysis, command to print the script's title to the GEE Console, masking for tree-cover in the selected study area that was derived from the Global Forest Change data, collection of visual parameters, and command to display the boundary of the selected AOI and the tree-cover to the GEE Map.

Part 3 associated with functions to derive start and end dates for each reference and target images, based on the user's input in Part 1. Furthermore, these dates are listed in the list for each pair of reference and target images. Lastly, there is a command to print the list of date pairs for each forest loss analysis to the GEE Console.

Part 4 collects functions to generate cloud-free image by using the selected cloud/haze elimination method. In this script, there are two available cloud/haze elimination methods, which are the greenest-pixel method and the simple composite method. The greenest-pixel method applies Normalized Difference Vegetation Index (NDVI) values of an image collection to obtain the highest NDVI value on each pixel that is assumed as the cloud-free pixel. Meanwhile, the simple composite method selects a subset of scenes at each location, converts to top-of-atmosphere (TOA) reflectance, applies the simple cloud score algorithm and takes the median of the least cloudy pixels.

Part 5 consists of commands to obtain cloud-free images for all reference and target images in the investigation period by using functions that defined in the previous parts. Furthermore, there is a conditional function to display the cloud-free image collection to the GEE Map.

Part 6 comprises functions to analyze forest loss by utilizing the selected forest loss analysis method. In this script, there are two forest loss analysis methods, which are the combination of NDVI, Normalized Difference Water Index (NDWI), and Normalized Burn Ratio (NBR) method and the integration of Spectral Mixture Analysis (SMA) and Normalized Difference Fraction Index (NDFI) method. The first method analyzes the difference between NDVI, NDWI, and NBR images for a given reference and target images, so that a decreasing value of those three indices at a given area or pixel that is greater than the given threshold value would be considered as forest loss. Meanwhile, the second method utilizes SMA-derived fraction images for generating NDFI image for a given reference and target image, so that a decreasing value of NDFI at a given area or pixel that is greater than the given threshold value would be considered as forest

loss. Lastly, there is a command to display loss-image collection to GEE Map, as well as the deforestation images of each reference and target image for the integration of SMA and NDFI method.

Part 7 associated with the function to derive the greenest and least-greenest images. The simple composite method is being used as the default cloud/haze elimination method for generating the greenest and least-greenest images due to its better performance as compared to the greenest-pixel method. Furthermore, the greenest image is subtracted by the least-greenest image to generate the accumulation of tree-cover loss for each year. Lastly, there is a command to display the greenest, least-greenest, and the tree-cover loss accumulation images to the GEE Map.

Part 8 collects function to export the loss-image collection to user's Asset in GEE, user's Google Drive account, or to both of them. The exported loss-image would have a pixel size of 30 meter and a Universal Transverse Mercator (UTM) WGS84 projection.

3.3.2.1.2 Brief analysis for cloud/haze elimination methods

In this script, there are two available cloud/haze elimination methods, which are the greenest-pixel method and the simple composite method. In order to analyze the performance of each method, visual interpretation of the derived cloud-free image by each method was taken. However, cloud-free image derived by both methods are almost in the similar quality (Figure 3.1). This conclusion is supported by the fact that in this annual forest loss detection script a relatively long duration of investigation periods is being used to derive the cloud-free image, so that each method has more than enough image collection to derive a good quality of cloud-free image. Therefore, to objectively analyze the performance of each method, the usage of CPU time and memory for each method was analyzed.

In GEE setting, there is an additional performance profiling tabs that could be enabled and shown. This Profiler tab displays information about the resources (CPU time, memory) consumed by specific algorithms and other parts of a computation. Thus, the simple composite method is using less memory as compared to the greenest-pixel method (Figure 3.2). A more efficient method would allow more memory space to be use by other algorithm so that could lead to a better performance. Thus, in this script, the simple composite is set to be the default cloud/haze elimination method.

Figure 3.1 The cloud-free image of 2014 derived by using the greenest-pixel method (left), and the simple composite method (right).

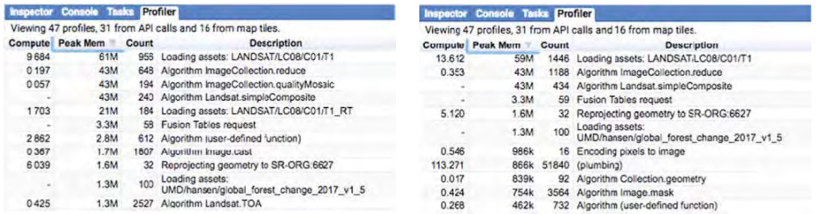


Figure 3.2 The memory usage of the greenest-pixel method (left) and the simple composite method (right).

3.3.2.1.4 Brief analysis for forest loss analyses methods

In this script, there are two forest loss analysis methods, which are the combination of NDVI, NDWI, and NBR method and the integration of SMA and NDFI method. In order to objectively analyze the performance of each method, accuracy assessment of the derived loss area by each method was taken. The truth data obtained from the Global Forest Change Version 1.5 (https://earthenginepartners.appspot.com/science-2013-global-forest/download_v1.5.html) were used for the accuracy assessment purposes. Furthermore, three threshold values with a fraction of one digit after the comma (i.e., tIndex = 0.1; tIndex = 0.2; and tIndex = 0.3) were tested and analyzed to obtain the optimum threshold value on each AOI for each method.

Table 3.1 Landsat-8 Annual Forest loss Detection for West Sepik Province (NDVI, NDWI, NBR Method)

Image ID	Analysis	Annual Forest Loss (sq. Km)	Forest lossyear data from Global Forest Change (sq. Km)	Absolute Difference
Threshold Value (tIndex) = 0.1				
WSP_L8annualLossImage_analysis_1	Forest Loss in 2015 (Forest Area 2014 - Forest Area 2015)	430.95	163.97	266.98
WSP_L8annualLossImage_analysis_2	Forest Loss in 2016 (Forest Area 2015- Forest Area 2016)	622.21	136.37	485.84
WSP_L8annualLossImage_analysis_3	Forest Loss in 2017 (Forest Area 2016- Forest Area 2017)	1728.71	131.87	1596.84
			Mean Absolute Difference	**783.22**
Threshold Value (tIndex) = 0.2				
WSP_L8annualLossImage_analysis_1	Forest Loss in 2015 (Forest Area 2014 - Forest Area 2015)	93.78	163.97	70.19
WSP_L8annualLossImage_analysis_2	Forest Loss in 2016 (Forest Area 2015- Forest Area 2016)	112.64	136.37	23.73
WSP_L8annualLossImage_analysis_3	Forest Loss in 2017 (Forest Area 2016- Forest Area 2017)	212.60	131.87	80.73
			Mean Absolute Difference	**58.22**
Threshold Value (tIndex) = 0.3				
WSP_L8annualLossImage_analysis_1	Forest Loss in 2015 (Forest Area 2014 - Forest Area 2015)	19.48	163.97	144.49
WSP_L8annualLossImage_analysis_2	Forest Loss in 2016 (Forest Area 2015- Forest Area 2016)	15.09	136.37	121.28
WSP_L8annualLossImage_analysis_3	Forest Loss in 2017 (Forest Area 2016- Forest Area 2017)	20.20	131.87	111.67
			Mean Absolute Difference	**125.81**

Table 3.2 Landsat-8 Annual Forest Loss Detection for West Sepik Province (SMA and NDFI Method)

Image ID	Analysis	Annual Forest Loss (sq. Km)	Forest lossyear data from Global Forest Change (sq. Km)	Absolute Difference
Threshold Value (tIndex) = 0.1				
WSP_L8annualLossImage_analysis_1	Forest Loss in 2015 (Forest Area 2014 - Forest Area 2015)	416.22	163.97	252.25
WSP_L8annualLossImage_analysis_2	Forest Loss in 2016 (Forest Area 2015- Forest Area 2016)	241.37	136.37	105.00
WSP_L8annualLossImage_analysis_3	Forest Loss in 2017 (Forest Area 2016- Forest Area 2017)	261.50	131.87	129.63
			Mean Absolute Difference	**162.29**
Threshold Value (tIndex) = 0.2				
WSP_L8annualLossImage_analysis_1	Forest Loss in 2015 (Forest Area 2014 - Forest Area 2015)	396.67	163.97	232.70
WSP_L8annualLossImage_analysis_2	Forest Loss in 2016 (Forest Area 2015- Forest Area 2016)	234.48	136.37	98.11
WSP_L8annualLossImage_analysis_3	Forest Loss in 2017 (Forest Area 2016- Forest Area 2017)	252.30	131.87	120.43
			Mean Absolute Difference	**150.41**
Threshold Value (tIndex) = 0.3				
WSP_L8annualLossImage_analysis_1	Forest Loss in 2015 (Forest Area 2014 - Forest Area 2015)	386.86	163.97	222.89
WSP_L8annualLossImage_analysis_2	Forest Loss in 2016 (Forest Area 2015- Forest Area 2016)	230.69	136.37	94.32
WSP_L8annualLossImage_analysis_3	Forest Loss in 2017 (Forest Area 2016- Forest Area 2017)	247.34	131.87	115.47
			Mean Absolute Difference	**144.23**

The result of accuracy assessment for Landsat-8 annual forest loss detection script for West Sepik Province by using the combination of NDVI, NDWI, and NBR method is shown in Table 3.1, whereas those using the integration of SMA and NDFI is provided in Table 3.2. Thus, the best accuracy for West Sepik Province by using the combination of NDVI, NDWI, and NBR method was yielded by using the threshold value of *0.2* as well as resulted the lowest mean absolute difference with the truth data (Mean Absolute Difference = *58.22*; Highlighted in green). Thus, the optimum threshold value for West Sepik Province by using the combination of NDVI, NDWI, and NBR method is *0.2*. Meanwhile, the best accuracy for West Sepik Province by using the integration of SMA and NDFI method was yielded by using the threshold value of *0.3* as well as resulted the lowest mean absolute difference with the truth data (Mean Absolute Difference = *144.23*; Highlighted in green). Thus, the optimum threshold value for West Sepik Province by using the integration of SMA and NDFI method is *0.3*. Finally, by comparing the best accuracy obtained by both forest loss analysis methods for West Sepik Province, the combination of NDVI, NDWI, and NBR yielded a better performance as compared to those derived by the other method.

Table 3.3 Landsat-8 Annual Forest Loss Detection for West New Britain Province (NDVI, NDWI, NBR Method)

Image ID	Analysis	Annual Forest Loss (sq. Km)	Forest lossyear data from Global Forest Change (sq. Km)	Absolute Difference
Threshold Value (tIndex) = 0.1				
WNB_L8annualLossImage_analysis_1	Forest Loss in 2015 (Forest Area 2014 - Forest Area 2015)	1276.01	348.92	927.09
WNB_L8annualLossImage_analysis_2	Forest Loss in 2016 (Forest Area 2015- Forest Area 2016)	158.17	98.26	59.91
WNB_L8annualLossImage_analysis_3	Forest Loss in 2017 (Forest Area 2016- Forest Area 2017)	1144.87	73.18	1071.69
			Mean Absolute Difference	**686.23**
Threshold Value (tIndex) = 0.2				
WNB_L8annualLossImage_analysis_1	Forest Loss in 2015 (Forest Area 2014 - Forest Area 2015)	398.61	348.92	49.69
WNB_L8annualLossImage_analysis_2	Forest Loss in 2016 (Forest Area 2015- Forest Area 2016)	26.91	98.26	71.35
WNB_L8annualLossImage_analysis_3	Forest Loss in 2017 (Forest Area 2016- Forest Area 2017)	211.51	73.18	138.33
			Mean Absolute Difference	**86.46**
Threshold Value (tIndex) = 0.3				
WNB_L8annualLossImage_analysis_1	Forest Loss in 2015 (Forest Area 2014 - Forest Area 2015)	106.71	348.92	242.21
WNB_L8annualLossImage_analysis_2	Forest Loss in 2016 (Forest Area 2015- Forest Area 2016)	2.86	98.26	95.40
WNB_L8annualLossImage_analysis_3	Forest Loss in 2017 (Forest Area 2016- Forest Area 2017)	18.91	73.18	54.27
			Mean Absolute Difference	**130.63**

Table 3.4 Landsat-8 Annual Forest Loss Detection for West New Britain Province (SMA and NDFI Method)

Image ID	Analysis	Annual Forest Loss (sq. Km)	Forest lossyear data from Global Forest Change (sq. Km)	Absolute Difference
Threshold Value (tIndex) = 0.1				
WNB_L8annualLossImage_analysis_1	Forest Loss in 2015 (Forest Area 2014 - Forest Area 2015)	701.80	348.92	352.88
WNB_L8annualLossImage_analysis_2	Forest Loss in 2016 (Forest Area 2015- Forest Area 2016)	72.61	98.26	25.65
WNB_L8annualLossImage_analysis_3	Forest Loss in 2017 (Forest Area 2016- Forest Area 2017)	315.91	73.18	242.73
			Mean Absolute Difference	**207.09**
Threshold Value (tIndex) = 0.2				
WNB_L8annualLossImage_analysis_1	Forest Loss in 2015 (Forest Area 2014 - Forest Area 2015)	691.45	348.92	342.53
WNB_L8annualLossImage_analysis_2	Forest Loss in 2016 (Forest Area 2015- Forest Area 2016)	71.05	98.26	27.21
WNB_L8annualLossImage_analysis_3	Forest Loss in 2017 (Forest Area 2016- Forest Area 2017)	314.23	73.18	241.05
			Mean Absolute Difference	**203.60**
Threshold Value (tIndex) = 0.3				
WNB_L8annualLossImage_analysis_1	Forest Loss in 2015 (Forest Area 2014 - Forest Area 2015)	685.01	348.92	336.09
WNB_L8annualLossImage_analysis_2	Forest Loss in 2016 (Forest Area 2015- Forest Area 2016)	70.08	98.26	28.18
WNB_L8annualLossImage_analysis_3	Forest Loss in 2017 (Forest Area 2016- Forest Area 2017)	312.96	73.18	239.78
			Mean Absolute Difference	**201.35**

Furthermore, the result of accuracy assessment for Landsat-8 annual forest loss detection script for West New Britain Province by using the combination of NDVI, NDWI, and NBR method is shown in Table 3.3, whereas those using the integration of SMA and NDFI is provided in Table 3.4. Thus, the best accuracy for West New Britain Province by using the combination of NDVI, NDWI, and NBR method was yielded by using the threshold value of *0.2* as well as resulted the lowest mean absolute difference with the truth data (Mean Absolute Difference = *86.46*; Highlighted in green). Thus, the optimum threshold value for West New Britain Province by using the combination of NDVI, NDWI, and NBR method is *0.2*. Meanwhile, the best accuracy for West New Britain Province by using the integration of SMA and NDFI method was yielded by using the threshold value of *0.3* as well as resulted the lowest mean absolute difference with the truth data (Mean Absolute Difference = *201.35*; Highlighted in green). Thus, the optimum threshold value for West Sepik Province by using the integration of SMA and NDFI method is *0.3*. Finally, by comparing the best accuracy obtained by both forest loss analysis methods for West New Britain Province, the combination of NDVI, NDWI, and NBR yielded a better performance as compared to those derived by the other method.

3.3.2.1.5 Brief analysis for the greenest and least-greenest images

In this script, the greenest, least-greenest, and tree-cover loss accumulation for each year in the investigation period were generated. The greenest image is obtained by taking the highest NDVI value on each pixel over an image collection for January to May (i.e., in the rainy season), the least-greenest image is obtained by taking the lowest NDVI value on each pixel over an image collection for June to December (i.e., in the dry season), and the tree-cover loss accumulation image is calculated by subtracted by the greenest image with the least-greenest image. The example of these images are shown in Figure 3.3.

For the greenest and least-greenest images, the greener the color means that the higher the NDVI value for a given pixel. As for the tree-cover loss accumulation image, a red color means a positive value (a decreasing NDVI value) that could be assumed as a tree-cover loss, whereas a black color means a negative value (an increasing NDVI value) that could be assumed as a tree-cover gain. Thus, the tree-cover loss accumulation could be used to understand the forest loss dynamic on each AOI for each year. However, another methods or interpretation strategies are necessary in order to take advantage of these images for the future script development.

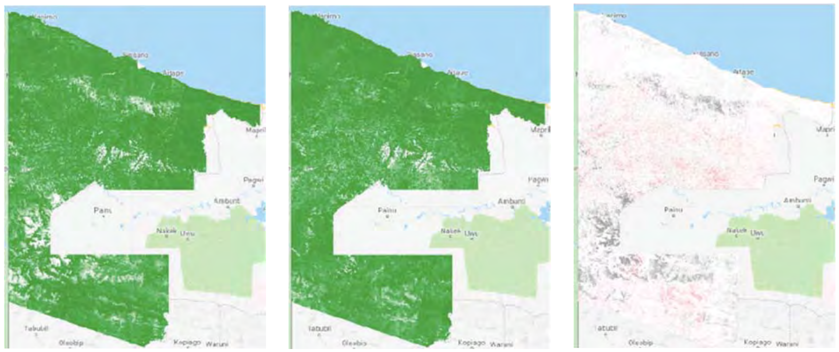
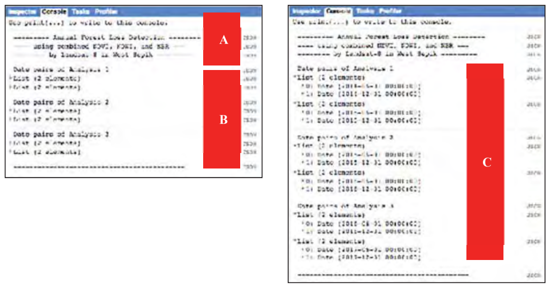


Figure 3.3 The greenest (left), least-greenest (center), and the tree-cover loss accumulation (right) images for West Sepik Province in 2014.

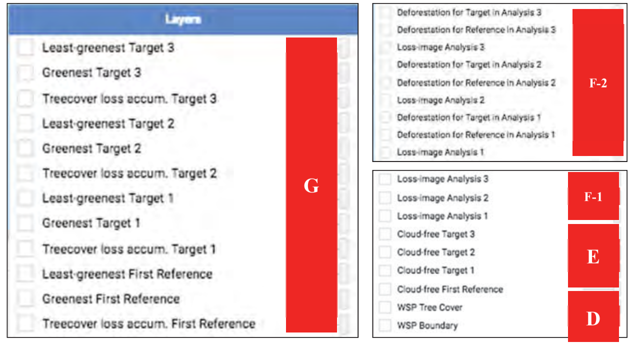
3.3.2.1.6 The printed and displayed outputs

The brief explanation of the printed outputs by the Landsat-8 annual forest loss detection script in the GEE Console are listed as follows:



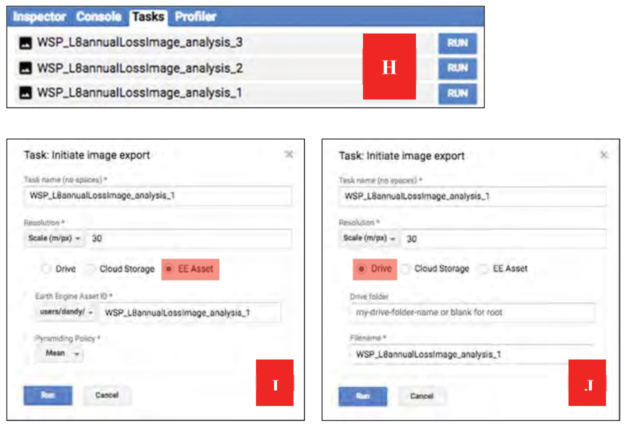
The **A** section displays the title of the script, including the forest loss analyzed method being selected, the name of the sensor being used, and name of the AOI being analyzed. The **B** section displays lists of date pair of the REFERENCE and TARGET IMAGE for all analyses. In a list of date pair, the upper list shows the date of a REFERENCE IMAGE (start date and end date) and the lower list shows the date of a TARGET IMAGE (start date and end date). The number of lists of date pair is depend on the number of TARGET IMAGES. Users are recommended to click the zippy symbol (‣) to see the detail information of a list of date pair as shown in the section **C**.

Furthermore, the brief explanation of the displayed outputs by the Landsat-8 annual forest loss detection script in the GEE Map's layers are listed as follows:



The **D** section is the boundary of the selected AOI (*AOI_name* Boundary) and the tree-cover map that derived from the Global Forest Change data for the selected AOI (*AOI_name* Tree Cover). The **E** section is the cloud-free image collections for the FIRST REFERENCE IMAGE and for each TARGET IMAGE, please check the box to display a cloud-free image to the GEE Map (R: SWIR1; G: NIR; B: RED). The **F-1** section would be appear if the combination of NDVI, NDWI, and NBR is selected as the forest loss analysis method, this section is associated with the loss-image collections for each analysis, please check the box to display a loss-image to the Map. The **F-2** section would be appear if the integration of SMA and NDFI is selected as the forest loss analysis method, this section is associated with the loss-image, the deforestation image for the REFERENCE IMAGE and the deforestation for the TARGET IMAGE for each analysis, please check the box to display these images to the Map. In a loss-image, forest loss areas are shown in red color. Meanwhile, the deforestation areas are shown in orange and dark blue for the deforestation image for the REFERENCE IMAGE and the deforestation for the TARGET IMAGE, respectively. The **G** section is the tree-cover loss accumulation, greenest, least-greenest images for each year in the investigation period.

Finally, in order to proceed the export options to user's Asset in GEE and/or to user's Google Drive account, please make sure to click the 'Run' button in the Tasks tab as shown below:



The **H** section is a list of loss-image collections waited to be exported to either user's Asset in GEE or user's Google Drive account, users are kindly requested to click the 'Run' button to proceed export. By clicking the 'Run' button, the **I** section would be appear for exporting to user's Asset in GEE option, while the **J** section would be appear for exporting to user's Google Drive account. Please kindly check and confirm the details on the box before clicking the 'Run' button.

3.3.2.2 Regarding the "Sentinel-2 Annual Forest Loss Detection for Papua New Guinea (Version 2018.09.17)" script

3.3.2.2.1 The main structure of the script

This script is intended to detect the annual forest loss areas for two AOIs in Papua New Guinea by using Sentinel-2 images. The script is divided into eight parts, which are: *(1) Input Commands, (2) Parameters Collections, (3) Parameters for Investigation Periods, (4) Cloud-free Functions, (5) Image Collections, (6) Forest Loss Analysis, (7) Compare Greenest and Least Greenest,* and *(8) Parameters for Export Images.*

Part 1 consists of all input commands (14 in total) that should be defined by the user in order to run the script. These commands include the duration of investigation periods for the reference and target images, the total amount of target images to be used for the forest loss analysis, the AOI selection, the option of methods to be used for cloud/haze elimination purposes, the option to show the cloud-free to the GEE Map, the option of methods to be used for forest loss analysis purposes, the definition of threshold value, the option to show the loss-image to the GEE Map, the option to generate greenest, least-greenest and tree-cover loss accumulation images, and options to export the loss-images to user's Asset and/or Google Drive. In the end of this part, there is an information of the additional feature to calculate forest loss areas by using the dedicated loss-area calculation script. The script for calculating forest loss areas is being separated from the forest loss detection script to obtain a better performance (i.e., GEE memory usage and computation time) on each script.

Part 2 comprises the collection of general parameters that being used in the script. These parameters include the definition of image collections, date formatting for the investigation period, conditional functions for the selected AOI, conditional functions for the selected method for forest loss analysis, command to print the script's title to the GEE Console, masking for tree-cover in the selected study area that was derived from the Global Forest Change data, collection of visual parameters, and command to display the boundary of the selected AOI and the tree-cover to the GEE Map.

Part 3 associated with functions to derive start and end dates for each reference and target images, based on the user's input in Part 1. Furthermore, these dates are listed in the list for each pair of reference and target images. Lastly, there is a command to print the list of date pairs for each forest loss analysis to the GEE Console.

Part 4 collects functions to generate cloud-free image by using the selected cloud/haze elimination method. In this script, there are three available cloud/haze elimination methods, which are the greenest-pixel

method, the QA band method and the cloud-shadow masking method. The greenest-pixel method applies Normalized Difference Vegetation Index (NDVI) values of an image collection to obtain the highest NDVI value on each pixel that is assumed as the cloud-free pixel. Meanwhile, the QA band method utilizes the cloud and cirrus flags derived from Sentinel-2 QA band to mask cloudy pixels over an image collection. Furthermore, the cloud-shadow method employs the spectral information on BLUE and WATER VAPOR bands to mask cloudy pixels and utilizing the combination of MEAN SOLAR AZIMUTH ANGLE and MEAN SOLAR ZENITH ANGLE information on the metadata to mask the potential shadow areas.

Part 5 consists of commands to obtain cloud-free images for all reference and target images in the investigation period by using functions that defined in the previous parts. Furthermore, there is a conditional function to display the cloud-free image collection to the GEE Map.

Part 6 comprises functions to analyze forest loss by utilizing the selected forest loss analysis method. In this script, there are two forest loss analysis methods, which are the combination of NDVI, NDWI, and NBR method and the integration of SMA and NDFI method. The first method analyzes the difference between NDVI, NDWI, and NBR images for a given reference and target images, so that a decreasing value of those three indices at a given area or pixel that is greater than the given threshold value would be considered as forest loss. Meanwhile, the second method utilizes SMA-derived fraction images for generating NDFI image for a given reference and target image, so that a decreasing value of NDFI at a given area or pixel that is greater than the given threshold value would be considered as forest loss. Lastly, there is a command to display loss-image collection to GEE Map, as well as the deforestation images of each reference and target image for the integration of SMA and NDFI method.

Part 7 associated with the function to derive the greenest and least-greenest images. The cloud-shadow masking method is being used as the default cloud/haze elimination method for generating the greenest and least-greenest images due to its better performance as compared to the other methods. Furthermore, the greenest image is subtracted by the least-greenest image to generate the accumulation of tree-cover loss for each year. Lastly, there is a command to display the greenest, least-greenest, and the tree-cover loss accumulation images to the GEE Map.

Part 8 collects function to export the loss-image collection to user's Asset in GEE, user's Google Drive account, or to both of them. The exported loss-image would have a pixel size of 10 meter and a Universal Transverse Mercator (UTM) WGS84 projection.

3.3.2.2.2 Brief analysis for cloud/haze elimination methods

In this script, there are three available cloud/haze elimination methods, which are the greenest-pixel method, the QA band method and the cloud-shadow masking method. In order to analyze the performance of each method, visual interpretation of the derived cloud-free image by each method was taken (Figure 3.4).

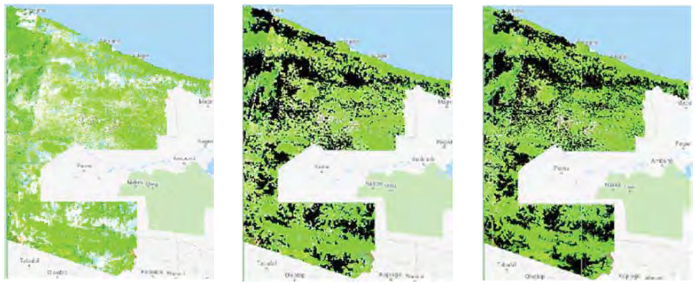


Figure 3.4 The cloud-free image of 2015 (black-colored areas are masked cloud and/or shadow areas) derived by using the greenest-pixel method (left), the QA band method (center), and the cloud-shadow masking method (right).

In fact, the Sentinel-2A satellite was launched on June, 23rd 2015, so that the image archive for 2015 is very limited. Thus, the cloud-free image of 2015 derived by using the greenest-pixel image is seriously contaminated by cloud/haze. Meanwhile, cloud/haze-contaminated areas are successfully masked out from the image by using both the QA band and the cloud-shadow masking method. Moreover, the cloud-free image derived by using cloud-shadow masking method yielded more consistent image quality and produced more cloud-free areas.

In addition to the visual interpretation, the usage of CPU time and memory for each method was also analyzed. In GEE setting, there is an additional performance profiling tabs that could be enabled and shown. This Profiler tab displays information about the resources (CPU time, memory) consumed by specific algorithms and other parts of a computation. Thus, the cloud-shadow masking method is using the least memory as compared to the other method (Figure 3.5). A more efficient method would allow more memory space to be use by other algorithm so that could lead to a better performance. Thus, in this script, the cloud-shadow masking method is set to be the default cloud/haze elimination method due to its better performance as compared to the other methods.

Figure 3.5 The memory usage of the greenest-pixel method (left), the QA band method (center), and the cloud-shadow masking method (right).

3.3.2.2.3 Brief analysis for forest loss analyses methods

In this script, there are two forest loss analysis methods, which are the combination of NDVI, NDWI, and NBR method and the integration of SMA and NDFI method. In order to objectively analyze the performance

of each method, accuracy assessment of the derived loss area by each method was taken. The truth data obtained from the Global Forest Change Version 1.5 (https://earthenginepartners.appspot.com/science-2013-global-forest/download_v1.5.html) were used for the accuracy assessment purposes. Furthermore, three threshold values with a fraction of one digit after the comma (i.e., tIndex = 0.1; tIndex = 0.2; and tIndex = 0.3) were tested and analyzed to obtain the optimum threshold value on each AOI for each method.

Table 3.5 Sentinel-2 Annual Forest Loss Detection for West Sepik Province (NDVI, NDWI, NBR Method)

Image ID	Analysis	Annual Forest Loss (sq. Km)	Forest lossyear data from Global Forest Change (sq. Km)	Absolute Difference
Threshold Value (tIndex) = 0.1				
WSP_S2annualLossImage_analysis_1	Forest Loss in 2016 (Forest Area 2015- Forest Area 2016)	1561.85	136.37	1425.48
WSP_S2annualLossImage_analysis_2	Forest Loss in 2017 (Forest Area 2016- Forest Area 2017)	1101.27	131.87	969.40
			Mean Absolute Difference	**1197.44**
Threshold Value (tIndex) = 0.2				
WSP_S2annualLossImage_analysis_1	Forest Loss in 2016 (Forest Area 2015- Forest Area 2016)	265.97	136.37	129.60
WSP_S2annualLossImage_analysis_2	Forest Loss in 2017 (Forest Area 2016- Forest Area 2017)	146.88	131.87	15.01
			Mean Absolute Difference	**72.31**
Threshold Value (tIndex) = 0.3				
WSP_S2annualLossImage_analysis_1	Forest Loss in 2016 (Forest Area 2015- Forest Area 2016)	28.28	136.37	108.09
WSP_S2annualLossImage_analysis_2	Forest Loss in 2017 (Forest Area 2016- Forest Area 2017)	22.84	131.87	109.03
			Mean Absolute Difference	**108.56**

Table 3.6 Sentinel-2 Annual Forest Loss Detection for West Sepik Province (SMA and NDFI Method)

Image ID	Analysis	Annual Forest Loss (sq. Km)	Forest lossyear data from Global Forest Change (sq. Km)	Absolute Difference
Threshold Value (tIndex) = 0.1				
WSP_S2annualLossImage_analysis_1	Forest Loss in 2016 (Forest Area 2015- Forest Area 2016)	1786.57	136.37	1650.20
WSP_S2annualLossImage_analysis_2	Forest Loss in 2017 (Forest Area 2016- Forest Area 2017)	1304.22	131.87	1172.35
			Mean Absolute Difference	**1411.28**
Threshold Value (tIndex) = 0.2				
WSP_S2annualLossImage_analysis_1	Forest Loss in 2016 (Forest Area 2015- Forest Area 2016)	1744.88	136.37	1608.51
WSP_S2annualLossImage_analysis_2	Forest Loss in 2017 (Forest Area 2016- Forest Area 2017)	1253.60	131.87	1121.73
			Mean Absolute Difference	**1365.12**
Threshold Value (tIndex) = 0.3				

WSP_S2annualLossImage_analysis_1	Forest Loss in 2016 (Forest Area 2015- Forest Area 2016)	1717.38	136.37	1581.01
WSP_S2annualLossImage_analysis_2	Forest Loss in 2017 (Forest Area 2016- Forest Area 2017)	1222.59	131.87	1090.72
			Mean Absolute Difference	**1335.87**

The result of accuracy assessment for Sentinel-2 annual forest loss detection script for West Sepik Province by using the combination of NDVI, NDWI, and NBR method is shown in Table 3.5, whereas those using the integration of SMA and NDFI is provided in Table 3.6. Thus, the best accuracy for West Sepik Province by using the combination of NDVI, NDWI, and NBR method was yielded by using the threshold value of *0.2* as well as resulted the lowest mean absolute difference with the truth data (Mean Absolute Difference = *72.31*; Highlighted in green). Thus, the optimum threshold value for West Sepik Province by using the combination of NDVI, NDWI, and NBR method is *0.2*. Meanwhile, the best accuracy for West Sepik Province by using the integration of SMA and NDFI method was yielded by using the threshold value of *0.3* as well as resulted the lowest mean absolute difference with the truth data (Mean Absolute Difference = *1335.87*; Highlighted in green). Thus, the optimum threshold value for West Sepik Province by using the integration of SMA and NDFI method is *0.3*. Finally, by comparing the best accuracy obtained by both forest loss analysis methods for West Sepik Province, the combination of NDVI, NDWI, and NBR yielded a better performance as compared to those derived by the other method.

Table 3.7 Sentinel-2 Annual Forest Loss Detection for West New Britain Province (NDVI, NDWI, NBR Method)

Image ID	Analysis	Annual Forest Loss (sq. Km)	Forest lossyear data from Global Forest Change (sq. Km)	Absolute Difference
Threshold Value (tIndex) = 0.1				
WNB_S2annualLossImage_analysis_1	Forest Loss in 2016 (Forest Area 2015- Forest Area 2016)	769.97	98.26	671.71
WNB_S2annualLossImage_analysis_2	Forest Loss in 2017 (Forest Area 2016- Forest Area 2017)	783.17	73.18	709.99
			Mean Absolute Difference	**690.85**
Threshold Value (tIndex) = 0.2				
WNB_S2annualLossImage_analysis_1	Forest Loss in 2016 (Forest Area 2015- Forest Area 2016)	121.41	98.26	23.15
WNB_S2annualLossImage_analysis_2	Forest Loss in 2017 (Forest Area 2016- Forest Area 2017)	114.90	73.18	41.72
			Mean Absolute Difference	**32.44**
Threshold Value (tIndex) = 0.3				
WNB_S2annualLossImage_analysis_1	Forest Loss in 2016 (Forest Area 2015- Forest Area 2016)	15.88	98.26	82.38
WNB_S2annualLossImage_analysis_2	Forest Loss in 2017 (Forest Area 2016- Forest Area 2017)	17.59	73.18	55.59
			Mean Absolute Difference	**68.99**

Table 3.8 Sentinel-2 Annual Forest Loss Detection for West New Britain Province (SMA and NDFI Method)

Image ID	Analysis	Annual Forest Loss (sq. Km)	Forest lossyear data from Global Forest Change (sq. Km)	Absolute Difference
Threshold Value (tIndex) = 0.1				
WNB_S2annualLossImage_analysis_1	Forest Loss in 2016 (Forest Area 2015- Forest Area 2016)	510.69	98.26	412.43
WNB_S2annualLossImage_analysis_2	Forest Loss in 2017 (Forest Area 2016- Forest Area 2017)	752.02	73.18	678.84
			Mean Absolute Difference	**545.64**
Threshold Value (tIndex) = 0.2				
WNB_S2annualLossImage_analysis_1	Forest Loss in 2016 (Forest Area 2015- Forest Area 2016)	496.76	98.26	398.50
WNB_S2annualLossImage_analysis_2	Forest Loss in 2017 (Forest Area 2016- Forest Area 2017)	729.83	73.18	656.65
			Mean Absolute Difference	**527.58**
Threshold Value (tIndex) = 0.3				
WNB_S2annualLossImage_analysis_1	Forest Loss in 2016 (Forest Area 2015- Forest Area 2016)	487.81	98.26	389.55
WNB_S2annualLossImage_analysis_2	Forest Loss in 2017 (Forest Area 2016- Forest Area 2017)	714.86	73.18	641.68
			Mean Absolute Difference	**515.62**

Furthermore, the result of accuracy assessment for Sentinel-2 annual forest loss detection script for West New Britain Province by using the combination of NDVI, NDWI, and NBR method is shown in Table 3.7, whereas those using the integration of SMA and NDFI is provided in Table 3.8. Thus, the best accuracy for West New Britain Province by using the combination of NDVI, NDWI, and NBR method was yielded by using the threshold value of *0.2* as well as resulted the lowest mean absolute difference with the truth data (Mean Absolute Difference = *32.34*; Highlighted in green). Thus, the optimum threshold value for West New Britain Province by using the combination of NDVI, NDWI, and NBR method is *0.2*. Meanwhile, the best accuracy for West New Britain Province by using the integration of SMA and NDFI method was yielded by using the threshold value of *0.3* as well as resulted the lowest mean absolute difference with the truth data (Mean Absolute Difference = *515.62*; Highlighted in green). Thus, the optimum threshold value for West Sepik Province by using the integration of SMA and NDFI method is *0.3*. Finally, by comparing the best accuracy obtained by both forest loss analysis methods for West New Britain Province, the combination of NDVI, NDWI, and NBR yielded a better performance as compared to those derived by the other method.

3.3.2.2.4 Brief analysis for the greenest and least-greenest images

In this script, the greenest, least-greenest, and tree-cover loss accumulation for each year (except in 2015 due to there is no available Sentinel-2 images before June, 23rd 2015) in the investigation period were generated. The greenest image is obtained by taking the highest NDVI value on each pixel over an image collection for January to May (i.e., in the rainy season), the least-greenest image is obtained by taking the lowest NDVI value on each pixel over an image collection for June to December (i.e., in the dry season), and the tree-cover loss accumulation image is calculated by subtracted by the greenest image with the least-greenest image. The example of these images are shown in Figure 3.6.

For the greenest and least-greenest images, the greener the color means that the higher the NDVI value for a given pixel. As for the tree-cover loss accumulation image, a red color means a positive value (a decreasing NDVI value) that could be assumed as a tree-cover loss, whereas a black color means a negative value (an increasing NDVI value) that could be assumed as a tree-cover gain. Thus, the tree-cover loss accumulation could be used to understand the forest loss dynamic on each AOI for each year. However, another methods or interpretation strategies are necessary in order to take advantage of these images for the future script development.

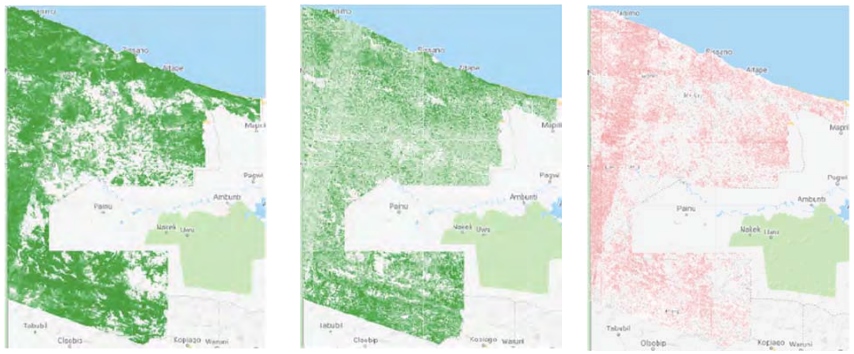
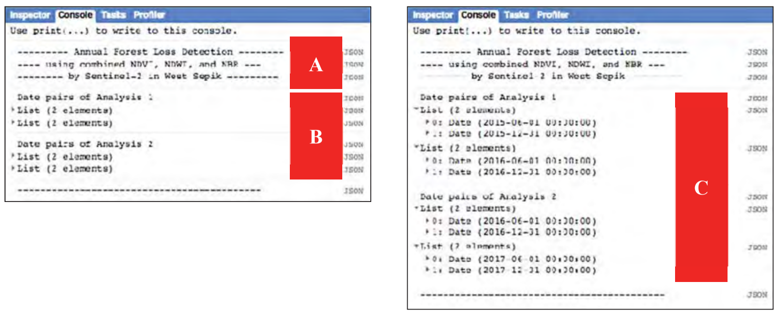


Figure 3.6 The greenest (left), least-greenest (center), and the tree-cover loss accumulation (right) images for West Sepik Province in 2016.

3.3.2.2.5 The printed and displayed outputs

The brief explanation of the printed outputs by the Sentinel-2 annual forest loss detection script in the GEE Console are listed as follows:

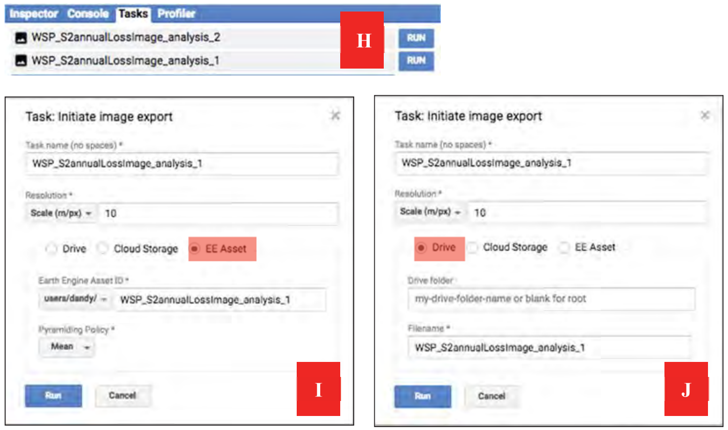


The **A** section displays the title of the script, including the forest loss analyzed method being selected, the name of the sensor being used, and name of the AOI being analyzed. The **B** section displays lists of date pair of the REFERENCE and TARGET IMAGE for all analyses. In a list of date pair, the upper list shows the date of a REFERENCE IMAGE (start date and end date) and the lower list shows the date of a TARGET IMAGE (start date and end date). The number of lists of date pair is depend on the number of TARGET IMAGES. Users are recommended to click the zippy symbol (▸) to see the detail information of a list of date pair as shown in the section **C**.

Furthermore, the brief explanation of the displayed outputs by the Sentinel-2 annual forest loss detection script in the GEE Map's layers are listed as follows:

The **D** section is the boundary of the selected AOI (*AOI_name* Boundary) and the tree-cover map that derived from the Global Forest Change data for the selected AOI (*AOI_name* Tree Cover). The **E** section is the cloud-free image collections for the FIRST REFERENCE IMAGE and for each TARGET IMAGE, please check the box to display a cloud-free image to the GEE Map (R: SWIR1; G: NIR; B: RED). The **F-1** section would be appear if the combination of NDVI, NDWI, and NBR is selected as the forest loss analysis method, this section is associated with the loss-image collections for each analysis, please check the box to display a loss-image to the Map. The **F-2** section would be appear if the integration of SMA and NDFI is selected as the forest loss analysis method, this section is associated with the loss-image, the deforestation image for the REFERENCE IMAGE and the deforestation for the TARGET IMAGE for each analysis, please check the box to display these images to the Map. In a loss-image, forest loss areas are shown in red color. Meanwhile, the deforestation areas are shown in orange and dark blue for the deforestation image for the REFERENCE IMAGE and the deforestation for the TARGET IMAGE, respectively. The **G** section is the tree-cover loss accumulation, greenest, least-greenest images for each year in the investigation period.

Finally, in order to proceed the export options to user's Asset in GEE and/or to user's Google Drive account, please make sure to click the 'Run' button in the Tasks tab as shown below:



The **H** section is a list of loss-image collections waited to be exported to either user's Asset in GEE or user's Google Drive account, users are kindly requested to click the 'Run' button to proceed export. By clicking the 'Run' button, the **I** section would be appear for exporting to user's Asset in GEE option, while the **J** section would be appear for exporting to user's Google Drive account. Please kindly check and confirm the details on the box before clicking the 'Run' button.

3.3.2.2 Regarding the "Sentinel-2 Weekly Forest Loss Detection for Papua New Guinea (Version 2018.09.17)" script

3.3.2.2.1 The main structure of the script

This script is intended to detect the weekly forest loss areas for two AOIs in Papua New Guinea by using Sentinel-2 images. The script is divided into eight parts, which are: *(1) Input Commands, (2) Parameters Collections, (3) Cloud-free Functions, (4) Parameters for First Reference Image, (5) Parameters for Target Image Collections, (6) Parameters for Continuous Reference Image Collections, (7) Forest Loss Analysis,* and *(8) Parameters for Export Images.*

Part 1 consists of all input commands (11 in total) that should be defined by the user in order to run the script. These commands include the duration of investigation periods for the FIRST REFERENCE IMAGE and TARGET IMAGES to be defined by the user, the total weeks of the TARGET IMAGES duration, the AOI selection, the option of methods to be used for cloud/haze elimination purposes, the option of methods to be used for forest loss analysis purposes, the definition of threshold value, and options to export the loss-images to user's Asset and/or Google Drive. In the end of this part, there is an information of the additional feature to calculate forest loss areas by using the dedicated loss-area calculation script. The script for

calculating forest loss areas is being separated from the forest loss detection script to obtain a better performance (i.e., GEE memory usage and computation time) on each script.

Part 2 comprises the collection of general parameters that being used in the script. These parameters include the definition of image collections, date formatting for the investigation period, conditional functions for the selected AOI, conditional functions for the selected method for forest loss analysis, command to print the script's title to the GEE Console, masking for tree-cover in the selected study area that was derived from the Global Forest Change data, collection of visual parameters, and command to display the boundary of the selected AOI and the tree-cover to the GEE Map.

Part 3 associated with functions to generate cloud-free image by using the selected cloud/haze elimination method. In this script, there are three available cloud/haze elimination methods, which are the greenest-pixel method, the QA band method and the cloud-shadow masking method. The greenest-pixel method for the Sentinel-2 weekly forest loss detection script includes with a function that would always change the start date of an image collection until it gets an image collection with the average cloud contamination is less than or equal to 10% or until all filters has been completed. Meanwhile, the QA band method utilizes the cloud and cirrus flags derived from Sentinel-2 QA band to mask cloudy pixels over an image collection. Furthermore, the cloud-shadow method employs the spectral information on BLUE and WATER VAPOR bands to mask cloudy pixels and utilizing the combination of MEAN SOLAR AZIMUTH ANGLE and MEAN SOLAR ZENITH ANGLE information on the metadata to mask the potential shadow areas.

Part 4 collects commands to display the duration of the FIRST REFERENCE IMAGE, to generate the cloud-free image for the FIRST REFERENCE IMAGE, and to display it to the GEE Map. Meanwhile, part 5 collects commands to display the duration of the TARGET IMAGES, to generate the cloud-free images for the TARGET IMAGES, and to display those images to the GEE Map. In part 6, the list of cloud-free image pair for each weekly forest loss analysis is constructed.

Part 7 comprises functions to analyze forest loss by utilizing the selected forest loss analysis method. In this script, there are two forest loss analysis methods, which are the combination of NDVI, NDWI, and NBR method and the integration of SMA and NDFI method. The first method analyzes the difference between NDVI, NDWI, and NBR images for a given reference and target images, so that a decreasing value of those three indices at a given area or pixel that is greater than the given threshold value would be considered as forest loss. Meanwhile, the second method utilizes SMA-derived fraction images for generating NDFI image for a given reference and target image, so that a decreasing value of NDFI at a given area or pixel that is greater than the given threshold value would be considered as forest loss. Lastly, there is a command to display loss-image collection to GEE Map, as well as the deforestation images of each reference and target image for the integration of SMA and NDFI method.

Part 8 collects function to export the loss-image collection to user's Asset in GEE, user's Google Drive account, or to both of them. The exported loss-image would have a pixel size of 10 meter and a Universal Transverse Mercator (UTM) WGS84 projection.

3.3.2.2.2 Brief analysis for cloud/haze elimination methods

In this script, there are three available cloud/haze elimination methods, which are the greenest-pixel method, the QA band method and the cloud-shadow masking method. In order to analyze the performance of each method, visual interpretation of the derived cloud-free image by each method was taken (Figure 3.7).

Figure 3.7 The cloud-free image for a weekly image from 2018-01-28 to 2018-02-04 (black-colored areas are masked cloud and/or shadow areas) derived by using the greenest-pixel method (left), the QA band method (center), and the cloud-shadow masking method (right).

In fact, the greenest-pixel method for Sentinel-2 weekly forest loss detection script applied a filter that could obtain image collection up to the previous ten weeks from the start date of the initial week. Thus, the cloud-free image for a weekly image from 2018-01-28 to 2018-02-04 derived by using the greenest-pixel image could obtain a relatively cloud-free image by the support that obtained from additional inputs of image collection from other duration. Meanwhile, cloud/haze-contaminated areas are successfully masked out from the image by using both the QA band and the cloud-shadow masking method by applying only one-week image collection without any support that obtained from additional inputs of image collection from other duration. Moreover, the cloud-free image derived by using cloud-shadow masking method yielded more cloud-free areas as compared to those derived by the QA band method.

In addition to the visual interpretation, the usage of CPU time and memory for each method was also analyzed. In GEE setting, there is an additional performance profiling tabs that could be enabled and shown. This Profiler tab displays information about the resources (CPU time, memory) consumed by specific algorithms and other parts of a computation. Thus, the cloud-shadow masking method is using the least memory as compared to the other method (Figure 3.8). Meanwhile, the greenest-pixel method is using a significantly large memory. A more efficient method would allow more memory space to be use by other algorithm so that could lead to a better performance. Thus, in this script, the cloud-shadow masking method is set to be the default cloud/haze elimination method due to its better performance as compared to the other methods.

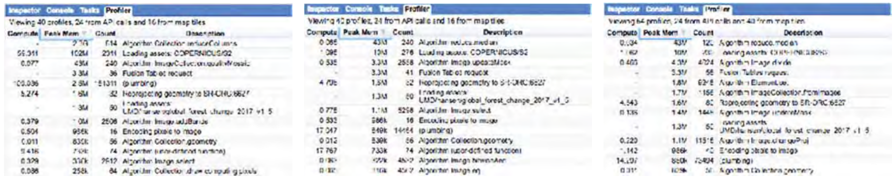


Figure 3.8. The memory usage of the greenest-pixel method (left), the QA band method (center), and the cloud-shadow masking method (right).

3.3.2.2.3 Brief analysis for forest loss analyses methods

In this script, there are two forest loss analysis methods, which are the combination of NDVI, NDWI, and NBR method and the integration of SMA and NDFI method. In order to objectively analyze the performance of each method, accuracy assessment of the derived loss area by each method was taken for the investigation period from 2018-02-04 to 2018-03-04, which is the period that obtained the best accuracy from the current Sentinel-2 weekly forest loss detection script. The truth data obtained from GLAD Alerts data within the Global Forest Watch website (https://www.globalforestwatch.org/map) were used for the accuracy assessment purposes. Furthermore, three threshold values with a fraction of one digit after the comma (i.e., tIndex = 0.1; tIndex = 0.2; and tIndex = 0.3) were tested and analyzed to obtain the optimum threshold value on each AOI for each method.

Table 3.9 Sentinel-2 Weekly Forest Loss Detection for West Sepik Province (NDVI, NDWI, NBR Method)

Reference Image		Target Image		Weekly Forest Loss (sq. Km)	GLAD Alert Weekly Forest Loss (sq. Km)	Absolute Difference
Start Date	End Date	Start Date	End Date			
Threshold Value (tIndex) = 0.1						
2018/1/28	2018/2/4	2018/2/4	2018/2/11	614.29	21.19	593.10
2018/2/4	2018/2/11	2018/2/11	2018/2/18	1631.35	25.93	1605.42
2018/2/11	2018/2/18	2018/2/18	2018/2/25	468.07	1.88	466.19
2018/2/18	2018/2/25	2018/2/25	2018/3/4	367.92	8.38	359.54
					Mean Absolute Difference	**756.06**
Threshold Value (tIndex) = 0.2						
2018/1/28	2018/2/4	2018/2/4	2018/2/11	161.06	21.19	139.87
2018/2/4	2018/2/11	2018/2/11	2018/2/18	248.68	25.93	222.75
2018/2/11	2018/2/18	2018/2/18	2018/2/25	62.85	1.88	60.97
2018/2/18	2018/2/25	2018/2/25	2018/3/4	28.11	8.38	19.73
					Mean Absolute Difference	**110.83**
Threshold Value (tIndex) = 0.3						
2018/1/28	2018/2/4	2018/2/4	2018/2/11	7.66	21.19	13.53
2018/2/4	2018/2/11	2018/2/11	2018/2/18	13.95	25.93	11.98
2018/2/11	2018/2/18	2018/2/18	2018/2/25	4.11	1.88	2.23
2018/2/18	2018/2/25	2018/2/25	2018/3/4	1.50	8.38	6.88

					Mean Absolute Difference	8.66

Table 3.10 Sentinel-2 Weekly Forest Loss Detection for West Sepik Province (SMA and NDFI Method)

Reference Image		Target Image		Weekly Forest Loss (sq. Km)	GLAD Alert Weekly Forest Loss (sq. Km)	Absolute Difference
Start Date	End Date	Start Date	End Date			
Threshold Value (tIndex) = 0.1						
2018/1/28	2018/2/4	2018/2/4	2018/2/11	1135.98	21.19	1114.79
2018/2/4	2018/2/11	2018/2/11	2018/2/18	865.95	25.93	840.02
2018/2/11	2018/2/18	2018/2/18	2018/2/25	259.67	1.88	257.79
2018/2/18	2018/2/25	2018/2/25	2018/3/4	73.31	8.38	64.93
					Mean Absolute Difference	569.38
Threshold Value (tIndex) = 0.2						
2018/1/28	2018/2/4	2018/2/4	2018/2/11	1114.90	21.19	1093.71
2018/2/4	2018/2/11	2018/2/11	2018/2/18	840.34	25.93	814.41
2018/2/11	2018/2/18	2018/2/18	2018/2/25	249.23	1.88	247.35
2018/2/18	2018/2/25	2018/2/25	2018/3/4	71.91	8.38	63.53
					Mean Absolute Difference	554.75
Threshold Value (tIndex) = 0.3						
2018/1/28	2018/2/4	2018/2/4	2018/2/11	1101.46	21.19	1080.27
2018/2/4	2018/2/11	2018/2/11	2018/2/18	824.12	25.93	798.19
2018/2/11	2018/2/18	2018/2/18	2018/2/25	243.44	1.88	241.56
2018/2/18	2018/2/25	2018/2/25	2018/3/4	71.05	8.38	62.67
					Mean Absolute Difference	545.67

The result of accuracy assessment for Sentinel-2 weekly forest loss detection script for West Sepik Province by using the combination of NDVI, NDWI, and NBR method is shown in Table 3.9, whereas those using the integration of SMA and NDFI is provided in Table 3.10. Thus, the best accuracy for West Sepik Province by using the combination of NDVI, NDWI, and NBR method was yielded by using the threshold value of *0.3* as well as resulted the lowest mean absolute difference with the truth data (Mean Absolute Difference = *8.66*; Highlighted in green). Thus, the optimum threshold value for West Sepik Province by using the combination of NDVI, NDWI, and NBR method is *0.3*. Meanwhile, the best accuracy for West Sepik Province by using the integration of SMA and NDFI method was yielded by using the threshold value of *0.3* as well as resulted the lowest mean absolute difference with the truth data (Mean Absolute Difference = *545.67*; Highlighted in green). Thus, the optimum threshold value for West Sepik Province by using the integration of SMA and NDFI method is *0.3*. Finally, by comparing the best accuracy obtained by both forest loss analysis methods for West Sepik Province, the combination of NDVI, NDWI, and NBR yielded a better performance as compared to those derived by the other method.

Table 3.11 Sentinel-2 Weekly Forest Loss Detection for West New Britain Province (NDVI, NDWI, NBR Method)

Reference Image		Target Image		Weekly Forest Loss (sq. Km)	GLAD Alert Weekly Forest Loss (sq. Km)	Absolute Difference
Start Date	End Date	Start Date	End Date			
Threshold Value (tIndex) = 0.1						
2017/12/31	2018/1/7	2018/1/7	2018/1/14	754.00	0.01	753.99
2018/1/7	2018/1/14	2018/1/14	2018/1/21	311.24	0.01	311.23
2018/1/14	2018/1/21	2018/1/21	2018/1/28	374.98	17.22	357.76
2018/1/21	2018/1/28	2018/1/28	2018/2/4	7.47	1.59	5.88
					Mean Absolute Difference	357.22
Threshold Value (tIndex) = 0.2						
2017/12/31	2018/1/7	2018/1/7	2018/1/14	203.38	0.01	203.37
2018/1/7	2018/1/14	2018/1/14	2018/1/21	46.32	0.01	46.31
2018/1/14	2018/1/21	2018/1/21	2018/1/28	83.26	17.22	66.04
2018/1/21	2018/1/28	2018/1/28	2018/2/4	0.93	1.59	0.66
					Mean Absolute Difference	79.10
Threshold Value (tIndex) = 0.3						
2017/12/31	2018/1/7	2018/1/7	2018/1/14	28.49	0.01	28.48
2018/1/7	2018/1/14	2018/1/14	2018/1/21	4.05	0.01	4.04
2018/1/14	2018/1/21	2018/1/21	2018/1/28	9.59	17.22	7.63
2018/1/21	2018/1/28	2018/1/28	2018/2/4	0.07	1.59	1.52
					Mean Absolute Difference	10.42

Table 3.12 Sentinel-2 Weekly Forest Loss Detection for West New Britain Province (SMA and NDFI Method)

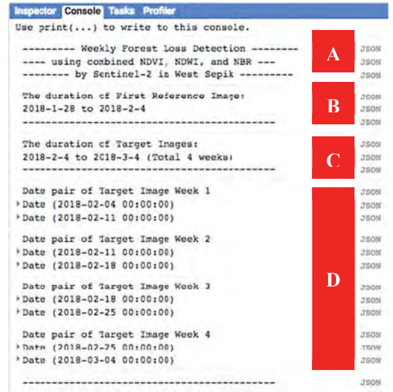
Reference Image		Target Image		Weekly Forest Loss (sq. Km)	GLAD Alert Weekly Forest Loss (sq. Km)	Absolute Difference
Start Date	End Date	Start Date	End Date			
Threshold Value (tIndex) = 0.1						
2017/12/31	2018/1/7	2018/1/7	2018/1/14	416.46	0.01	416.45
2018/1/7	2018/1/14	2018/1/14	2018/1/21	115.01	0.01	115.00
2018/1/14	2018/1/21	2018/1/21	2018/1/28	289.45	17.22	272.23
2018/1/21	2018/1/28	2018/1/28	2018/2/4	1.20	1.59	0.39
					Mean Absolute Difference	201.02
Threshold Value (tIndex) = 0.2						
2017/12/31	2018/1/7	2018/1/7	2018/1/14	407.48	0.01	407.47

2018/1/7	2018/1/14	2018/1/14	2018/1/21	111.53	0.01	111.52
2018/1/14	2018/1/21	2018/1/21	2018/1/28	286.42	17.22	269.20
2018/1/21	2018/1/28	2018/1/28	2018/2/4	1.19	1.59	0.40
					Mean Absolute Difference	**197.15**
Threshold Value (tIndex) = 0.3						
2017/12/31	2018/1/7	2018/1/7	2018/1/14	402.00	0.01	401.99
2018/1/7	2018/1/14	2018/1/14	2018/1/21	109.54	0.01	109.53
2018/1/14	2018/1/21	2018/1/21	2018/1/28	284.29	17.22	267.07
2018/1/21	2018/1/28	2018/1/28	2018/2/4	1.18	1.59	0.41
					Mean Absolute Difference	**194.75**

Furthermore, the result of accuracy assessment for Sentinel-2 weekly forest loss detection script for West New Britain Province by using the combination of NDVI, NDWI, and NBR method is shown in **Table 3.3**, whereas those using the integration of SMA and NDFI is provided in **Table 3.4**. Thus, the best accuracy for West New Britain Province by using the combination of NDVI, NDWI, and NBR method was yielded by using the threshold value of *0.3* as well as resulted the lowest mean absolute difference with the truth data (Mean Absolute Difference = *10.42*; Highlighted in green). Thus, the optimum threshold value for West New Britain Province by using the combination of NDVI, NDWI, and NBR method is *0.3*. Meanwhile, the best accuracy for West New Britain Province by using the integration of SMA and NDFI method was yielded by using the threshold value of *0.3* as well as resulted the lowest mean absolute difference with the truth data (Mean Absolute Difference = *194.75*; Highlighted in green). Thus, the optimum threshold value for West Sepik Province by using the integration of SMA and NDFI method is *0.3*. Finally, by comparing the best accuracy obtained by both forest loss analysis methods for West New Britain Province, the combination of NDVI, NDWI, and NBR yielded a better performance as compared to those derived by the other method.

3.3.2.2.4 The printed and displayed outputs

The brief explanation of the printed outputs by the Sentinel-2 weekly forest loss detection script in the GEE Console are listed as follows:

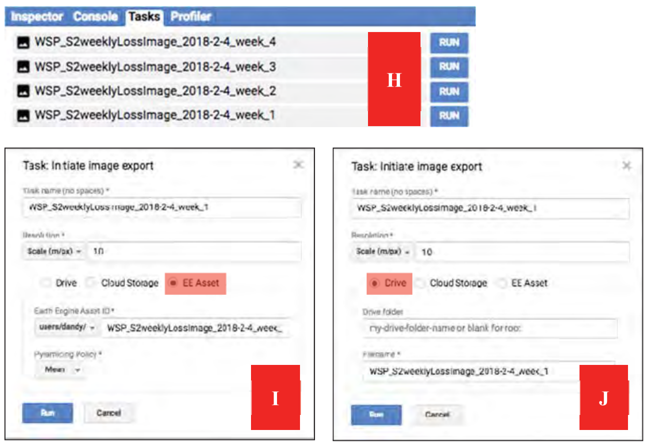


The **A** section displays the title of the script, including the forest loss analyzed method being selected, the name of the sensor being used, and name of the AOI being analyzed. The **B** section is the duration of FIRST REFERENCE IMAGE being selected for the analysis. The **C** section is the duration of TARGET IMAGES being selected for the analysis and the information of the TOTAL WEEKS. The **D** section is the weekly date pairs of the TARGET IMAGES duration. In a date pair, the upper date is the start date of a week (SUNDAY) and the lower date is the end date a week (the following SUNDAY). The number of date pairs is depend on the number of weeks in the TARGET IMAGES duration.

Furthermore, the brief explanation of the displayed outputs by the Sentinel-2 weekly forest loss detection script in the GEE Map's layers are listed as follows:

The **E** section is the boundary of the selected AOI (*AOI_name* Boundary) and the tree-cover map that derived from the Global Forest Change data for the selected AOI (*AOI_name* Tree Cover). The **F** section is the cloud-free image collections for the FIRST REFERENCE IMAGE and for each TARGET IMAGE, please check the box to display a cloud-free image to the GEE Map (R: SWIR1; G: NIR; B: RED). The **G-1** section would be appear if the combination of NDVI, NDWI, and NBR is selected as the forest loss analysis method, this section is associated with the loss-image collections for each analysis, please check the box to display a loss-image to the Map. The **G-2** section would be appear if the integration of SMA and NDFI is selected as the forest loss analysis method, this section is associated with the loss-image, the deforestation image for the REFERENCE IMAGE and the deforestation for the TARGET IMAGE for each analysis, please check the box to display these images to the Map. In a loss-image, forest loss areas are shown in red color. Meanwhile, the deforestation areas are shown in orange and dark blue for the deforestation image for the REFERENCE IMAGE and the deforestation for the TARGET IMAGE, respectively.

Finally, in order to proceed the export options to user's Asset in GEE and/or to user's Google Drive account, please make sure to click the 'Run' button in the Tasks tab as shown below:



The **H** section is a list of loss-image collections waited to be exported to either user's Asset in GEE or user's Google Drive account, users are kindly requested to click the 'Run' button to proceed export. By clicking the 'Run' button, the **I** section would be appear for exporting to user's Asset in GEE option, while the **J** section would be appear for exporting to user's Google Drive account. Please kindly check and confirm the details on the box before clicking the 'Run' button.

3.4 Conclusion

The present chapter has been successfully updated the annual and weekly forest loss detection systems to adapt circumstances in Papua New Guinea based on the clarified issues encountered in the assessment process of the current scripts. The conclusion of this chapter is listed as follows:

a. Regarding cloud/haze elimination methods, the simple composite method could be used in the updated Landsat-8 annual forest loss detection system. Meanwhile, the QA band and the cloud-shadow masking methods could be used in the updated Sentinel-2 annual and weekly forest loss detection systems.
b. As for the integration of SMA and NDFI method, predetermined spectral endmember library could be used to develop fraction images for generating NDFI image.
c. Regarding the greenest and least-greenest method, the NDVI could be used as the index to define the level of greenest or least-greenest for a given pixel.
d. As for the threshold value, an optimum threshold value for a forest loss detection script is defined as a threshold value that produces the lowest difference of forest loss areas as compared to those derived by the truth data.
e. The simple composite method was added in the updated Landsat-8 annual forest loss detection system to overcome the key issue.
f. The simple composite method is using less memory as compared to the greenest-pixel method so that it was set as the default method for Landsat-8 annual forest loss detection system.
g. The QA band and cloud-shadow masking methods were added in the updated Sentinel-2 annual and weekly forest loss detection systems to overcome the key issue.
h. The cloud-shadow masking method was set to be the default cloud/haze elimination method due to its better performance as compared to the other methods.
i. The integration of SMA and NDFI was added in the updated annual and weekly forest loss detection systems.
j. The brief analysis of the performances of the integration of SMA and NDFI method is compiled.
k. Commands to generate greenest and least-greenest images were added in the updated Landsat-8 and Sentinel-2 annual forest loss detection systems.
l. The greenest, least-greenest, and tree-cover loss accumulation images for each year in the investigation period were derived in the updated Landsat-8 and Sentinel-2 annual forest loss detection systems.
m. Three threshold values with a fraction of one digit after the comma (i.e., tIndex = 0.1; tIndex = 0.2; and tIndex = 0.3) would be tested and analyzed on each AOI for each script.
n. The recommended threshold value on each AOI for each script are obtained.

Chapter 4
Develop a monitoring system for selective logging concessions utilizing the Google Earth Engine technology

4.1 Background

The capabilities of the previously developed scripts (i.e., the annual and weekly forest loss detection system utilizing Landsat-8 and Sentinel-2 imagery developed for the other country) have been updated to adapt circumstances in Papua New Guinea based on the clarified issues encountered in the assessment process. Therefore, annual and weekly forest loss detection systems for selective logging concessions would be developed based on the updates that have been applied in the previous scripts.

The main focus of this chapter is to develop a monitoring system for detecting deforestations in selective logging concessions in Papua New Guinea by using remote sensing application on the Google Earth Engine platform as early as and as accurate as possible.

On the other hand, as additional information to the development of future scripts, collecting information on remote sensing applications that are using Jacobs Index (Jacobs 1974) in their analysis would be done in parallel (i.e., at an early stage). Jacobs Index is initially proposed as an index to measure food selection (or selective feeding) that is independent of the relative abundance, and reflect directly differential mortality rates.

Furthermore, to be more objective and confident to assess cloud/haze elimination methods to be applied in the development of future scripts, accuracy assessment would be carried out for each cloud/haze elimination method, i.e., [1] dark-object subtraction (DOS) (this method would be performed if there is no disclosure to reproduce the method and if the method could be implemented as a Google Earth Engine script); [2] Fmask algorithm; and [3] QA band method. In this assessment, a total of 100 points would be randomly generated as evaluation points for the accuracy assessment purposes, which allocates the cloudy and cloudless areas in a given area of interest.

Finally, the integration of cloud/haze/shadow mask and the least Normalized Difference Vegetation Index (NDVI), the implementation of loss area calculation script, as well as the consideration to calculate the loss area per 1 km grid would be added to the development of the future scripts.

4.2 Objectives

The objectives of this chapter are listed as follows:

1. to collect information on remote sensing applications that are using Jacobs Index in their analysis and organize a list of references that includes document names and their brief summaries,
2. to conduct and analyze accuracy assessment procedure for each cloud/haze elimination method, i.e., [1] DOS; [2] Fmask algorithm; and [3] QA band method,

3. to apply the integration of cloud/haze/shadow mask and the least NDVI, the implementation of loss area calculation script, as well as the consideration to calculate the loss area per 1 km grid to the development of the future scripts,
4. to apply the best cloud/haze elimination method based on the result of the accuracy assessment procedure in the forest loss detection systems for the Annual and Weekly Forest Loss Detection systems for selective logging concessions in Papua New Guinea,
5. to apply the integration of cloud/haze/shadow mask and the least NDVI, the implementation of loss area calculation script, as well as the consideration to calculate the loss area per 1 km grid in the forest loss detection systems for the Annual Forest Loss Detection systems for selective logging concessions in Papua New Guinea.

4.3 Outputs and Results

4.3.1 List of references on remote sensing applications that are using Jacobs Index

This part describes brief information on remote sensing applications that are using Jacobs Index in their analyses and organize it into a list of references that includes document names and their brief summaries. The information described below was mainly extracted from research papers due to those applied or embedded in public Google Earth Engine scripts was not available. Furthermore, remote sensing applications that are using Jacobs Index in their analyses are varied from wildfire analyses to animal conservation analyses. The details of the information are listed as follows:

a. **Reference:** Barros, A.M.G, and Pereira, J.M.C. Wildfire Selectivity for Land Cover Type: Does Size Matter?. *PLoS ONE*. 2014, 9(1): e84760. doi:10.1371/journal.pone.0084760

Summary: The present study aims to determine how selectivity responds to increasing fire size, for different land cover types by using the quantile regression. The annual fire perimeter maps from 1990 to 1994 were generated by using semi-automatic supervised classification of single-date post-fire season Landsat images, performed with Classification and Regression Trees (CART) algorithm. This study relied primarily on near-infrared and mid-infrared bands so that atmospheric correction procedures were able to be avoided. However, relative radiometric calibration for eight Landsat images was performed for each observation year to derive the mosaic image that covering the entire mainland of Portugal to ensure consistent performance of the image classification rules produced with CART. In this study, the Jacobs Index was applied to assess the differential degree of burning of land cover types fire. The analogy of using Jacobs Index for fire selectivity is that the spatial location of an ignition is the higher order process that conditions the type, amount and accessibility of land cover available, once that ignition becomes a spreading fire. Jacobs Index was derived based on the proportion of each type of land cover that is used by and available to a fire in the study area. The index value ranges between -1 (for an extreme avoidance) to 1 (for an extreme preference), and taking the value 0 for an indifference. The obtained ranking for land cover types according to fire proneness, from less to most fire prone is: annual crops (D = - 0.78), evergreen oak woodlands (D = - 0.53), eucalypt plantations (D = - 0.38), pine stands (D = 0.11) and shrublands (D = 0.35). To conclude, land cover proneness to fire is higher for shrublands and pine forests than for annual crops and evergreen oak woodlands. However, as fire size increases, selectivity decreases for all examined land cover types.

b. **Reference:** Paudel, P.K., Hais, M., and Kindlmann, P. Habitat suitability models of mountain ungulates: identifying potential areas for conservation. *Zoological Studies*, 2015, 54, 37. doi: 10.1186/s40555-015-0116-9

Summary: This study aims to produce habitat suitability maps for three mountain ungulates (barking deer (*Muntiacus muntjak*), Himalayan goral (*Naemorhedus goral*) and Himalayan serow (*Capricornis thar*)) in the midhills of western Nepal by using four main environmental variables (i.e., slope and topographic ruggedness of the terrain, forest type and distance to the nearest village). Furthermore, locations of sightings and signs of presence of these mountain ungulates that collected during surveys along transect were used to derive a suitability value for each variable by using Jacobs index. Moreover, a multiplication approach was used to combine environmental variables and produce a habitat suitability map for each species. In this study, two cloud-free single-date Landsat ETM scenes taken on 25 December 2001 and 21 February 2003 were obtained. Both scenes were geometrically corrected and classified using a Maximum Likelihood classifier based on 146 training areas, which included 11 vegetation and two land use units. The accuracy of the image classification was evaluated using 783 validation points. Furthermore, ASTER Global Digital Elevation Model (ASTER GDEM) data were used to derive the terrain data. Topographic ruggedness was calculated using the VRM (vector ruggedness measure) that based on a geomorphological method for measuring vector dispersion that is less correlated with slope. The distance to the village map was derived by classifying forest area into five categories based on its proximity to the nearest village applying the existing land cover map of the study area. The Jacobs Index was calculated for each species and each category of environmental variable. The index value varies from 1 for maximum association to −1 for no association. For each species and each of environmental variables, a suitability map was constructed by the following procedures: (1) Each pixel of the study area was categorized into one of the five classes of habitat suitability according to the Jacobs Index value corresponding to this pixel and of environmental variables and species in question. (2) For each species, four suitability maps (one map for each environmental variables) were multiplied to create a single suitability map for the species. This study estimated that of the total area studied, 57% is suitable for *M. muntjak*, 67% for *N. goral* and 41% for *C. thar*. Although there are suitable habitats for all species throughout the study area, the availability of high-quality habitats for these species varied considerably. Moreover, suitable habitats for *N. goral* and *C. thar* were fragmented and mostly restricted to the southern and northern parts of the study area.

c. **Reference:** Dupuis-Desormeaux, M., Davidson, Z., Pratt, L., Mwololo, M., and MacDonald, S.E. Testing the effects of perimeter fencing and elephant exclosures on lion predation patterns in a Kenyan wildlife conservancy. *PeerJ*, 2016, 4, e1681. doi: 10.7717/peerj.1681

Summary: This study aims to investigate the effect of perimeter fencing on predation patterns in a semi-porous reserve, testing whether predators have learned to take advantage of perimeter fencing to increase hunting success, and to test whether predation events were over-represented either near or inside the exclosures. Furthermore, the spatial distribution of kills locations was mapped to examine whether lion predation patterns differed near the perimeter fencing and inside the elephant exclosures. The Jacobs Index was used in this study to derived prey selectivity index (PSI) in relation to the prey killed inside the exclosures versus available prey, and compared it to the selectivity index for lion kills outside of the exclosures. Jacobs index is calculated based on the proportion of the total kills for a particular species at the study site and the proportional availability of this prey species. Jacobs Index ranges from −1 to +1, where negative values represent relative avoidance (−1 being complete avoidance) and positive values represent relative preference (+1 being complete preference). Thus, the PSI inside the exclosures generally reflected the PSI outside the zones although there were some increases in the preferences for waterbuck and warthog and some decreases in the proportions of plains zebra and eland. Moreover, a supervised classification of the vegetation cover using Landsat 8 images was performed to better understand the role of vegetation in the exclosures. The supervised classification was matched with the ground plot survey data and five classes of vegetation cover were derived, ranging from grasslands (tree cover less than 2%) to forests (tree cover larger than 40%). Thus, the number of kills that fell within each zone was tabulated and compared with the actual kills versus expected kills given the area covered by each zone in order to get a better understanding of lion hunting habitat preferences. Furthermore, the vegetation cover and the number of lion kills in each vegetation cover class were analyzed. Out of the 628 lion kills, 619 could be associated with a distinctive class of vegetation. Kills were under-represented in both extreme types of cover, i.e., open grasslands and in forested areas. Kills were over-represented in mixed habitat, where tree cover ranged from 2% to 40%, i.e., in woody grassland, shrubland and woodland. In this study, the spatial analysis was used to compare the predation patterns near the perimeter fencing and inside the exclosures to predation in the rest of the conservancy. Predation was not over-represented near the perimeter fence but the pattern of predation near the fence suggests that fences may be a contributing factor to predation success. Overall, the study indicates that predation was over-represented inside and within 50 m of the exclosures.

d. **Reference:** Mutunga, K.C., Time series monitoring of bush encroachment by *Euclea Divinorum* in Ol Peseta Conservancy, Laikipia, Kenya. 2017. url: https://www.rufford.org/files/19422-1%20Detailed%20Final%20Report.pdf

Mutunga, K.C., Kinyanjui, M.J., and Kimanzi, J.K. Time Series Monitoring of Bush Encroachment by *Euclea divinorum* in Ol Pejeta Conservancy Laikipia, Kenya. *International Journal of Natural Resource Ecology and Management*.2017, 2(5), 85-93. doi: 10.11648/j.ijnrem.20170205.11

Summary: This study examined the land cover changes from 1987 to 2016, the topographic features attributable to those land cover changes, the differences in species diversity and composition in encroached and non-encroached habitats as well as habitat preference or avoidance by wild animals in the conservancy. Landsat-legacy (Landsat 5 TM, Landsat 7 ETM+, and Landsat 8 OLI) images were acquired during dry seasons in the year 1987, 1995, 2000, 2005, 2010 and 2016. Furthermore, these images were radiometrically normalized by converting Digital Number (DN) to Top-of-Atmosphere reflectance and followed by applying a Dark-object Subtraction (DOS) technique. Afterward, they were reprojected to Universal Transverse Mercator (UTM) WGS84 Zone 37N and classified into five land cover types by using a Maximum Likelihood classifier. The Jacobs Index was used to analyze the habitat (i.e., derived from the land cover classes) preference or avoidance by various feeding guilds (i.e., carnivores, grazers, browsers, and mixed feeders) found in the study area. Jacobs Index was calculated based on the proportion of observations on each type of habitat that is used by and available for each species in the study area. The index value ranges from -1 for avoidance, 0 for random selection, to 1 for preference. Eventually, the open-grassland habitat yielded the highest Jacobs Index means (D = 0.42), and the *Euclea divinorum* habitat obtained the lowest (D = - 0.79). To conclude, by using Jacobs Index means, it was found that all feeding guilds in the study area avoided habitats dominated by *Euclea divinorum* significantly while they prefer open-grassland dominated habitats.

e. **Reference:** Reilly, M.J., Elia, M., Spies, T.A., Gregory, M.J., Sanesi, G., and Lafortezza, R. Cumulative effects of wildfires on forest dynamics in the eastern Cascade Mountains, USA. *Ecological Applications*, 2018, 28(2), 291–308. doi: 10.1002/eap.1644

Summary: This study aims to assess the contribution of wildfire to forest dynamics across 4.25 million ha of forest in the Eastern Cascade Mountains of Oregon, Washington, and Northern California USA from 1985 to 2010 using imputed maps of forest structure (i.e., tree size and canopy cover) and remote sensing-derived burn severity maps. The regional burn severity maps were utilized to examine and compare temporal patterns of area burned and burn severity among the five landscapes: (1) all forest lands, the three major vegetation zones including the (2) ponderosa pine, (3) mixed conifer, and (4) subalpine zones, and (5) late successional reserves (LSRs). The burn severity maps were derived using the relative change in the Normalized Burn Ratio (RdNBR), which uses band 4 (near-infrared) and band 7 (shortwave-infrared) from Landsat 5 TM images. Moreover, the burn severity maps were classified with a thresholds scheme based on percent change in live basal area: low-severity (<25%), moderate-severity (25–75%), and high-severity (>75%) fires. In this study, the Jacobs Index was applied to determine how fire-prone landscapes (i.e., vegetation zones and LSRs) were compared to the region as a whole. Jacobs Index was derived based on the area burned in each landscape strata in relation to the respective abundance of each strata in the study region. The index values equal to zero when the class burns in proportion to its total extent. Negative values indicate that a class is burning less than expected given its availability, while positive values imply that a class is burning more than what expected given its availability. The Jacobs Index indicated that the ponderosa pine (D = - 0.33) and mixed conifer (D = - 0.11) zones were burning less than would be expected given their abundance in the region, while the subalpine zone (D = 0.57) had some of the highest Jacobs Index values. Overall, the study indicates that wildfires affected 10% of forests in the region, but the cumulative effects at this scale were primarily slight losses of closed-canopy conditions and slight gains in open-canopy conditions.

4.3.2 Accuracy assessment report of cloud/haze elimination methods for Landsat-8 and Sentinel-2 images

4.3.2.1 Regarding dark object subtraction (DOS)

- As the approach for the cloud/haze elimination that applied in their study, Hansen et al. (2016) was separately identified cloud cover, haze, water and shadow to create a pool of viable land observations by utilizing per-pixel quality assessment. On the assessment, a set of cloud, shadow and water detection models was used. As further describes in Potapov et al. (2012), the cloud, shadow and water detection models correspond to a set of classification tree models (i.e., Classification and Regression Tree or CART algorithm) derived from training data.
- For collecting training data, a set of Landsat images was selected in different parts of the tropical forest zone, and each classified to land, water, cloud, and shadow classes. Thus, from these images, 1% samples were randomly selected and used to create the generalized classification tree models. Afterward, these observations were put through the radiometric normalization to reduce reflectance variations between image dates due to atmospheric conditions and surface anisotropy. The bulk corrections for atmospheric effects were made by using the computationally simple dark object subtraction (DOS) method as the primary correction.
- The DOS is a type of image-based atmospheric corrections. Based on Chavez (1988) the basic assumption of DOS radiometric normalization technique is that within an image some pixels are in complete shadow and their radiances received at the satellite are due to atmospheric scattering (i.e., path radiance). This assumption is combined with the fact that very few targets on the Earth's surface are absolute black, so an assumed one-percent minimum reflectance is better than zero percent. The accuracy of image-based atmospheric corrections techniques is generally lower than physically based corrections, however, they are very useful when no *in situ* atmospheric measurements are available as they can improve the estimation of land surface reflectance.
- DOS reveals to be a technique for radiometric normalization to remove or reduce the impacts of atmospheric effects. As mentioned in Potapov et al. (2012), the DOS technique was applied after the CART-based per-pixel cloud/shadow/water screening quality assessment for reducing reflectance variations between image dates due to atmospheric conditions.
- An available DOS script that was initially written for Landsat 8 top-of-atmosphere (TOA) reflectance images was obtained from public GEE repository (URL: https://groups.google.com/d/msg/google-earth-engine-developers/BaaBxGMpR9k/mSVw8KTeCQAJ). The DOS algorithm described on that script could be converted to a GEE function and applied to future scripts development, further improving the reliability of the cloud-free image subsequent to the cloud/haze elimination procedure.

- As a note, DOS radiometric normalization technique is unnecessary to be applied if the atmospherically corrected surface reflectance image from data provider (e.g., the USGS Landsat 8 Surface Reflectance Tier 1 dataset) is being used in image analysis processes in order to avoid an over-correction. Therefore, in the development of the future scripts, the DOS radiometric normalization would only be applied to TOA reflectance Landsat-8 and Sentinel-2 images.
- A script was developed to tests the applicability of DOS radiometric normalization technique for Landsat-8 and Sentinel-2 composite images in Papua New Guinea. The DOS function would be added to the development of the future scripts and applied after the cloud/haze elimination procedure, as demonstrated in the Hansen et al. (2016) forest loss monitoring study. The URL of the script is as follow: https://code.earthengine.google.com/1b6749369ac55581316ccb67a38764b4

4.3.2.2 Regarding the accuracy assessment of cloud/haze elimination methods for Landsat-8

The QA band method (i.e., available in the following repository: *Examples/Cloud Masking/Landsat8 TOA Reflectance QA band*) and the CFMASK-derived QA band method (i.e., available in the following repository: *Examples/Cloud Masking/Landsat8 Surface Reflectance*) for Landsat-8 images were evaluated to understand their performances for eliminating cloud/haze in two area of interests (AOIs) in Papua New Guinea. Thus, a total of 100 points (50 points for cloudy areas and another 50 points for cloudless areas) were randomly generated and evaluated by applying visual interpretation on each AOI. These points were used as the “actual” points for the accuracy assessment purposes. Furthermore, the “predicted” points were derived from a cloud/haze elimination method. Afterward, a confusion matrix was computed by comparing the “actual" values and “predicted” values so that the accuracy indicators could be obtained. The accuracy indicators utilized in the current accuracy assessment procedure are the user’s accuracy (UA), producer’s accuracy (PA) and the overall accuracy (OA). Thus, the result of accuracy assessment of cloud/haze elimination methods for Landsat-8 in West Sepik Province and in West New Britain Province are presented in Table 4.1 and Table 4.2, respectively.

Table 4.1 Accuracy assessment result of cloud/haze elimination methods for Landsat-8 in West Sepik Province

URL: https://code.earthengine.google.com/90fac522ea20405f1ce0d6f9107cdbf5

Class (Class Value: Class Name)	User’s Accuracy (UA)	Producer’s Accuracy (PA)	Overall Accuracy (OA)
QA band method			
0: Cloudy areas	1	0.8	0.90
1: Cloudless areas	0.8333333333333334	1	
CFMASK-derived QA band method			
0: Cloudy areas	0.9772727272727273	0.86	0.92
1: Cloudless areas	0.875	0.98	

Table 4.2 Accuracy assessment result of cloud/haze elimination methods for Landsat-8 in West New Britain Province

URL: https://code.earthengine.google.com/4c72dd383493684268827e1a3a140da8

Class (Class Value: Class Name)	User’s Accuracy (UA)	Producer’s Accuracy (PA)	Overall Accuracy (OA)
QA band method			
0: Cloudy areas	1	0.6	0.80
1: Cloudless areas	0.7142857142857143	1	
CFMASK-derived QA band method			
0: Cloudy areas	1	0.68	0.84
1: Cloudless areas	0.7575757575757576	1	

As for the accuracy indicators of cloud/haze elimination methods for Landsat-8 in West Sepik Province, the CFMASK-derived QA band method yielded a slightly better performance (OA = 0.92) as compared to those derived by the QA band method (OA = 0.90). Meanwhile, as for the accuracy indicators of cloud/haze elimination methods for Landsat-8 in West New Britain Province, the CFMASK-derived QA band method also produced a moderately better performance (OA = 0.84) as compared to those derived by the QA band method (OA = 0.80). Therefore, based on this accuracy assessment result, the CFMASK-derived QA band method would be set as the default cloud/haze elimination method for the Landsat-8 annual forest loss detection systems for selective logging concessions in Papua New Guinea.

4.3.2.3 Regarding the accuracy assessment of cloud/haze elimination methods for Sentinel-2

The QA band method (i.e., available from the following URL: https://code.earthengine.google.com/65a2794f7920e4f0a94f7d8e7f0cdd6e) and the FMASK algorithm method (Zhu and Woodcock 2012; Zhu et al. 2015; and also available from the following URL: https://code.earthengine.google.com/9cbdbbb7d31ea8dd0bc15dac8f2d1dfe) for Sentinel-2 images were evaluated to analyze their performances for eliminating cloud/haze in two AOIs in Papua New Guinea. Thus, as those derived for the accuracy assessment of cloud/haze elimination methods for Landsat-8 images, a total of 100 points (50 points for cloudy areas and another 50 points for cloudless areas) were randomly generated and evaluated by applying visual interpretation on each AOI. These points were used as the "actual" points for the accuracy assessment purposes. Furthermore, the "predicted" points were derived from a cloud/haze elimination method. Afterward, a confusion matrix was computed by comparing the "actual" values and "predicted" values so that the accuracy indicators could be obtained. The accuracy indicators utilized in the current accuracy assessment procedure are the user's accuracy (UA), producer's accuracy (PA) and the overall accuracy (OA). Thus, the result of accuracy assessment of cloud/haze elimination methods for Sentinel-2 in West Sepik Province and in West New Britain Province are presented in Table 4.3 and Table 4.4, respectively.

Table 4.3 Accuracy assessment result of cloud/haze elimination methods for Sentinel-2 in West Sepik Province

URL: https://code.earthengine.google.com/b2bc4577715e7f1865d1cd70a706ab54

Class (Class Value: Class Name)	User's Accuracy (UA)	Producer's Accuracy (PA)	Overall Accuracy (OA)
QA band method			
0: Cloudy areas	0.967741935483871	0.6	0.79
1: Cloudless areas	0.7101449275362319	0.98	
FMASK-algorithm method			
0: Cloudy areas	1	0.62	0.81
1: Cloudless areas	0.7246376811594203	1	

Table 4.4 Accuracy assessment result of cloud/haze elimination methods for Sentinel-2 in West New Britain Province

URL: https://code.earthengine.google.com/873f8c6f634790421344712 38f17764e

Class (Class Value: Class Name)	User's Accuracy (UA)	Producer's Accuracy (PA)	Overall Accuracy (OA)
QA band method			
0: Cloudy areas	0.8305084745762712	0.98	0.89
1: Cloudless areas	0.975609756097561	0.8	
FMASK-algorithm method			
0: Cloudy areas	0.9772727272727273	0.86	0.92
1: Cloudless areas	0.875	0.98	

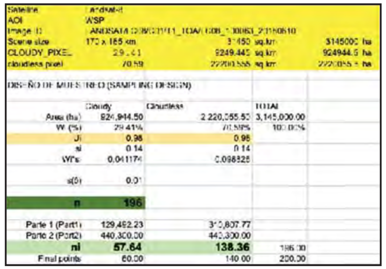
As for the accuracy indicators of cloud/haze elimination methods for Sentinel-2 in West Sepik Province, the FMASK-algorithm method yielded a slightly better performance (OA = 0.81) as compared to those derived by the QA band method (OA = 0.79). Meanwhile, as for the accuracy indicators of cloud/haze elimination methods for Sentinel-2 in West New Britain Province, the FMASK-algorithm method also produced a moderately better performance (OA = 0.92) as compared to those derived by the QA band method (OA = 0.89). Consequently, based on this accuracy assessment result, the FMASK-algorithm method would be set as the default cloud/haze elimination method for the Sentinel-2 annual and weekly forest loss detection systems for selective logging concessions in Papua New Guinea.

4.3.3 Accuracy assessment report of cloud/haze elimination methods with sampling design for Landsat-8 and Sentinel-2 images

4.3.3.1 Accuracy assessment of cloud/haze elimination methods for Landsat-8

The QA band method (i.e., available in the following GEE repository: *Examples/Cloud Masking/Landsat8 TOA Reflectance QA band*) and the CFMASK-derived QA band method (i.e., available in the following GEE repository: *Examples/Cloud Masking/Landsat8 Surface Reflectance*) for Landsat-8 images were evaluated to understand their performances for eliminating cloud/haze for a scene of Landsat-8 image that located within each area of interest (AOI) in Papua New Guinea. On this evaluation, a sampling design was used for calculating the number of sample size on each class to be used for the accuracy assessment procedure. The number of sample size for cloudy and cloudless areas for a Landsat-8 image in West

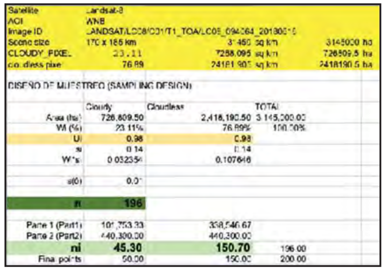
Sepik Province and in West New Britain Province computed by using the provided sample design are presented in Figure 4.1.



Satellite	Landsat-8		
AOI	WSP		
Image ID	[illegible]		
Scene size	170 x 185 km	31450 sq.km	3145000 ha
CLOUDY_PIXEL	29.41	9249.445 sq.km	924944.5 ha
cloudless pixel	70.59	22200.555 sq.km	[illegible] ha

DISEÑO DE MUESTREO (SAMPLING DESIGN)

	Cloudy	Cloudless	TOTAL
Area (ha)	924,944.50	2,220,055.50	3,145,000.00
Wi (%)	29.41%	70.59%	100.00%
Ui	0.98	0.98	
si	0.14	0.14	
Wi*si	0.041174	0.098825	
s(0)	0.01		
n	196		
Parte 1 (Part1)	129,492.23	310,807.77	
Parte 2 (Part2)	440,300.00	440,300.00	
ni	57.64	138.36	196.00
Final points	60.00	140.00	200.00



Satellite	Landsat-8		
AOI	WNB		
Image ID	LANDSAT/LC08/C01/T1_TOA/LC08_094064_2018[illegible]		
Scene size	170 x 185 km	31450 sq.km	3145000 ha
CLOUDY_PIXEL	23.11	7268.095 sq.km	726809.5 ha
cloudless pixel	76.89	24181.905 sq.km	2418190.5 ha

DISEÑO DE MUESTREO (SAMPLING DESIGN)

	Cloudy	Cloudless	TOTAL
Area (ha)	726,809.50	2,418,190.50	3,145,000.00
Wi (%)	23.11%	76.89%	100.00%
Ui	0.98	0.98	
si	0.14	0.14	
Wi*si	0.032354	0.107646	
s(0)	0.01		
n	196		
Parte 1 (Part1)	101,753.33	338,546.67	
Parte 2 (Part2)	440,300.00	440,300.00	
ni	45.30	150.70	196.00
Final points	50.00	150.00	200.00

Figure 4.1 The number of sample size for cloudy and cloudless areas for a Landsat-8 image in West Sepik Province (Left) and in West New Britain Province (Right) computed by using the provided sample design.

Afterwards, these points were randomly generated and evaluated by applying visual interpretation on each AOI. These points were used as the "actual" points for the accuracy assessment purposes. Furthermore, the "predicted" points were derived from a cloud/haze elimination method. Next, a confusion matrix was computed by comparing the "actual" values and "predicted" values so that the accuracy indicators could be obtained. The accuracy indicators utilized in the current accuracy assessment procedure are the user's accuracy (UA), producer's accuracy (PA) and the overall accuracy (OA). Thus, the result of accuracy assessment of cloud/haze elimination methods for a Landsat-8 image in West Sepik Province and in West New Britain Province are presented in Table 4.5 and Table 4.6, respectively.

Table 4.5 Accuracy assessment result of cloud/haze elimination methods for a Landsat-8 image in West Sepik Province

URL: https://code.earthengine.google.com/4b65728cac166b97d4541cad88ee7cad

Class (Class Value: Class Name)	User's Accuracy (UA)	Producer's Accuracy (PA)	Overall Accuracy (OA)
QA band method			
0: Cloudy areas	0.8450704225352113	1	0.95
1: Cloudless areas	1	0.9214285714285714	
CFMASK-derived QA band method			
0: Cloudy areas	1	1	1.00
1: Cloudless areas	1	1	

Table 4.6 Accuracy assessment result of cloud/haze elimination methods for a Landsat-8 image in West New Britain Province

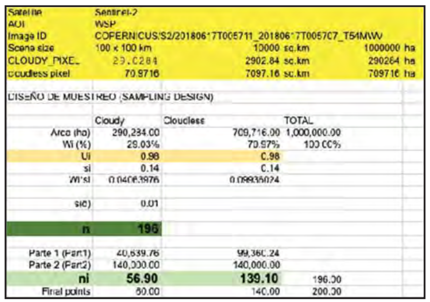
URL: https://code.earthengine.google.com/ec1675da64c183f5fcf833d0f249cae9

Class (Class Value: Class Name)	User's Accuracy (UA)	Producer's Accuracy (PA)	Overall Accuracy (OA)
QA band method			
0: Cloudy areas	0.8771929824561403	1	0.97
1: Cloudless areas	1	0.9533333333333334	
CFMASK-derived QA band method			
0: Cloudy areas	0.9387755102040817	1	0.98
1: Cloudless areas	1	0.9788732394366197	

As for the accuracy indicators of cloud/haze elimination methods for a Landsat-8 image in West Sepik Province, both method yielded similar PA (PA = 1.00) for the cloudy areas. However, the OA obtained by the CFMASK-derived QA band method was higher. Meanwhile, as for those in West New Britain Province, both method also yielded similar PA (PA = 1.00) for the cloudy areas. Nevertheless, the OA obtained by the CFMASK-derived QA band method was slightly better. Finally, the CFMASK-derived QA band method would be set as the default cloud/haze elimination method for the Landsat-8 annual forest loss detection systems for selective logging concessions in Papua New Guinea due to its better performance as compared to the other method.

4.3.3.2 Accuracy assessment of cloud/haze elimination methods for Sentinel-2

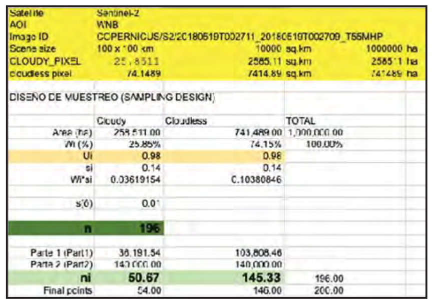
The QA band method (i.e., available from the following URL: https://code.earthengine.google.com/65a2794f7920e4f0a94f7d8e7f0cdd6e) and the FMASK algorithm method (Zhu and Woodcock 2012; Zhu et al. 2015; and also available from the following URL: https://code.earthengine.google.com/9cbdbbb7d31ea8dd0bc15dac8f2d1dfe) for Sentinel-2 images were evaluated to analyze their performances for eliminating cloud/haze for a scene of Sentinel-2 image that located within each AOI in Papua New Guinea. On this evaluation, a sampling design was used for calculating the number of sample size on each class to be used for the accuracy assessment procedure. The number of sample size for cloudy and cloudless areas for a Sentinel-2 image in West Sepik Province and in West New Britain Province computed by using the provided sample design are presented in Figure 4.2.



Satellite	Sentinel-2		
AOI	WSP		
Image ID	COPERNICUS/S2/20180617T005711_20180617T005707_T54MWV		
Scene size	100 x 100 km	10000 sq.km	1000000 ha
CLOUDY_PIXEL	29.0284	2902.84 sq.km	290284 ha
cloudless pixel	70.9716	7097.16 sq.km	709716 ha

DISEÑO DE MUESTREO (SAMPLING DESIGN)

	Cloudy	Cloudless	TOTAL
Area (ha)	290,284.00	709,716.00	1,000,000.00
Wi (%)	29.03%	70.97%	100.00%
Ui	0.98	0.98	
si	0.14	0.14	
Wi*si	0.04063976	0.09936024	
s(0)	0.01		
n	196		
Parte 1 (Part1)	40,639.76	99,360.24	
Parte 2 (Part2)	140,000.00	140,000.00	
ni	56.90	139.10	196.00
Final points	60.00	140.00	200.00



Satellite	Sentinel-2		
AOI	WNB		
Image ID	COPERNICUS/S2/20180519T002711_20180519T002709_T55MHP		
Scene size	100 x 100 km	10000 sq.km	1000000 ha
CLOUDY_PIXEL	25.8511	2585.11 sq.km	258511 ha
cloudless pixel	74.1489	7414.89 sq.km	741489 ha

DISEÑO DE MUESTREO (SAMPLING DESIGN)

	Cloudy	Cloudless	TOTAL
Area (ha)	258,511.00	741,489.00	1,000,000.00
Wi (%)	25.85%	74.15%	100.00%
Ui	0.98	0.98	
si	0.14	0.14	
Wi*si	0.03619154	0.10380846	
s(0)	0.01		
n	196		
Parte 1 (Part1)	36,191.54	103,808.46	
Parte 2 (Part2)	140,000.00	140,000.00	
ni	50.67	145.33	196.00
Final points	54.00	146.00	200.00

Figure 4.2 The number of sample size for cloudy and cloudless areas for a Sentinel-2 image in West Sepik Province (Left) and in West New Britain Province (Right) computed by using the provided sample design.

Afterwards, these points were randomly generated and evaluated by applying visual interpretation on each AOI. These points were used as the "actual" points for the accuracy assessment purposes. Furthermore, the "predicted" points were derived from a cloud/haze elimination method. Next, a confusion matrix was computed by comparing the "actual" values and "predicted" values so that the accuracy indicators could be obtained. The accuracy indicators utilized in the current accuracy assessment procedure are the UA, PA and the OA. Thus, the result of accuracy assessment of cloud/haze elimination methods for a Sentinel-2 image in West Sepik Province and in West New Britain Province are presented in **Table 4.7** and **Table 4.8**, respectively.

Table 4.7 Accuracy assessment result of cloud/haze elimination methods for a Sentinel-2 image in West Sepik Province

URL: https://code.earthengine.google.com/af80cd1479285884afe3db3628997f21

Class (Class Value: Class Name)	User's Accuracy (UA)	Producer's Accuracy (PA)	Overall Accuracy (OA)
QA band method			
0: Cloudy areas	1	0.7833333333333333	0.94
1: Cloudless areas	0.9150326797385621	1	
FMASK-algorithm method			
0: Cloudy areas	1	1	1.00
1: Cloudless areas	1	1	

Table 4.8 Accuracy assessment result of cloud/haze elimination methods for a Sentinel-2 image in West New Britain Province

URL: https://code.earthengine.google.com/ad06543cc0342aa93b448b8da57b6729

Class (Class Value: Class Name)	User's Accuracy (UA)	Producer's Accuracy (PA)	Overall Accuracy (OA)
QA band method			
0: Cloudy areas	0.9183673469387755	0.8333333333333334	0.94
1: Cloudless areas	0.9403973509933775	0.9726027397260274	
FMASK-algorithm method			
0: Cloudy areas	1	0.9814814814814815	1.00
1: Cloudless areas	0.9931972789115646	1	

As for the accuracy indicators of cloud/haze elimination methods for a Sentinel-2 image in West Sepik Province, the FMASK-algorithm method yielded a higher PA (PA = 1) for the cloudy areas as compared to

those derived by the QA band method (PA = 0.7833333333333333) for the cloudy areas. Meanwhile, as for those in West New Britain Province, the FMASK-algorithm method also produced a higher PA (PA = 0.9814814814814815) for the cloudy areas as compared to those derived by the QA band method (PA = 0.8333333333333334) for the cloudy areas. Consequently, the FMASK-algorithm method would be set as the default cloud/haze elimination method for the Sentinel-2 annual and weekly forest loss detection systems for selective logging concessions in Papua New Guinea due to its better performance as compared to the other method.

4.3.4 Regarding the Tree-cover loss accumulation by using greenest and least-greenest images

4.3.4.1 The definition of variables used in the calculation

The variables used in the tree-cover loss accumulation function is defined as follows:

a. Greenest image

The greenest image is generated by taking the highest (maximum) NDVI value on each pixel over an image collection for the rainy season (i.e., January to May in the AOIs), which is assumed that during those period the forest/vegetation covers are growing with less human interference (e.g., deforestation activities) due to not preferable weather condition to do such activities.

b. Least-greenest image

The least-greenest image is generated by taking the lowest (minimum) NDVI value on each pixel over an image collection for the dry season (i.e., June to December in the AOIs), which is assumed that during those period the forest/vegetation covers tend to be decreasing and disturbed by several human interference activities (e.g., deforestation activity) due to the preferable weather condition to do such activities.

c. Tree cover loss accumulation

The tree cover loss accumulation image is generated by subtracting the greenest image with the least-greenest image and take only the positive values (i.e., values greater than zero) to obtain "loss" areas and omit the "gain" areas.

4.3.4.2 The step-by-step process in the calculation

The workflow of the tree-cover loss accumulation function is defined as follows:

a. Step 1: Obtain cloud-free image collections for the rainy- and dry-season by using a cloud/haze elimination method.

b. Step 2: Generate NDVI for each image on each image collections.

c. Step 3: Derive the greenest image by taking the highest (maximum) NDVI value on each pixel in the rainy season image collection, and the least-greenest image by taking the lowest (minimum) NDVI value on each pixel in the dry season image collection.
d. Step 4: Generate the tree-cover loss accumulation image by subtracting the greenest image with the least-greenest image and take only the values that are greater than zero.
e. Step 5: Calculate the tree-cover loss accumulation area per 1km grid.

4.4 Conclusion

The present chapter has been successfully develop the monitoring systems for detecting deforestations in selective logging concessions in Papua New Guinea by using remote sensing application on the Google Earth Engine based on the updates that have been applied in the previous scripts. The conclusion of this chapter is listed as follows:

a. References on remote sensing applications that are using Jacobs Index have been listed and summarized.
b. DOS reveals to be a technique for radiometric normalization to remove or reduce the impacts of atmospheric effects, and the DOS function has been added to the Annual and Weekly Forest Loss Detection systems for selective logging concessions in Papua New Guinea, which applied after the cloud/haze elimination procedure.
c. The CFMASK-derived QA band method was set as the default cloud/haze elimination method for the Landsat-8 annual forest loss detection systems for selective logging concessions in Papua New Guinea.
d. The FMASK-algorithm method was set as the default cloud/haze elimination method for the Sentinel-2 annual and weekly forest loss detection systems for selective logging concessions in Papua New Guinea.
e. An additional function to generate the greenest image, least-greenest image and the tree-cover loss accumulation image was added to the Annual Forest Loss Detection systems for selective logging concessions in Papua New Guinea.
f. The loss area calculation script was implemented to the Annual and Weekly Forest Loss Detection systems for selective logging concessions in Papua New Guinea. Furthermore, the loss area is now being calculated per 1 km grid.
g. The best cloud/haze elimination method based on the result of the accuracy assessment procedure was applied to the Annual and Weekly Forest Loss Detection systems for selective logging concessions in Papua New Guinea.
h. The greenest/least-greenest function and the loss area calculation per 1 km grid function were applied to the Annual and Weekly Forest Loss Detection systems for selective logging concessions in Papua New Guinea.

Chapter 5
Development of a system for monitoring logging activities inside logging concessions in PNG using Google Earth Engine technology

5.1 Background

In the previous chapter, the annual and weekly forest loss detection systems have been developed for detecting deforestations in selective logging concessions in Papua New Guinea. Therefore, the main focus of this chapter is to develop a monitoring system for detecting deforestation and forest disturbance inside logging concessions in Papua New Guinea to improve the reliability of the previously developed systems further.

In this chapter, the improvement includes an investigation to empirically obtain the optimum threshold value to define a unit of forest loss in the analysis by comparing the calculated loss area with lossyear data obtained from Hansen Global Forest Change v1.5 (https://earthenginepartners.appspot.com/science-2013-global-forest/download_v1.5.html) and GLAD Alerts data obtained from Global Forest Watch website (https://www.globalforestwatch.org/map) that will serve as the truth data. These values would be set as the default and recommended threshold values for the end users in using the system.

Furthermore, to be more objective and confident to select the best cloud/haze elimination method for the target areas inside of logging concession (i.e., Rottock bay Consolidated Concession and Amanab Concession), accuracy assessment for the cloud/haze elimination methods would be carried out for each cloud/haze elimination method. In the assessment, a sampling design would be used for calculating the number of sample size on each class to be used for the accuracy assessment procedure. Moreover, a function of the topographic correction would also be developed.

In addition, as a continuation from the previous task, a new concept or strategy to implement the greenest and least-greenest images for calculating the tree-cover loss accumulation without the influence from seasonal variations would also be proposed for providing additional information to the system.

5.2 Objectives

The objectives of this chapter are listed as follows:

1. to improve the deforestation detection systems developed on GEE,
2. to perform an investigation to empirically obtain the optimum threshold value to define a unit of forest loss in the analysis by comparing the calculated loss area with the truth data,
3. to conduct an accuracy assessment for cloud/haze elimination method in the target areas inside of logging concession (i.e., Rottock bay Consolidated Concession and Amanab Consolidated Concession),
4. to prepare a new concept or strategy to implement the greenest and least-greenest images for calculating tree-cover loss accumulation without the influenced from seasonal variations,

5. to develop annual and weekly forest loss detection systems for monitoring logging activities inside boundaries of logging concession in Papua New Guinea.

5.3 Outputs and Results

5.3.1 The accuracy assessment report of cloud/haze elimination methods with sampling design for Landsat-8 and Sentinel-2 images

5.3.1.1 The Updates on the cloud/haze elimination method

The cloud buffer variable of the FMASK-algorithm method for Sentinel-2 cloud/haze elimination methods is now set to 10 pixels (previously was set to 0 pixels). This setting reduces cloud/haze residues on the derived cloud-free image (Figure 5.1) so that could improve the reliability of the forest loss detection systems.

```
// Get cloud-free image for each image in the collection.
var FMASKcloudFree = ee.ImageCollection(imageFilter_topo).map(
  function(image) {

    // Declare local variables.
    var toa = sentinel2toa(image);
    var cloud = sentinelCloudScore(toa);
    var shadow = shadowMask(toa,cloud);

    var cloud_buffer = 10;
    // Cloud buffer is defined to reduced cloud/haze residues.
    var ee_cloud_buffer = ee.Image(cloud_buffer);
    var mask = cloud.or(shadow).fastDistanceTransform(cloud_buffer,'pixels').gt(ee_cloud_buffer);
    var image1 = image.addBands(mask.select([0],['Fmaskcloudmask']));

  return image1.updateMask(mask);
```

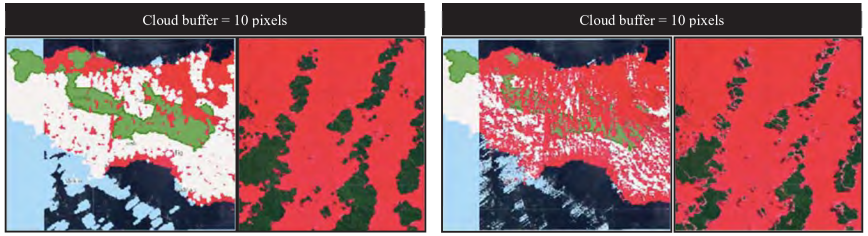


Figure 5.1 The effect of the different setting of cloud buffer variable of the FMASK-algorithm method for Sentinel-2 cloud/haze elimination methods.

5.3.1.2 The Accuracy assessment for Amanab Consolidated Concession

5.3.1.2.1 The number of sample size

The sampling design was used for calculating the number of sample size on each class to be used for the accuracy assessment procedure. The number of sample size for cloudy and cloudless areas for a Landsat-8 and Sentinel-2 image in Amanab Consolidated Concession computed by using the provided sample design are presented as follow:

Satellite	Landsat-8			
AOI	AMANAB			
Image ID	LANDSAT/LC08/C01/T1_TOA/LC08_100063_20180610			
Scene size	170 x 185 km	31450 sq.km		3145000 ha
CLOUDY PIXEL	29.41	9249.445 sq.km		924944.5 ha
cloudless pixel	70.59	22200.555 sq.km		2220055.5 ha
DISEÑO DE MUESTREO (SAMPLING DESIGN)				
	Cloudy	Cloudless	TOTAL	
Area (ha)	924,944.50	2,220,055.50	3,145,000.00	
Wi (%)	29.41%	70.59%	100.00%	
Ui	0.98	0.98		
si	0.14	0.14		
Wi*si	4.12%	9.88%		
s(ô)	0.01			
n	196.00			
Parte 1 (Part1)	129,492.23	310,807.77		
Parte 2 (Part2)	440,300.00	440,300.00		
ni	57.64	138.36	196.00	
Final points	60.00	140.00	200.00	

Satellite	Sentinel-2			
AOI	AMANAB			
Image ID	COPERNICUS/S2/20180403T005711_20180403T005706_T54MXB			
Scene size	100 x 100 km	10000 sq.km		1000000 ha
CLOUDY PIXEL	22.1216	2212.16 sq.km		221216 ha
cloudless pixel	77.8784	7787.84 sq.km		778784 ha
DISEÑO DE MUESTREO (SAMPLING DESIGN)				
	Cloudy	Cloudless	TOTAL	
Area (ha)	221,216.00	778,784.00	1,000,000.00	
Wi (%)	22.12%	77.88%	100.00%	
Ui	0.98	0.98		
si	0.14	0.14		
Wi*si	3.10%	10.90%		
s(ô)	0.01			
n	196.00			
Parte 1 (Part1)	30,970.24	109,029.76		
Parte 2 (Part2)	140,000.00	140,000.00		
ni	43.36	152.64	196.00	
Final points	48.00	154.00	200.00	

Figure 5.2 The number of sample size for cloudy and cloudless areas for a Landsat-8 image (left) and Sentinel-2 image (right) in Amanab Consolidated Concession.

5.3.1.2.2 Accuracy assessment result

The result for accuracy assessment of cloud/haze elimination methods for Landsat-8 and Sentinel-2 images in Amanab Consolidated Concession are shown in Table 5.1 and Table 5.2, respectively.

Table 5.1 Accuracy assessment result of cloud/haze elimination methods for a Landsat-8 image in Amanab Consolidated Conc.

URL: https://code.earthengine.google.com/94cfd804b699105b8ef8b13d30ce12a6

Class Value: Class Name	User's Accuracy (UA)	Producer's Accuracy (PA)	Overall Accuracy (OA)
QA band method			
0: Cloudy	0.85	1.00	0.95
1: Cloudless	1.00	0.92	
CFMASK-derived QA band method			
0: Cloudy	1.00	1.00	1.00
1: Cloudless	1.00	1.00	

Table 5.2 Accuracy assessment result of cloud/haze elimination methods for a Sentinel-2 image in Amanab Consolidated Conc.

URL: https://code.earthengine.google.com/6e4c632804b3aeba25cf190fa5ffc286

Class Value: Class Name	User's Accuracy (UA)	Producer's Accuracy (PA)	Overall Accuracy (OA)
QA band method			
0: Cloudy	1.00	0.91	0.98
1: Cloudless	0.97	1.00	
FMASK-algorithm method			
0: Cloudy	1.00	1.00	1.00
1: Cloudless	1.00	1.00	

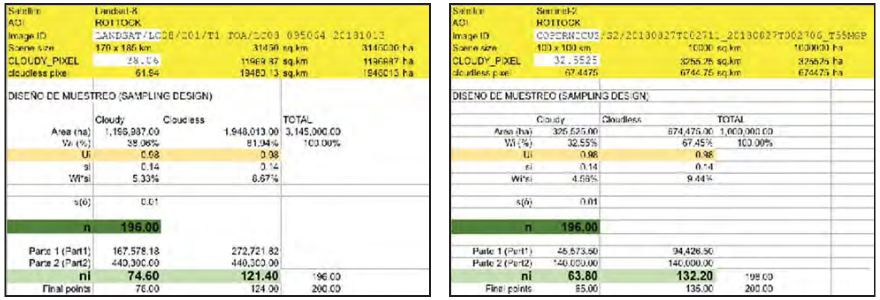
5.3.1.2.3 Brief analysis

Due to their better performances (i.e., a higher PA for cloudy class and/or a higher OA) as compared to the other method, the CFMASK-derived QA band method and the FMASK-algorithm method would be set as the default cloud/haze elimination method for the Landsat-8 and Sentinel-2 forest loss detection systems for Amanab Consolidated Concession, respectively.

5.3.1.3 The Accuracy assessment for Rottock Bay Consolidated Concession

5.3.1.2.1 The number of sample size

The sampling design was used for calculating the number of sample size on each class to be used for the accuracy assessment procedure. The number of sample size for cloudy and cloudless areas for a Landsat-8 and Sentinel-2 image in Rottock Bay Consolidated Concession computed by using the provided sample design are presented as follow:



Satellite	Landsat-8			
AOI	ROTTOCK			
Image ID	LANDSAT/LC08/C01/T1_TOA/LC08_095064_20181013			
Scene size	170 x 185 km	31450 sq.km		3145000 ha
CLOUDY_PIXEL	38.06	11969.87 sq.km		1196987 ha
cloudless pixel	61.94	19480.13 sq.km		1948013 ha
DISEÑO DE MUESTREO (SAMPLING DESIGN)				
	Cloudy	Cloudless	TOTAL	
Area (ha)	1,196,987.00	1,948,013.00	3,145,000.00	
Wi (%)	38.06%	61.94%	100.00%	
Ui	0.98	0.98		
si	0.14	0.14		
Wi*si	5.33%	8.67%		
s(ô)	0.01			
n	196.00			
Parte 1 (Part1)	167,578.18	272,721.82		
Parte 2 (Part2)	440,300.00	440,300.00		
ni	74.60	121.40	196.00	
Final points	76.00	124.00	200.00	

Satellite	Sentinel-2			
AOI	ROTTOCK			
Image ID	COPERNICUS/S2/20180327T002711_20180327T002706_T55MGP			
Scene size	100 x 100 km	10000 sq.km		1000000 ha
CLOUDY_PIXEL	32.5525	3255.25 sq.km		325525 ha
cloudless pixel	67.4475	6744.75 sq.km		674475 ha
DISEÑO DE MUESTREO (SAMPLING DESIGN)				
	Cloudy	Cloudless	TOTAL	
Area (ha)	325,525.00	674,475.00	1,000,000.00	
Wi (%)	32.55%	67.45%	100.00%	
Ui	0.98	0.98		
si	0.14	0.14		
Wi*si	4.56%	9.44%		
s(ô)	0.01			
n	196.00			
Parte 1 (Part1)	45,573.50	94,426.50		
Parte 2 (Part2)	140,000.00	140,000.00		
ni	63.80	132.20	196.00	
Final points	65.00	135.00	200.00	

Figure 5.3 The number of sample size for cloudy and cloudless areas for a Landsat-8 image (left) and Sentinel-2 image (right) in Rottock Bay Consolidated Concession.

5.3.1.2.2 Accuracy assessment result

The result for accuracy assessment of cloud/haze elimination methods for Landsat-8 and Sentinel-2 images in Rottock Bay Consolidated Concession are shown in Table 5.3 and Table 5.4, respectively.

Table 5.3 Accuracy assessment result of cloud/haze elimination methods for a Landsat-8 image in Rottock Bay Cons. Conc.

URL: https://code.earthengine.google.com/80517505883c634e26f54d0b01bc43b5

Class Value: Class Name	User's Accuracy (UA)	Producer's Accuracy (PA)	Overall Accuracy (OA)
QA band method			
0: Cloudy	0.90	1.00	0.96
1: Cloudless	1.00	0.94	
CFMASK-derived QA band method			
0: Cloudy	1.00	1.00	1.00
1: Cloudless	1.00	1.00	

Table 5.4 Accuracy assessment result of cloud/haze elimination methods for a Sentinel-2 image in Rottock Bay Cons. Conc.

URL: https://code.earthengine.google.com/5002dca532d3ba5b33e100f75cc86003

Class Value: Class Name	User's Accuracy (UA)	Producer's Accuracy (PA)	Overall Accuracy (OA)
QA band method			
0: Cloudy	0.80	0.92	0.90
1: Cloudless	0.96	0.89	
FMASK-algorithm method			
0: Cloudy	1.00	1.00	1.00
1: Cloudless	1.00	1.00	

5.3.1.2.3 Brief analysis

Due to their better performances (i.e., a higher PA for cloudy class and/or a higher OA) as compared to the other method, the CFMASK-derived QA band method and the FMASK-algorithm method would be set as the default cloud/haze elimination method for the Landsat-8 and Sentinel-2 forest loss detection systems for Rottock Bay Consolidated Concession, respectively.

5.3.2 The Details of the optimum threshold values for forest loss detection systems for monitoring logging activities inside of logging concessions in PNG

5.3.2.1 Updates on the forest lost detection system

5.3.2.1.1 Topographic correction

The topographic correction function that based on Teillet, P.M., et al. (1982) is added to the forest lost detection systems. The topographic function is added to the Landsat-8 script and the Sentinel-2 scripts as shown in Figure 5.4.

Figure 5.4 The topographic correction function that based on Teillet, P.M., et al. (1982) for the Landsat-8 script (left) and the Sentinel-2 scripts (right).

5.3.2.1.2 Loss area calculation grid size

The grid size for calculating loss area is now set to 250 meters (previously was set to 1 kilometer). This setting improves the details of the accuracy of the derived loss-area image so that could enhance the reliability of the forest loss detection systems.

5.3.2.2 The Landsat-8 annual forest loss detection system

5.3.2.2.1 The optimum threshold values

The *lossyear* band of the Hansen Forest Change v1.5 is served as the "truth data" for the Landsat-8 annual forest loss detection system to obtain the optimum threshold value (tIndex) for defining a unit of forest loss. These threshold values would be listed in the forest loss detection script as the recommended threshold value for the users. Hence, the optimum threshold values are listed in Table 5.5 and Table 5.6.

Table 5.5 Landsat-8 annual forest loss detection for Amanab Consolidated Concession

Year of analysis	Calculated loss area (sq. Km)	Truth-data loss area (sq. Km)	Absolute Difference
NDVI, NDWI, NBR Method Optimum threshold value = 0.215			
2015	3.904	26.602	22.698
2016	7.249	30.306	23.057
2017	30.796	29.593	1.203
		Mean Absolute Difference	**15.653**
SMA and NDFI Method Optimum threshold value = 1.925			

2015	7.437	26.602	19.165
2016	14.622	30.306	15.684
2017	31.540	29.593	1.947
		Mean Absolute Difference	**12.265**

Table 5.6 Landsat-8 annual forest loss detection for Rottock Bay Consolidated Conc.

Year of analysis	Calculated loss area (sq. Km)	Truth-data loss area (sq. Km)	Absolute Difference
NDVI, NDWI, NBR Method Optimum threshold value = 0.180			
2015	32.133	33.200	1.067
2016	1.050	6.669	5.619
2017	5.252	6.539	1.287
		Mean Absolute Difference	**2.658**
SMA and NDFI Method Optimum threshold value = 1.900			
2015	34.727	33.200	1.527
2016	2.100	6.669	4.569
2017	3.213	6.539	3.326
		Mean Absolute Difference	**3.141**

5.3.2.2.2 Brief analysis for Amanab Consolidated Concession

The optimum threshold value by using the combination of NDVI, NDWI, and NBR method and the integration of SMA and NDFI method is 0.215 and 1.925, respectively. These threshold values yield the lowest mean absolute difference as compared with the truth data and set as the recommended threshold values for the end user.

5.3.2.2.3 Brief analysis for Rottock Bay Consolidated Concession

The optimum threshold value by using the combination of NDVI, NDWI, and NBR method and the integration of SMA and NDFI method is 0.180 and 1.900, respectively. These threshold values yield the lowest mean absolute difference as compared with the truth data and set as the recommended threshold values for the end user.

5.3.2.3 The Sentinel-2 annual forest loss detection system

5.3.2.3.1 The optimum threshold values

The *lossyear* band of the Hansen Forest Change v1.5 is served as the "truth data" for the Sentinel-2 annual forest loss detection system to obtain the optimum threshold value (tIndex) for defining a unit of forest loss. These threshold values would be listed in the forest loss detection script as the recommended threshold value for the users. Hence, the optimum threshold values are listed in Table 5.7 and Table 5.8.

Table 5.7 Sentinel-2 annual forest loss detection for Amanab Consolidated Concession

Year of analysis	Calculated loss area (sq. Km)	Truth-data loss area (sq. Km)	Absolute Difference
NDVI, NDWI, NBR Method Optimum threshold value = 0.190			
2016	5.886	30.306	24.420
2017	29.160	29.593	0.433
		Mean Absolute Difference	**12.427**
SMA and NDFI Method Optimum threshold value = 1.955			
2016	5.019	30.306	25.287
2017	28.292	29.593	1.301
		Mean Absolute Difference	**13.294**

Table 5.8 Sentinel-2 annual forest loss detection for Rottock Bay Consolidated Conc.

Year of analysis	Calculated loss area (sq. Km)	Truth-data loss area (sq. Km)	Absolute Difference
NDVI, NDWI, NBR Method Optimum threshold value = 0.140			
2016	3.583	6.669	3.086
2017	6.425	6.539	0.114
		Mean Absolute Difference	**1.600**
SMA and NDFI Method Optimum threshold value = 1.905			
2016	2.964	6.669	3.705
2017	6.734	6.539	0.195
		Mean Absolute Difference	**1.950**

5.3.2.3.2 Brief analysis for Amanab Consolidated Concession

The optimum threshold value by using the combination of NDVI, NDWI, and NBR method and the integration of SMA and NDFI method is 0.190 and 1.955, respectively. These threshold values yield the lowest mean absolute difference as compared with the truth data and set as the recommended threshold values for the end user.

5.3.2.3.3 Brief analysis for Rottock Bay Consolidated Concession

The optimum threshold value by using the combination of NDVI, NDWI, and NBR method and the integration of SMA and NDFI method is 0.140 and 1.905, respectively. These threshold values yield the lowest mean absolute difference as compared with the truth data and set as the recommended threshold values for the end user.

5.3.2.4 The Sentinel-2 weekly forest loss detection system

5.3.2.4.1 The optimum threshold values

The weekly alerts derived from GLAD (Global Land Analysis & Discovery) data is served as the "truth data" for the Sentinel-2 weekly forest loss detection system to obtain the optimum threshold value (tIndex) for defining a unit of forest loss. In this investigation, the month with the most weekly alerts in 2018 (i.e., July for Amanab Consolidated Concession and August for Rottock Bay Consolidated Concession) was set as the reference month to generate the optimum threshold for the Sentinel-2 weekly forest loss detection system. These threshold values would be listed in the forest loss detection script as the recommended threshold value for the users. Hence, the optimum threshold values are listed in Table 5.9 and Table 5.10.

Table 5.9 Sentinel-2 weekly forest loss detection for Amanab Consolidated Concession

Reference Image		Target Image		Calculated loss area (sq. Km)	GLAD Alerts	Truth-data loss area (sq. Km)	Absolute Difference
Start Date	End Date	Start Date	End Date				
NDVI, NDWI, NBR Method Optimum threshold value = 0.190							
18/5/27	18/6/3	18/6/3	18/6/10	1.116	4778	4.300	3.184
18/6/3	18/6/10	18/6/10	18/6/17	4.276	4773	4.296	0.020
18/6/10	18/6/17	18/6/17	18/6/24	2.106	2024	1.822	0.284
18/6/17	18/6/24	18/6/24	18/7/1	2.045	2529	2.276	0.231
						Mean Absolute Difference	**0.930**
SMA and NDFI Method Optimum threshold value = 1.945							
18/5/27	18/6/3	18/6/3	18/6/10	1.425	4778	4.300	2.875
18/6/3	18/6/10	18/6/10	18/6/17	4.338	4773	4.296	0.042
18/6/10	18/6/17	18/6/17	18/6/24	2.106	2024	1.822	0.284
18/6/17	18/6/24	18/6/24	18/7/1	1.983	2529	2.276	0.293
						Mean Absolute Difference	**0.874**

Table 5.10 Sentinel-2 weekly forest loss detection for Rottock Bay Consolidated Conc.

Reference Image		Target Image		Calculated loss area (sq. Km)	GLAD Alerts	Truth-data loss area (sq. Km)	Absolute Difference
Start Date	End Date	Start Date	End Date				
NDVI, NDWI, NBR Method Optimum threshold value = 0.275							
18/7/29	18/8/5	18/8/5	18/8/12	0.000	1004	0.904	0.904
18/8/5	18/8/12	18/8/12	18/8/19	0.185	0	0.000	0.185
18/8/12	18/8/19	18/8/19	18/8/26	0.185	271	0.244	0.059
18/8/19	18/8/26	18/8/26	18/9/2	0.309	272	0.245	0.064
						Mean Absolute Difference	**0.303**
SMA and NDFI Method Optimum threshold value = 1.975							
18/7/29	18/8/5	18/8/5	18/8/12	0.000	1004	0.904	0.904
18/8/5	18/8/12	18/8/12	18/8/19	0.062	0	0.000	0.062
18/8/12	18/8/19	18/8/19	18/8/26	0.185	271	0.244	0.059
18/8/19	18/8/26	18/8/26	18/9/2	0.185	272	0.245	0.060
						Mean Absolute Difference	**0.271**

5.3.2.4.2 Brief analysis for Amanab Consolidated Concession

The optimum threshold value by using the combination of NDVI, NDWI, and NBR method and the integration of SMA and NDFI method is 0.190 and 1.945, respectively. These threshold values yield the lowest mean absolute difference as compared with the truth data and set as the recommended threshold values for the end user.

5.3.2.4.3 Brief analysis for Rottock Bay Consolidated Concession

The optimum threshold value by using the combination of NDVI, NDWI, and NBR method and the integration of SMA and NDFI method is 0.275 and 1.975, respectively. These threshold values yield the lowest mean absolute difference as compared with the truth data and set as the recommended threshold values for the end user.

5.3.3 The tree-cover loss accumulation by using greenest and least-greenest images

5.3.3.1 The definition of variables used in the calculation

The variables used in the tree-cover loss accumulation function is defined as follows:

a. Greenest image

The greenest image is generated by taking the highest (maximum) vegetation index (i.e., the NDVI) value on each pixel over an image collection throughout a given year in a given AOI.

b. Least-greenest image

The least-greenest image is generated by taking the lowest (minimum) vegetation index (i.e., the NDVI) value on each pixel over an image collection throughout a given year in a given AOI.

c. Tree-cover loss accumulation

The tree-cover loss accumulation image is generated by subtracting the greenest image with the least-greenest image and take all values that is greater than the user-defined threshold value (i.e., so-called tTreecover in the script).

d. Tree-cover loss threshold value (tTreecover)

A user-defined threshold value that is used to define a unit of tree-cover loss in the analysis.

5.3.3.2 The step-by-step process in the calculation

The workflow of the tree-cover loss accumulation function is defined as follows:

a. Step 1: Obtain an image collection for a given year in a given AOI.
b. Step 2: Apply topographic correction for each image in the image collection.
c. Step 3: Generate cloud-free image collection by using the CFMASK and FMASK cloud/haze elimination method for Landsat-8 and Sentinel-2, respectively.
d. Step 4: Derive the NDVI for each image in the cloud-free image collection.
e. Step 5: Generate the greenest image by taking the highest (maximum) NDVI value on each pixel in the image collection, and the least-greenest image by taking the lowest (minimum) NDVI value on each pixel in the image collection.
f. Step 6: Calculate the tree-cover loss accumulation by subtracting the greenest image with the least-greenest image and take all values that is greater than the user-defined threshold value (tTreecover).
g. Step 7: Calculate the tree-cover loss accumulation areas, print it to the GEE Console and display the tree-cover loss accumulation image to the GEE Map.

5.3.3.3 The optimum threshold values (tTreecover) for Landsat-8

5.3.3.3.1 The optimum threshold values (tTreecover)

The *lossyear* band of the Hansen Forest Change v1.5 is served as the “truth data” for the Landsat-8 annual tree-cover loss accumulation function to obtain the optimum threshold value (tTreecover) for defining a unit of tree-cover loss. These threshold values would be listed in the forest loss detection script as the recommended threshold value (tTreecover) for the users. Hence, the optimum threshold values are listed in Table 5.11 and Table 5.12.

Table 5.11 Landsat-8 tree-cover loss accumulation for Amanab Consolidated Concession

Year of analysis	Calculated loss area (sq. Km)	Truth-data loss area (sq. Km)	Absolute Difference
Optimum threshold value = 0.845			
2014	4.461	29.279	24.818
2015	0.124	26.602	26.478
2016	0.744	30.306	29.562
2017	28.999	29.593	0.594
		Mean Absolute Difference	**20.363**

Table 5.12 Landsat-8 tree-cover loss accumulation for Rottock Bay Consolidated Concession

Year of analysis	Calculated loss area (sq. Km)	Truth-data loss area (sq. Km)	Absolute Difference
Optimum threshold value = 0.585			
2014	2.346	6.457	4.111
2015	28.415	33.200	4.785
2016	15.071	6.669	8.402
2017	20.568	6.539	14.029
		Mean Absolute Difference	**7.832**

5.3.3.3.2 Brief analysis for Amanab Consolidated Concession

The optimum threshold value for calculating tree-cover loss accumulation is 0.845. This threshold value yields the lowest mean absolute difference as compared with the truth data and set as the recommended threshold value (tTreecover) for the end user.

5.3.3.3.3 Brief analysis for Rottock Bay Consolidated Concession

The optimum threshold value for calculating tree-cover loss accumulation is 0.585. This threshold value yields the lowest mean absolute difference as compared with the truth data and set as the recommended threshold value (tTreecover) for the end user.

5.3.3.4 The optimum threshold values (tTreecover) for Sentinel-2

5.3.3.4.1 The optimum threshold values (tTreecover)

The *lossyear* band of the Hansen Forest Change v1.5 is served as the "truth data" for the Sentinel-2 annual tree-cover loss accumulation function to obtain the optimum threshold value (tTreecover) for defining

a unit of tree-cover loss. These threshold values would be listed in the forest loss detection script as the recommended threshold value (tTreecover) for the users. Hence, the optimum threshold values are listed in Table 5.13 and Table 5.14.

Table 5.13 Sentinel-2 tree-cover loss accumulation for Amanab Consolidated Concession

Year of analysis	Calculated loss area (sq. Km)	Truth-data loss area (sq. Km)	Absolute Difference
Optimum threshold value = 0.740			
2016	8.900	30.306	21.406
2017	29.389	29.593	0.204
		Mean Absolute Difference	**10.805**

Table 5.14 Sentinel-2 tree-cover loss accumulation for Rottock Bay Consolidated Concession

Year of analysis	Calculated loss area (sq. Km)	Truth-data loss area (sq. Km)	Absolute Difference
Optimum threshold value = 0.715			
2016	6.364	6.669	0.305
2017	6.487	6.539	0.052
		Mean Absolute Difference	**0.179**

5.3.3.4.2 Brief analysis for Amanab Consolidated Concession

The optimum threshold value for calculating tree-cover loss accumulation is 0.740. This threshold value yields the lowest mean absolute difference as compared with the truth data and set as the recommended threshold value (tTreecover) for the end user.

5.3.3.4.3 Brief analysis for Rottock Bay Consolidated Concession

The optimum threshold value for calculating tree-cover loss accumulation is 0.715. This threshold value yields the lowest mean absolute difference as compared with the truth data and set as the recommended threshold value (tTreecover) for the end user.

5.4 Conclusion

The present chapter has been successfully developed monitoring systems for detecting deforestation and forest disturbance inside of logging concessions in Papua New Guinea, to improve the reliability of the previously developed systems further. The conclusion of this chapter is listed as follows:

a. The topographic correction function that based on Teillet, P.M., et al. (1982) is added to the forest lost detection systems.

b. The grid size for calculating loss area is now set to 250 meters, which could improve the accuracy of the loss-area calculation as well as enhance the reliability of the forest loss detection systems.
c. The optimum threshold value to define a unit of forest loss in the analysis (tIndex) was obtained for each forest loss detection system. These values are listed on each forest loss detection system as the recommended threshold values for the end user.
d. For both AOIs, the CFMASK-derived QA band method and the FMASK-algorithm method are set as the default cloud/haze elimination method for the Landsat-8 and Sentinel-2 forest loss detection systems, respectively, due to their better performances (i.e., a higher PA for cloudy class and/or a higher OA) as compared to the other method.
e. A strategy to implement the greenest and least-greenest images for calculating the tree-cover loss accumulation without the influence from seasonal variations was proposed for providing additional information to the system.
f. The annual and weekly forest loss detection systems for monitoring logging activities inside boundaries of logging concession in Papua New Guinea were developed.

Chapter 6
Preparation of user manuals to instruct the users for utilizing the developed forest loss detection systems

6.1 Background

On the previous chapter, the annual and weekly forest loss detection systems have been developed for monitoring logging activities inside boundaries of logging concession in Papua New Guinea. Therefore, the main focus of this work is to prepare the documents of the user manuals to instruct the users for utilizing the developed annual and weekly forest loss detection systems for monitoring logging activities inside of logging concession in Papua New Guinea.

For each document of the user manual would cover: (1) The general introduction and the description of each part written on each forest loss detection script, (2) The script guidelines that cover the step-by-step instructions and the explanation of the printed and displayed outputs, and (3) The conclusion and remarks.

6.2 Objectives

The objectives of this chapter are listed as follows:

1. Prepare the user manual of the Landsat-8 and Sentinel-2 annual forest loss detection systems for monitoring logging activities inside of logging concession in Papua New Guinea.
2. Prepare the user manual of the Sentinel-2 weekly forest loss detection systems for monitoring logging activities inside of logging concession in Papua New Guinea.
3. Prepare a final report outlining methods applied and the results taken with recommendations for the past months.

6.3 Outputs and Results

6.3.1 The User Manual for Landsat-8 Annual Forest Loss Detection (v2018.12.11) and Sentinel-2 Annual Forest Loss Detection (v2018.12.11)

6.3.1.1 Introduction

The Landsat-8 Annual Forest Loss Detection (v2018.12.11) and the Sentinel-2 Annual Forest Loss Detection (v2018.12.11) are similar scripts that intended to monitor the annual logging activities inside of logging concessions in Papua New Guinea. In these scripts, two forest loss detection methods are available to be selected, i.e., the combination of Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), and Normalized Burn Ratio (NBR) method and the integration of Spectral Mixture Analysis (SMA) and Normalized Difference Fraction Index (NDFI) method. The only difference between these scripts is the sensor that is used to derive satellite images; thus user manuals for both scripts are combined for users' convenience. Each script is divided into nine parts, which are: (1) Input Commands,

(2) Parameters Collections, (3) Parameters for Investigation Periods, (4) Cloud/Haze Elimination Functions, (5) Image Collections, (6) Forest Loss Analysis, (7) Loss Area Calculation, (8) Parameters for Export Images, and (9) Tree-cover loss accumulation.

a. Part 1: Input Commands

In this part, all input commands (15 in total) should be defined by the user prior to run the script. The first command (COMMAND-1) is to assign the START DATE of the FIRST REFERENCE IMAGE that includes three variables, i.e., firstRefStart_YEAR to define the year, firstRefStart_MONTH to define the month, and firstRefStart_DATE to define the date. The second command (COMMAND-2) is to assign the END DATE of the FIRST REFERENCE IMAGE that includes three variables, i.e., firstRefEnd_YEAR to define the year, firstRefEnd_MONTH to define the month, and firstRefEnd_DATE to define the date. The third command (COMMAND-3) is to assign the START DATE of the FIRST TARGET IMAGE that includes three variables, i.e., firstTargetStart_YEAR to define the year, firstTargetStart_MONTH to define the month, and firstTargetStart_DATE to define the date. The fourth command (COMMAND-4) is to assign the END DATE of the FIRST TARGET IMAGE that includes three variables, i.e., firstTargetEnd_YEAR to define the year, firstTargetEnd_MONTH to define the month, and firstTargetEnd_DATE to define the date. The fifth command (COMMAND-5) is to define the TOTAL amount of TARGET IMAGES to be used for analysis, which includes the FIRST TARGET IMAGE. The sixth command (COMMAND-6) is to select the area of interest (AOI) to be used for forest loss detection. These scripts are supported annual forest loss detection for two AOIs in Papua New Guinea that is the Amanab Consolidated Concession and the Rottock Bay Consolidated Concession. The seventh command (COMMAND-7) is to select the method to be used for cloud/haze elimination purposes. For the Landsat-8 based script, two cloud/haze elimination methods are available to be used, i.e., the QA band method and the CFMASK-derived QA band method. For the Sentinel-2 based script, two cloud/haze elimination methods are available to be used, i.e., the QA band method and the FMASK-algorithm method. On each script, the recommended method to be used for cloud/haze elimination is listed for the user's convenience. The eighth command (COMMAND-8) is an option whether to display the cloud-free images to the Google Earth Engine (GEE) Map or not. The ninth command (COMMAND-9) is to select the method to be used for forest loss detection purposes. In these scripts, two forest loss detection methods are available to be selected, i.e., the combination of NDVI, NDWI, and NBR method and the integration of SMA and NDFI method. The tenth command (COMMAND-10) is to assign the threshold value to define a unit of forest loss in the analysis (so-called the tIndex). On each script, the recommended tIndex to be applied to each AOI and on each forest loss detection method is listed for the user's convenience. The eleventh command (COMMAND-11) is an option whether to display the loss images to the GEE Map or not. The twelfth command (COMMAND-12) is an option whether to calculate the loss areas in square kilometers and print it to the GEE Console or not. The thirteenth command (COMMAND-13) is an option whether to export the loss images to user's Assets in GEE or not. The fourteenth command (COMMAND-14) is an option whether to export the loss images to user's Google Drive account or not. The last command (COMMAND-15) is an option whether to generate the greenest and

least-greenest images as well as calculate the tree-cover loss accumulation for each year. If the user selects 'YES,' the threshold value to define a unit of tree-cover loss in the analysis (so-called the tTreecover) should be defined. On each script, the recommended tTreecover to be applied to each AOI is listed for the user's convenience.

b. Part 2: Parameters Collections

This part comprises the collection of general parameters that are used on the scripts. These parameters include: (a) The definition of image collections, (b) The date formatting for the investigation period, (c) The conditional functions for the selected AOI, (d) The conditional functions for the selected method for forest loss detection, (e) A command to print the script's title to the GEE Console, (f) A command for masking the tree-cover in the selected AOI that is derived from the Hansen Global Forest Change v1.5 data, (g) A collection of visual parameters, and (h) A command to display the boundary of the selected AOI to the GEE Map.

c. Part 3: Parameters for Investigation Periods

In this part, the functions to automatically derive the START DATE and END DATE for each reference and target images are defined. Furthermore, these dates are grouped in the list for each pair of reference and target images. Lastly, there is a command to print out the list of the date-pairs for each analysis of forest loss detection to the GEE Console.

d. Part 4: Cloud/Haze Elimination Functions

This part collects functions to generate cloud-free images by using the cloud/haze elimination methods. For the Landsat-8 based script, two functions of cloud/haze elimination methods are defined, i.e., the QA band method and the CFMASK-derived QA band method. For the Sentinel-2 based script, two functions of cloud/haze elimination methods are defined, i.e., the QA band method and the FMASK-algorithm method. Basically, each cloud/haze elimination method follows the following workflow: (a) Define the local parameters to be used on the function, (b) Obtain the image collection from the image archive, (c) Apply the topographic correction function that is based on Teillet, P.M., et al. (1982), (d) Apply the cloud/haze elimination function for each image in the image collection, (e) Apply the Dark Object Subtraction (DOS) radiometric correction function that is based on Chavez (1988), (f) Generate the mosaic image of the annual cloud-free image by taking the median value of the image collection and clip it with the boundary of the selected AOI, (g) Generate the vegetation index images to be used for further image processing.

e. Part 5: Image Collections

In this part, the commands to obtain the cloud-free image for each reference and target images in the investigation period are listed. Furthermore, there is a conditional function to accommodate the option for displaying the cloud-free image collection to the GEE Map.

f. Part 6: Forest Loss Analysis

This part comprises functions to analyze forest loss by utilizing the forest loss detection methods. In these scripts, two forest loss detection methods are defined, i.e., the combination of NDVI, NDWI, and NBR method and the integration of SMA and NDFI method. The earlier-mentioned method analyzes the difference between NDVI, NDWI, and NBR images for a given reference and target images so that a decreasing value of those three indices at a given area or pixel that is greater than the given threshold value (tIndex) would be considered as forest loss. This method is adapted from the forest loss detection method derived by Hansen et al. (2016). Meanwhile, the later-mentioned method utilizes SMA-derived fraction images for generating NDFI image for a given reference and target image so that a decreasing value of NDFI at a given area or pixel that is greater than the given threshold value (tIndex) would be considered as forest loss. This method is initially proposed by Souza et al. (2003), Souza et al. (2005), and Souza et al. (2013). Lastly, the command to display the loss-image collection for each analysis to the GEE Map is listed.

g. Part 7: Loss Area Calculation

In this part, the function to calculate the loss areas is listed. In these scripts, the loss areas are calculated per 250 meters grid to accommodate a speedy computation. Furthermore, the unit of the loss areas is converted to square kilometers. At the end of this part, the command to print the loss-area for each analysis to the GEE Console is provided.

h. Part 8: Parameters for Export Images

This part collects conditional functions for exporting the loss-image collection to user's Assets in GEE and user's Google Drive account. Each exported loss-image would have a pixel size of 30 meters and 10 meters for Landsat-8 script and Sentinel-2 script, respectively, and a UTM WGS84 projection. The naming structure of each lost-image is described as follows:

For Landsat-8 Annual Forest Loss Detection (v2018.12.11)

(AOI)_L8annualLossImage_analysis_**(**n**)**

The (AOI) defines as the name of the area of interest of the image; 'AMANAB' for Amanab Consolidated Concession and 'ROTTOCK' for Rottock Bay Consolidated Concession. Meanwhile, the (n) defined as the sequence of the forest lost that is being analyzed, e.g., the first sequence (n = 1) is the annual forest lost image for the pair of FIRST REFERENCE IMAGE and the FIRST TARGET IMAGE, and so on until the end sequence of the analysis. To better understand the naming structure, please kindly have a look at these examples:

1. AMANAB_L8annualLossImage_analysis_1
   The AOI of this lost-image is the Amanab Consolidated Concession for the annual forest lost analysis in 2015 and is generated by subtracting the forest areas in 2014 (as the REFERENCE IMAGE; Start

Date: 2014/01/01; End Date: 2014/12/31) with the forest areas in 2015 (as the TARGET IMAGE; Start Date: 2015/01/01; End Date: 2015/12/31).

2. AMANAB_L8annualLossImage_analysis_2
   The AOI of this lost-image is the Amanab Consolidated Concession for the annual forest lost analysis in 2016 and is generated by subtracting the forest areas in 2015 (as the REFERENCE IMAGE; Start Date: 2015/01/01; End Date: 2015/12/31) with the forest areas in 2016 (as the TARGET IMAGE; Start Date: 2016/01/01; End Date: 2016/12/31).
3. AMANAB_L8annualLossImage_analysis_3
   The AOI of this lost-image is the Amanab Consolidated Concession for the annual forest lost analysis in 2017 and is generated by subtracting the forest areas in 2016 (as the REFERENCE IMAGE; Start Date: 2016/01/01; End Date: 2016/12/31) with the forest areas in 2017 (as the TARGET IMAGE; Start Date: 2017/01/01; End Date: 2017/12/31).
4. ROTTOCK_L8annualLossImage_analysis_1
   The AOI of this lost-image is the Rottock Bay Consolidated Concession for the annual forest lost analysis in 2015 and is generated by subtracting the forest areas in 2014 (as the REFERENCE IMAGE; Start Date: 2014/01/01; End Date: 2014/12/31) with the forest areas in 2015 (as the TARGET IMAGE; Start Date: 2015/01/01; End Date: 2015/12/31).
5. ROTTOCK_L8annualLossImage_analysis_2
   The AOI of this lost-image is the Rottock Bay Consolidated Concession for the annual forest lost analysis in 2016 and is generated by subtracting the forest areas in 2015 (as the REFERENCE IMAGE; Start Date: 2015/01/01; End Date: 2015/12/31) with the forest areas in 2016 (as the TARGET IMAGE; Start Date: 2016/01/01; End Date: 2016/12/31).
6. ROTTOCK_L8annualLossImage_analysis_3
   The AOI of this lost-image is the Rottock Bay Consolidated Concession for the annual forest lost analysis in 2017 and is generated by subtracting the forest areas in 2016 (as the REFERENCE IMAGE; Start Date: 2016/01/01; End Date: 2016/12/31) with the forest areas in 2017 (as the TARGET IMAGE; Start Date: 2017/01/01; End Date: 2017/12/31).

For Sentinel-2 Annual Forest Loss Detection (v2018.12.11)

(AOI)_S2annualLossImage_analysis_**(**n**)**

The (AOI) defines as the name of the area of interest of the image; 'AMANAB' for Amanab Consolidated Concession and 'ROTTOCK' for Rottock Bay Consolidated Concession. Meanwhile, the (n) defined as the sequence of the forest lost that is being analyzed, e.g., the first sequence (n = 1) is the annual forest lost image for the pair of FIRST REFERENCE IMAGE and the FIRST TARGET IMAGE, and so on until the end sequence of the analysis. To better understand the naming structure, please kindly have a look at these examples:

1. AMANAB_S2annualLossImage_analysis_1
   The AOI of this lost-image is the Amanab Consolidated Concession for the annual forest lost analysis

in 2016 and is generated by subtracting the forest areas in 2015 (as the REFERENCE IMAGE; Start Date: 2015/01/01; End Date: 2015/12/31) with the forest areas in 2016 (as the TARGET IMAGE; Start Date: 2016/01/01; End Date: 2016/12/31).

2. AMANAB_S2annualLossImage_analysis_2
   The AOI of this lost-image is the Amanab Consolidated Concession for the annual forest lost analysis in 2017 and is generated by subtracting the forest areas in 2016 (as the REFERENCE IMAGE; Start Date: 2016/01/01; End Date: 2016/12/31) with the forest areas in 2017 (as the TARGET IMAGE; Start Date: 2017/01/01; End Date: 2017/12/31).
3. ROTTOCK_S2annualLossImage_analysis_1
   The AOI of this lost-image is the Rottock Bay Consolidated Concession for the annual forest lost analysis in 2016 and is generated by subtracting the forest areas in 2015 (as the REFERENCE IMAGE; Start Date: 2015/01/01; End Date: 2015/12/31) with the forest areas in 2016 (as the TARGET IMAGE; Start Date: 2016/01/01; End Date: 2016/12/31).
4. ROTTOCK_S2annualLossImage_analysis_2
   The AOI of this lost-image is the Rottock Bay Consolidated Concession for the annual forest lost analysis in 2017 and is generated by subtracting the forest areas in 2016 (as the REFERENCE IMAGE; Start Date: 2016/01/01; End Date: 2016/12/31) with the forest areas in 2017 (as the TARGET IMAGE; Start Date: 2017/01/01; End Date: 2017/12/31).

e. Part 9: Tree-cover loss accumulation.

This part collects the function to generate the tree-cover loss accumulation by utilizing the greenest and the least-greenest images. The tree-cover loss accumulation method follows the following workflow:

(i) Obtain an image collection for a given year in a given AOI,
(ii) Apply the topographic correction for each image in the image collection,
(iii) Generate the cloud-free image collection by using the CFMASK and FMASK cloud/haze elimination method for Landsat-8 based script and Sentinel-2 based script, respectively,
(iv) Derive the NDVI image for each image in the cloud-free image collection,
(v) Generate the greenest image by taking the highest (maximum) NDVI value on each pixel in the image collection, and the least-greenest image by taking the lowest (minimum) NDVI value on each pixel in the image collection,
(vi) Calculate the tree-cover loss accumulation by subtracting the greenest image with the least-greenest image and take all values that is greater than the threshold value (so called the tTreecover that is describes as a user-defined threshold value that is used to determine a unit of tree-cover loss in the analysis),
(vii) Calculate the tree-cover loss accumulation areas, print them to the GEE Console, and display the tree-cover loss accumulation image to the GEE Map.

6.3.1.2 Script Guidelines

The primary objective of these scripts is to monitor the annual logging activities inside boundaries of logging concessions in Papua New Guinea. Therefore, the following script guidelines are intended to instruct the users for utilizing the Landsat-8 Annual Forest Loss Detection (v2018.12.11) and the Sentinel-2 Annual Forest Loss Detection (v2018.12.11).

a. Step-by-step instructions

To obtain the best advantage of these scripts, the users are kindly requested to follow the step-by-step instructions on how to use these scripts that are described as follows:

1. Navigate to the Google Earth Engine (GEE) Code Editor in Google Chrome, log in with a GEE-registered Google account, and open a forest loss detection script.
2. Prior to run the script, users are requested to read the input command's instructions and fill out the input commands (15 in total) that are available in the "Part 1:Input Commands."
3. Proceed with the COMMAND-1 and COMMAND-2 to define the period (i.e., the start date and the end date) of the FIRST REFERENCE IMAGE for the analysis. Each command includes three variables to assign the year, the month, and the date separately. Please type the preferred period as shown below:

For Landsat-8 Annual Forest Loss Detection (v2018.12.11)

```
// [COMMAND-1] FIRST REFERENCE IMAGE - Start Date
/*  Instruction:
(a) Define the Start Date of the FIRST REFERENCE IMAGE.
(b) Insert the YEAR, MONTH, and DATE on separate variables.
*/
var firstRefStart_YEAR = 2014;
var firstRefStart_MONTH = 1;
var firstRefStart_DATE = 1;


// [COMMAND-2] FIRST REFERENCE IMAGE - End Date
/*  Instruction:
(a) Define the End Date of the FIRST REFERENCE IMAGE.
(b) Insert the YEAR, MONTH, and DATE on separate variables.
*/
var firstRefEnd_YEAR = 2014;
var firstRefEnd_MONTH = 12;
var firstRefEnd_DATE = 31;
```

For Sentinel-2 Annual Forest Loss Detection (v2018.12.11)

```
// [COMMAND-1] FIRST REFERENCE IMAGE - Start Date
/*  Instruction:
(a) Define the Start Date of the FIRST REFERENCE IMAGE.
(b) Insert the YEAR, MONTH, and DATE on separate variables.
*/
var firstRefStart_YEAR = 2015;
var firstRefStart_MONTH = 1;
var firstRefStart_DATE = 1;


// [COMMAND-2] FIRST REFERENCE IMAGE - End Date
/*  Instruction:
(a) Define the End Date of the FIRST REFERENCE IMAGE.
(b) Insert the YEAR, MONTH, and DATE on separate variables.
*/
var firstRefEnd_YEAR = 2015;
var firstRefEnd_MONTH = 12;
var firstRefEnd_DATE = 31;
```

4. Proceed with the COMMAND-3 and COMMAND-4 to define the period (i.e., the start date and the end date) of the FIRST TARGET IMAGE for the analysis. Each command includes three variables to assign the year, the month, and the date separately. Please type the preferred period as shown below:
For Landsat-8 Annual Forest Loss Detection (v2018.12.11)

```
// [COMMAND-3] FIRST TARGET IMAGE - Start Date
/*  Instruction:
(a) Define the Start Date of the FIRST TARGET IMAGE.
(b) Insert the YEAR, MONTH, and DATE on separate variables.
*/
var firstTargetStart_YEAR = 2015;
var firstTargetStart_MONTH = 1;
var firstTargetStart_DATE = 1;


// [COMMAND-4] FIRST TARGET IMAGE - End Date
/*  Instruction:
(a) Define the End Date of the FIRST TARGET IMAGE.
(b) Insert the YEAR, MONTH, and DATE on separate variables.
*/
var firstTargetEnd_YEAR = 2015;
var firstTargetEnd_MONTH = 12;
var firstTargetEnd_DATE = 31;
```

For Sentinel-2 Annual Forest Loss Detection (v2018.12.11)

```
// [COMMAND-3] FIRST TARGET IMAGE - Start Date
/*  Instruction:
(a) Define the Start Date of the FIRST TARGET IMAGE.
(b) Insert the YEAR, MONTH, and DATE on separate variables.
*/
var firstTargetStart_YEAR = 2016;
var firstTargetStart_MONTH = 1;
var firstTargetStart_DATE = 1;


// [COMMAND-4] FIRST TARGET IMAGE - End Date
/*  Instruction:
(a) Define the End Date of the FIRST TARGET IMAGE.
(b) Insert the YEAR, MONTH, and DATE on separate variables.
*/
var firstTargetEnd_YEAR = 2016;
var firstTargetEnd_MONTH = 12;
var firstTargetEnd_DATE = 31;
```

5. Proceed with the COMMAND-5 to define the total amount of the TARGET IMAGES to be used for analysis, which includes the FIRST TARGET IMAGE. Please type the amount as shown below:
For Landsat-8 Annual Forest Loss Detection (v2018.12.11)

```
// [COMMAND-5] TARGET IMAGES
/*  Instruction:
Define the amount of TARGET IMAGES to be used for analysis,
which INCLUDING the FIRST TARGET IMAGE.
*/
var totalTarget = 3;
```

For Sentinel-2 Annual Forest Loss Detection (v2018.12.11)

```
// [COMMAND-5] TARGET IMAGES
/*  Instruction:
Define the amount of TARGET IMAGES to be used for analysis,
which INCLUDING the FIRST TARGET IMAGE.
*/
var totalTarget = 2;
```


6. Proceed with the COMMAND-6 to select the area of interest (AOI) to be used for forest loss detection. Both scripts are supported annual forest loss detection for two AOIs that are the Amanab Consolidated Concession (‘AMANAB’) and the Rottock Bay Consolidated Concession (‘ROTTOCK’). Please type the preferred AOI as shown below, for both scripts:

```
// [COMMAND-6] AREA OF INTEREST
/*  Instruction:
Select the Area of interest (AOI) to be calculated:
(a) Type 'AMANAB' for Amanab Consolidated Concession.
(b) Type 'ROTTOCK' for Rottock Bay Consolidated Concession.
*/
var aoi_select = 'AMANAB';
```

7. Proceed with the COMMAND-7 to select the method to be used for cloud/haze elimination purposes. For the Landsat-8 based script, two cloud/haze elimination methods are available to be used, i.e., the QA band method and the CFMASK-derived QA band method. For the Sentinel-2 based script, two cloud/haze elimination methods are available to be used, i.e., the QA band method and the FMASK-algorithm method. On each script, the recommended method to be used for cloud/haze elimination is listed for the user’s convenience. Please type the preferred cloud/haze elimination method as shown below:
For Landsat-8 Annual Forest Loss Detection (v2018.12.11)

```
// [COMMAND-7] CLOUD/HAZE ELIMINATION METHOD
/*  Instruction:
Select the method to be used for cloud/haze elimination.
(a) Type 'QA_BAND' for using the QAband method.
(b) Type 'CFMASK' for using the CFMASK-derived QAband method.
-----------------------------
RECOMMENDED METHOD: 'CFMASK'
-----------------------------
*/
var getImageFunction = 'CFMASK';
```

For Sentinel-2 Annual Forest Loss Detection (v2018.12.11)

```
// [COMMAND-7] CLOUD/HAZE ELIMINATION METHOD
/*  Instruction:
Select the method to be used for cloud/haze elimination.
(a) Type 'QA_BAND' for using the QAband method.
(b) Type 'FMASK' for using the FMASK-algorithm method.
-----------------------------
RECOMMENDED METHOD: 'FMASK'
-----------------------------
*/
var getImageFunction = 'FMASK';
```

8. Proceed with the COMMAND-8 to select whether to display the cloud-free images to the GEE Map or not. Please type the preferred option as shown below, for both scripts:

```
// [COMMAND-8] CLOUD-FREE IMAGES
/*  Instruction:
Do you want to display cloud-free images to the GEE Map?
(a) Type 'YES' to display.
(b) Type 'NO' to not display.
*/
var showCloudFree = 'YES';
```

9. Proceed with the COMMAND-9 to select the method to be used for forest loss detection purposes. For both scripts, two forest loss detection methods are available to be selected, i.e., the combination of

NDVI, NDWI, and NBR method and the integration of SMA and NDFI method. Please type the forest loss detection method as shown below, for both scripts:

```
// [COMMAND-9] FOREST LOSS DETECTION METHOD
/*  Instruction:
Select the method to be used for forest loss detection.
(a) Type 'NDVI_NDWI_NBR' for using the combination of NDVI, NDWI, and NBR.
(b) Type 'SMA_NDFI' for using the integration of SMA and NDFI.
*/
var methodOfAnalysis = 'NDVI_NDWI_NBR';
```

10. Proceed with the COMMAND-10 to assign the threshold value to define a unit of forest loss in the analysis (so-called the tIndex). On each script, the recommended tIndex to be applied to each AOI and on each forest loss detection method is listed for the user's convenience. Please type the preferred tIndex as shown below:

<u>For Landsat-8 Annual Forest Loss Detection (v2018.12.11)</u>

```
// [COMMAND-10] THRESHOLD VALUE
/*  Instruction:
Set a threshold value to define a unit of forest loss in the analysis.
-------------------------------------------------
RECOMMENDED THRESHOLD VALUE:
(1) 'AMANAB'
    (a) For 'NDVI_NDWI_NBR' set tIndex to 0.215
    (b) For 'SMA_NDFI' set tIndex to 1.925
(2) 'ROTTOCK'
    (a) For 'NDVI_NDWI_NBR' set tIndex to 0.180
    (b) For 'SMA_NDFI' set tIndex to 1.900
-------------------------------------------------
*/
var tIndex = 0.215;
```

<u>For Sentinel-2 Annual Forest Loss Detection (v2018.12.11)</u>

```
// [COMMAND-10] THRESHOLD VALUE
/*  Instruction:
Set a threshold value to define a unit of forest loss in the analysis.
-------------------------------------------------
RECOMMENDED THRESHOLD VALUE:
(1) 'AMANAB'
    (a) For 'NDVI_NDWI_NBR' set tIndex to 0.190
    (b) For 'SMA_NDFI' set tIndex to 1.955
(2) 'ROTTOCK'
    (a) For 'NDVI_NDWI_NBR' set tIndex to 0.140
    (b) For 'SMA_NDFI' set tIndex to 1.905
-------------------------------------------------
*/
var tIndex = 0.190;
```

11. Proceed with the COMMAND-11 to select whether to display the loss images to the GEE Map or not. Please type the preferred option as shown below, for both scripts:

```
// [COMMAND-11] LOSS IMAGES
/*  Instruction:
Do you want to display loss-images to the GEE Map?
(a) Type 'YES' to display.
(b) Type 'NO' to not display.
*/
var showLossImages = 'YES';
```


12. Proceed with the COMMAND-12 to select whether to calculate the loss areas in square kilometers and print it to the GEE Console or not. Please type the preferred option as shown below, for both scripts:

```
// [COMMAND-12] LOSS AREA CALCULATION
/*  Instruction:
Do you want to calculate loss area and print it to the GEE Console?
(a) Type 'YES' to proceed.
(b) Type 'NO' to not proceed.
*/
var calLossArea = 'YES';
```

13. Proceed with the COMMAND-13 and COMMAND-14 to select whether to export the loss images to user's Assets in GEE or not and to export the loss images to user's Google Drive account or not, respectively. Please type the preferred option as shown below, for both scripts:

```
// [COMMAND-13] EXPORT LOSS IMAGES TO ASSET
/*  Instruction:
Do you want to export loss-images to user's Asset?
(a) Type 'YES' to export.
(b) Type 'NO' to not export.
*/
var exportLossToAsset = 'NO';


// [COMMAND-14] EXPORT LOSS IMAGES TO GOOGLE DRIVE
/*  Instruction:
Do you want to export loss-images to user's Google Drive?
(a) Type 'YES' to export.
(b) Type 'NO' to not export.
*/
var exportLossToDrive = 'NO';
```

14. Proceed with the COMMAND-15 to select whether to generate the greenest and least-greenest images as well as calculate the tree-cover loss accumulation for each year. If the user selects 'YES,' the threshold value to define a unit of tree-cover loss in the analysis (so-called the tTreecover) should also be defined. On each script, the recommended tTreecover to be applied to each AOI is listed for the user's convenience. Please type the preferred option and tTreecover (only defined if the preferred option is a 'YES') as shown below:

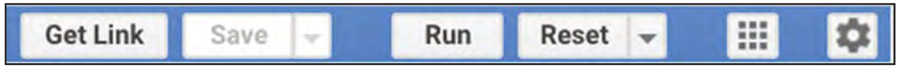
<u>For Landsat-8 Annual Forest Loss Detection (v2018.12.11)</u>

```
// [COMMAND-15] TREE-COVER LOSS ACCUMULATION
/*  Instruction:
Do you want to generate greenest and least-greenest images,
and calculate tree-cover loss accumulation for each year?
(a) Type 'YES' and define the threshold value to define a unit of tree-cover loss.
(b) Type 'NO' to not proceed.
-------------------------------------------------
RECOMMENDED THRESHOLD VALUE:
(1) For 'AMANAB' set tTreecover to 0.845
(2) For 'ROTTOCK' set tTreecover to 0.585
-------------------------------------------------
*/
var showTreecoverAccum = 'NO';
var tTreecover = 0.845;
```

For Sentinel-2 Annual Forest Loss Detection (v2018.12.11)

```
// [COMMAND-15] TREE-COVER LOSS ACCUMULATION
/* Instruction:
Do you want to generate greenest and least-greenest images,
and calculate tree-cover loss accumulation for each year?
(a) Type 'YES' and define the threshold value to define a unit of tree-cover loss.
(b) Type 'NO' to not proceed.
----------------------------------------------------------
RECOMMENDED THRESHOLD VALUE:
(1) For 'AMANAB' set tTreecover to 0.740
(2) For 'ROTTOCK' set tTreecover to 0.715
----------------------------------------------------------
*/
var showTreecoverAccum = 'NO';
var tTreecover = 0.740;
```

15. Finally, please kindly check that all input commands have been filled correctly by following each instruction and click 'Run' button on the top-side of the GEE Code Editor to start the forest loss analysis.



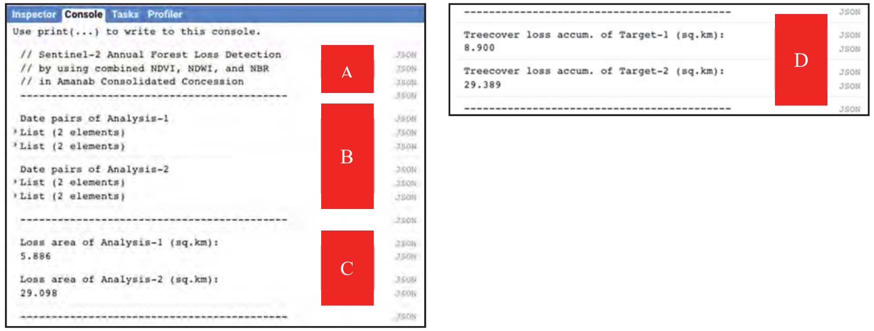
b. Description of the printed results and displayed outputs.

To understand the printed results in the GEE Console and the displayed outputs in the GEE Map, the users are kindly recommended to have a look at the following descriptions:

1. The printed results in the GEE Console are shown as follows:

For Landsat-8 Annual Forest Loss Detection (v2018.12.11)

For Sentinel-2 Annual Forest Loss Detection (v2018.12.11)

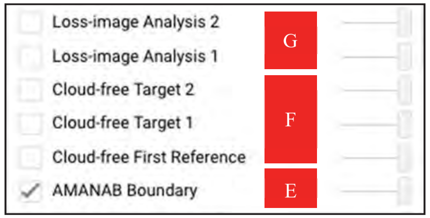


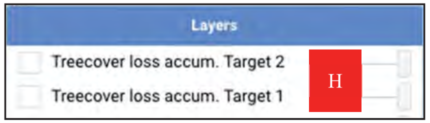
For both scripts, the A section displays the title of the script that includes the name of the sensor being used, the information about the selected forest loss detection method, and the name of the AOI being analyzed. Afterward, the B section displays the lists of date pairs of the REFERENCE and TARGET IMAGE for all analyses. On each list of date-pairs, the upper list shows the date of the REFERENCE IMAGE (the start date and end date) and the lower list shows the date of the TARGET IMAGE (the start date and end date). The number of the lists of date pairs depends on the total amount of TARGET IMAGES. The users are recommended to click the zippy symbol (▸) to see the detail information of a list of date-pairs. Meanwhile, the C section shows the calculated loss areas for all analysis in square kilometers (sq. km). Finally, the D section shows the calculated tree-cover loss accumulation areas for all years (including the year of the FIRST REFERENCE IMAGE) in square kilometers (sq. km).

2. The displayed outputs in the GEE Map that are listed in the 'Layers' tab are shown as follows:

For Landsat-8 Annual Forest Loss Detection (v2018.12.11)

For Sentinel-2 Annual Forest Loss Detection (v2018.12.11)

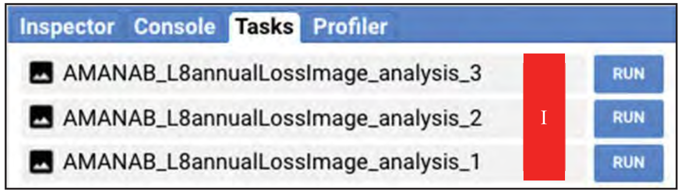


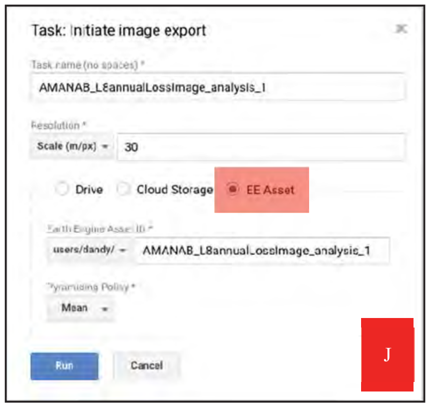


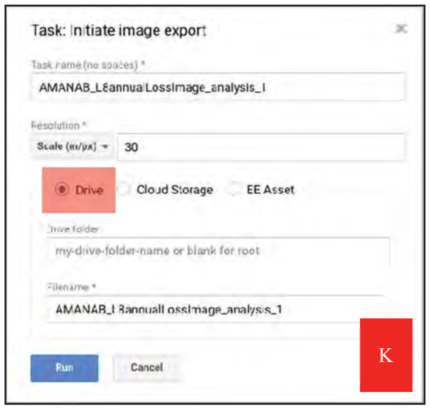
For both scripts, the E section is the layer of the boundary of the selected area of interest (AOI_name Boundary). Afterward, the F section is the cloud-free image collection for the FIRST REFERENCE IMAGE and each TARGET IMAGE; please check the box to display a cloud-free image to the GEE Map (R: SWIR1; G: NIR; B: RED). Moreover, the G section is associated with the loss-image collection for each forest loss analysis; please check the box to display a loss-image to the GEE Map. On a loss-image, the detected forest loss areas are shown in red color. Lastly, the H section is related to the tree-cover loss accumulation image collection for all years in the investigation period (including the year of the FIRST REFERENCE IMAGE). On a tree-cover loss accumulation image, the detected tree-cover loss accumulation areas are shown in red color.

3. Finally, to proceed the export options to user's Assets in GEE and or to user's Google Drive account, please navigate to the GEE 'Tasks' tab for validating export as shown below:

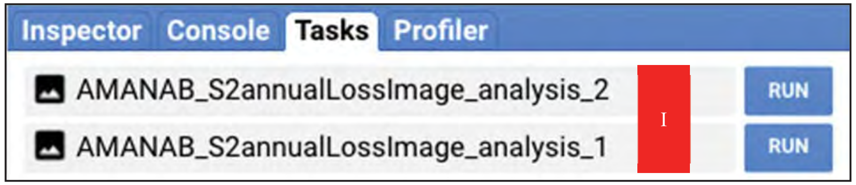
For Landsat-8 Annual Forest Loss Detection (v2018.12.11)

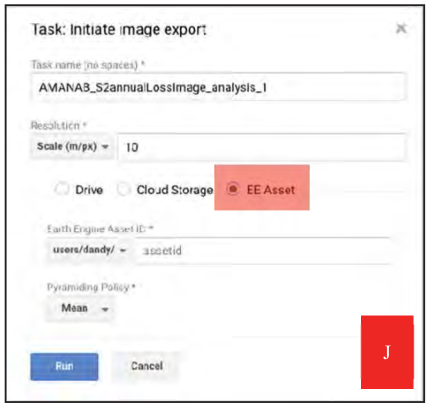


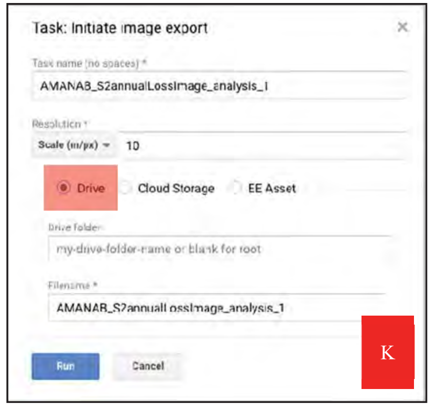




For Sentinel-2 Annual Forest Loss Detection (v2018.12.11)







For both scripts, the I section is the list of the loss-image collection waited to be exported to either user's Assets in GEE or user's Google Drive account; the users are kindly requested to click the 'Run' button to proceed the export. By clicking the 'Run' button, the J section would appear for exporting to user's Assets in GEE option, while the K section would appear for exporting to user's Google Drive account option. Please kindly check and confirm the details and click the 'Run' button on the pop-up window to start the export.

6.3.1.3 Conclusion and remarks

The Landsat-8 Annual Forest Loss Detection (v2018.12.11) and the Sentinel-2 Annual Forest Loss Detection (v2018.12.11) scripts are developed to monitor the annual logging activities inside of logging concessions in Papua New Guinea. These scripts are supported the annual forest loss detection for two AOIs, which are the Amanab Consolidated Concession and the Rottock Bay Consolidated Concession. On each script, two forest loss detection methods are available to be selected, i.e., the combination of NDVI, NDWI, and NBR method and the integration of SMA and NDFI method.

The outputs of these scripts are: (a) The annual forest loss areas calculated in square kilometers unit for each analysis, (b) The forest loss image for each analysis in TIFF format that could be displayed in the GEE Map and or exported to the user's Assets in GEE or Google Drive account, (c) The additional tree-cover loss accumulation areas calculated in square kilometers unit for each year in the investigation period, and (d) The additional tree-cover loss accumulation image for each year in the investigation period that could be displayed in the GEE Map. Furthermore, the main advantage of using these scripts is the potential to generate the annual forest lost areas by utilizing either Landsat-8 or Sentinel-2 images. This information could be used to monitor the annual logging activities inside of logging concessions in Papua New Guinea during a given investigation period. Moreover, the dynamic trend of the logging activities in both AOIs could be understood so that might help stakeholders to advance the decision-making actions, especially from the viewpoint of geospatial analysis.

On both scripts, the users are able to select the preferred methods for cloud/haze elimination (For the Landsat-8 based script: The QA band method and the CFMASK-derived QA band method; For the Sentinel-2 based script: The QA band method and the FMASK-algorithm method) and forest loss detection (The combination of NDVI, NDWI, and NBR method and the integration of SMA and NDFI method), as well as to define the preferred threshold value for defining a unit of forest loss in the analysis (the tIndex). Therefore, the result of the forest loss detection highly depends on the selected methods and threshold values. For the user's convenience, the recommended methods and threshold values are listed for both scripts. Moreover, the performance of these recommendations has been analyzed and validated with the Hansen Forest Change v1.5 data (http://earthenginepartners.appspot.com/science-2013-global-forest).

Finally, as quick-start guidance for using these scripts, the users are kindly requested to follow the default settings for filling the input commands on each script as listed below:

For Landsat-8 Annual Forest Loss Detection (v2018.12.11)

Table 3.1 Landsat-8 Annual Forest loss Detection			
Input Commands			
Command	**Variable**	**Value**	**Remark**
COMMAND-1	firstRefStart_YEAR	2014	
	firstRefStart_MONTH	1	
	firstRefStart_DATE	1	
COMMAND-2	firstRefEnd_YEAR	2014	
	firstRefEnd_MONTH	12	
	firstRefEnd_DATE	31	
COMMAND-3	firstTargetStart_YEAR	2015	
	firstTargetStart_MONTH	1	
	firstTargetStart_DATE	1	
COMMAND-4	firstTargetEnd_YEAR	2015	
	firstTargetEnd_MONTH	12	
	firstTargetEnd_DATE	31	
COMMAND-5	totalTarget	3	The TARGET IMAGES are 2015, 2016, and 2017.
COMMAND-6	aoi_select	'AMANAB'	For forest loss detection in Amanab Consolidated Concession
	aoi_select	'ROTTOCK'	For forest loss detection in Rottock Bay Consolidated Concession
COMMAND-7	getImageFunction	'CFMASK'	
COMMAND-8	showCloudFree	'YES'	
COMMAND-9	methodOfAnalysis	'NDVI_NDWI_NBR'	Using the combination of NDVI. NDWI, and NBR method.
	methodOfAnalysis	'SMA_NDFI'	Using the integration of SMA and NDFI method.
COMMAND-10	tIndex	0.215	For COMMAND-6 = 'AMANAB' and COMMAND-7 = 'NDVI_NDWI_NBR'
	tIndex	1.925	For COMMAND-6 = 'AMANAB' and COMMAND-7 = 'SMA_NDFI'
	tIndex	0.180	For COMMAND-6 = 'ROTTOCK' and COMMAND-7 = 'NDVI_NDWI_NBR'
	tIndex	1.900	For COMMAND-6 = 'ROTTOCK' and COMMAND-7 = 'SMA_NDFI'
COMMAND-11	showLossImages	'YES'	
COMMAND-12	calLossArea	'YES'	
COMMAND-13	exportLossToAsset	'YES'	Exporting all loss images to user's Assets in GEE.
COMMAND-14	exportLossToDrive	'YES'	Exporting all loss images to user's Google Drive account.
COMMAND-15	showTreecoverAccum	'YES'	
	tTreecover	0.845	For COMMAND-6 = 'AMANAB' and showTreecoverAccum = 'YES'
	tTreecover	0.585	For COMMAND-6 = 'ROTTOCK' and showTreecoverAccum = 'YES'
Results for Amanab Consolidated Concession			
Forest Loss Detection			
Image ID	**Analysis**	**Annual Forest Loss (sq. Km) for NDVI, NDWI, and NBR Method**	**Annual Forest Loss (sq. Km) for SMA and NDFI Method**
AMANAB_L8annualLossImage_analysis_1	Forest Loss in 2015 (Forest Area 2014 - Forest Area 2015)	3.904	7.437
AMANAB_L8annualLossImage_analysis_2	Forest Loss in 2016 (Forest Area 2015- Forest Area 2016)	7.249	14.622
AMANAB_L8annualLossImage_analysis_3	Forest Loss in 2017 (Forest Area 2016- Forest Area 2017)	30.796	31.540
Tree-cover Loss Accumulation			
Year		**Tree-cover Loss Accumulation (sq. Km)**	
AMANAB Tree-cover Loss Accumulation in 2014		4.461	
AMANAB Tree-cover Loss Accumulation in 2015		0.124	
AMANAB Tree-cover Loss Accumulation in 2016		0.744	
AMANAB Tree-cover Loss Accumulation in 2017		28.999	
Results for Rottock Bay Consolidated Concession			
Forest Loss Detection			
Image ID	**Analysis**	**Annual Forest Loss (sq. Km) for NDVI, NDWI, and NBR Method**	**Annual Forest Loss (sq. Km) for SMA and NDFI Method**

ROTTOCK_L8annualLossImage_analysis_1	Forest Loss in 2015 (Forest Area 2014 - Forest Area 2015)	32.133	34.727
ROTTOCK_L8annualLossImage_analysis_2	Forest Loss in 2016 (Forest Area 2015- Forest Area 2016)	1.050	2.100
ROTTOCK_L8annualLossImage_analysis_3	Forest Loss in 2017 (Forest Area 2016- Forest Area 2017)	5.252	3.213
Tree-cover Loss Accumulation			
Year		**Tree-cover Loss Accumulation (sq. Km)**	
ROTTOCK Tree-cover Loss Accumulation in 2014		2.346	
ROTTOCK Tree-cover Loss Accumulation in 2015		28.415	
ROTTOCK Tree-cover Loss Accumulation in 2016		15.071	
ROTTOCK Tree-cover Loss Accumulation in 2017		20.568	

For Sentinel-2 Annual Forest Loss Detection (v2018.12.11)

Table 3.2 Sentinel-2 Annual Forest loss Detection			
Input Commands			
Command	**Variable**	**Value**	**Remark**
COMMAND-1	firstRefStart_YEAR	2015	
	firstRefStart_MONTH	1	
	firstRefStart_DATE	1	
COMMAND-2	firstRefEnd_YEAR	2015	
	firstRefEnd_MONTH	12	
	firstRefEnd_DATE	31	
COMMAND-3	firstTargetStart_YEAR	2016	
	firstTargetStart_MONTH	1	
	firstTargetStart_DATE	1	
COMMAND-4	firstTargetEnd_YEAR	2016	
	firstTargetEnd_MONTH	12	
	firstTargetEnd_DATE	31	
COMMAND-5	totalTarget	2	The TARGET IMAGES are 2016, and 2017.
COMMAND-6	aoi_select	'AMANAB'	For forest loss detection in Amanab Consolidated Concession
	aoi_select	'ROTTOCK'	For forest loss detection in Rottock Bay Consolidated Concession
COMMAND-7	getImageFunction	'FMASK'	
COMMAND-8	showCloudFree	'YES'	
COMMAND-9	methodOfAnalysis	'NDVI_NDWI_NBR'	Using the combination of NDVI. NDWI, and NBR method.

	methodOfAnalysis	'SMA_NDFI'	Using the integration of SMA and NDFI method.
COMMAND-10	tIndex	0.190	For COMMAND-6 = 'AMANAB' and COMMAND-7 = 'NDVI_NDWI_NBR'
	tIndex	1.955	For COMMAND-6 = 'AMANAB' and COMMAND-7 = 'SMA_NDFI'
	tIndex	0.140	For COMMAND-6 = 'ROTTOCK' and COMMAND-7 = 'NDVI_NDWI_NBR'
	tIndex	1.905	For COMMAND-6 = 'ROTTOCK' and COMMAND-7 = 'SMA_NDFI'
COMMAND-11	showLossImages	'YES'	
COMMAND-12	calLossArea	'YES'	
COMMAND-13	exportLossToAsset	'YES'	Exporting all loss images to user's Assets in GEE.
COMMAND-14	exportLossToDrive	'YES'	Exporting all loss images to user's Google Drive account.
COMMAND-15	showTreecoverAccum	'YES'	
	tTreecover	0.740	For COMMAND-6 = 'AMANAB' and showTreecoverAccum = 'YES'
	tTreecover	0.715	For COMMAND-6 = 'ROTTOCK' and showTreecoverAccum = 'YES'
Results for Amanab Consolidated Concession			
Forest Loss Detection			
Image ID	**Analysis**	**Annual Forest Loss (sq. Km) for NDVI, NDWI, and NBR Method**	**Annual Forest Loss (sq. Km) for SMA and NDFI Method**
AMANAB_S2annualLossImage_analysis_1	Forest Loss in 2016 (Forest Area 2015- Forest Area 2016)	5.886	5.081
AMANAB_S2annualLossImage_analysis_2	Forest Loss in 2017 (Forest Area 2016- Forest Area 2017)	29.098	28.230
Tree-cover Loss Accumulation			
Year		**Tree-cover Loss Accumulation (sq. Km)**	
AMANAB Tree-cover Loss Accumulation in 2016		8.900	
AMANAB Tree-cover Loss Accumulation in 2017		29.389	
Results for Rottock Bay Consolidated Concession			
Forest Loss Detection			
Image ID	**Analysis**	**Annual Forest Loss (sq. Km) for NDVI, NDWI, and NBR Method**	**Annual Forest Loss (sq. Km) for SMA and NDFI Method**
ROTTOCK_S2annualLossImage_analysis_1	Forest Loss in 2016 (Forest Area 2015- Forest Area 2016)	3.521	2.841
ROTTOCK_S2annualLossImage_analysis_1	Forest Loss in 2017 (Forest Area 2016- Forest Area 2017)	7.228	7.289
Tree-cover Loss Accumulation			
Year		**Tree-cover Loss Accumulation (sq. Km)**	
ROTTOCK Tree-cover Loss Accumulation in 2016		6.364	
ROTTOCK Tree-cover Loss Accumulation in 2017		6.487	

6.3.2 The User Manual for Sentinel-2 Weekly Forest Loss Detection (v2018.12.11)

6.3.2.1 Introduction

The Sentinel-2 Weekly Forest Loss Detection (v2018.12.11) is a script intended to monitor the weekly logging activities inside of logging concessions in Papua New Guinea. Two forest loss detection methods are available to be selected, i.e., the combination of Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), and Normalized Burn Ratio (NBR) method and the integration of Spectral Mixture Analysis (SMA) and Normalized Difference Fraction Index (NDFI) method. This script is divided into nine parts, which are: (1) Input Commands, (2) Parameters Collections, (3) Cloud/Haze Elimination Functions, (4) Parameters for First Reference Image, (5) Parameters for Target Image Collections, (6) Parameters for Continuous Reference Image Collections, (7) Forest Loss Analysis, (8) Loss Area Calculation, and (9) Parameters for Export Images.

a. Part 1: Input Commands

In this part, all input commands (14 in total) should be defined by the user prior to run the script. The first command (COMMAND-1) is to assign the START DATE of the FIRST REFERENCE IMAGE that includes three variables, i.e., firstRefStart_YEAR to define the year, firstRefStart_MONTH to define the month, and firstRefStart_DATE to define the date. In this script, the START DATE of the FIRST REFERENCE IMAGE is the date of the LAST SUNDAY of a given MONTH. The second command (COMMAND-2) is to assign the END DATE of the FIRST REFERENCE IMAGE that includes three variables, i.e., firstRefEnd_YEAR to define the year, firstRefEnd_MONTH to define the month, and firstRefEnd_DATE to define the date. In this script, the END DATE of the FIRST REFERENCE IMAGE is the date of the following SUNDAY counted from the START DATE of the FIRST REFERENCE IMAGE. Therefore, the duration from the START DATE to the END DATE of the FIRST REFERENCE IMAGE is an ONE-WEEK duration counted from the LAST SUNDAY of a given MONTH to the following SUNDAY of the following MONTH. The third command (COMMAND-3) is to assign the START DATE of the TARGET IMAGES DURATION that includes three variables, i.e., targetStart_YEAR to define the year, targetStart_MONTH to define the month, and targetStart_DATE to define the date. In this script, the START DATE of the TARGET IMAGES DURATION is the date of the FIRST SUNDAY of a MONTH. The users are recommended to assign the same date for the START DATE of the TARGET IMAGES DURATION (COMMAND-3) and the END DATE of the FIRST REFERENCE IMAGE (COMMAND-2). The fourth command (COMMAND-4) is to assign the END DATE of the TARGET IMAGES DURATION that includes three variables, i.e., targetEnd_YEAR to define the year, targetEnd_MONTH to define the month, and targetEnd_DATE to define the date. In this script, the END DATE of the TARGET IMAGES DURATION is the date of the FIRST SUNDAY of the following MONTH counted from the START DATE of the TARGET IMAGES DURATION. Therefore, the duration from the START DATE to the END DATE of the TARGET IMAGES DURATION is an ONE-MONTH duration counted from the date of the FIRST

SUNDAY of a MONTH to the FIRST SUNDAY of the following MONTH. The fifth command (COMMAND-5) is to define the TOTAL WEEKS of the TARGET IMAGES DURATION to be used for analysis. An ONE-WEEK is counted from a given SUNDAY to the following SUNDAY. The sixth command (COMMAND-6) is to select the area of interest (AOI) to be used for forest loss detection. This script is supported the weekly forest loss detection for two AOIs in Papua New Guinea that is the Amanab Consolidated Concession and the Rottock Bay Consolidated Concession. The seventh command (COMMAND-7) is to select the method to be used for cloud/haze elimination purposes. On this script, two cloud/haze elimination methods are available to be used, i.e., the QA band method and the FMASK-algorithm method. The recommended method to be used for cloud/haze elimination is listed for the user's convenience. The eighth command (COMMAND-8) is an option whether to display the cloud-free images to the Google Earth Engine (GEE) Map or not. The ninth command (COMMAND-9) is to select the method to be used for forest loss detection purposes. On this script, two forest loss detection methods are available to be selected, i.e., the combination of NDVI, NDWI, and NBR method and the integration of SMA and NDFI method. The tenth command (COMMAND-10) is to assign the threshold value to define a unit of forest loss in the analysis (so-called the tIndex). On this script, the recommended tIndex to be applied to each AOI and on each forest loss detection method is listed for the user's convenience. The eleventh command (COMMAND-11) is an option whether to display the loss images to the GEE Map or not. The twelfth command (COMMAND-12) is an option whether to calculate the loss areas in square kilometers and print it to the GEE Console or not. The thirteenth command (COMMAND-13) is an option whether to export the loss images to user's Assets in GEE or not. The fourteenth command (COMMAND-14) is an option whether to export the loss images to user's Google Drive account or not.

b. Part 2: Parameters Collections

This part comprises the collection of general parameters that are used on the script. These parameters include: (a) The definition of image collections, (b) The date formatting for the investigation period, (c) The conditional functions for the selected AOI, (d) The conditional functions for the selected method for forest loss detection, (e) A command to print the script's title to the GEE Console, (f) A command for masking the tree-cover in the selected AOI that is derived from the Hansen Global Forest Change v1.5 data, (g) A collection of visual parameters, and (h) A command to display the boundary of the selected AOI to the GEE Map.

c. Part 3: Cloud/Haze Elimination Functions

This part collects functions to generate cloud-free images by using the cloud/haze elimination methods. On this script, two functions of cloud/haze elimination methods are defined, i.e., the QA band method and the FMASK-algorithm method. Basically, each cloud/haze elimination method follows the following workflow: (a) Define the local parameters to be used on the function, (b) Obtain the image collection from the image archive, (c) Apply the topographic correction function that is based on Teillet, P.M., et al. (1982), (d) Apply the cloud/haze elimination function for each image in the image collection, (e) Apply the Dark

Object Subtraction (DOS) radiometric correction function that is based on Chavez (1988), (f) Generate the mosaic image of the weekly cloud-free image by taking the median value of the image collection and clip it with the boundary of the selected AOI, (g) Generate the vegetation index images to be used for further image processing.

d. Part 4: Parameters for First Reference Image

In this part, the commands to display the duration of the FIRST REFERENCE IMAGE, to generate the cloud-free image collection for the FIRST REFERENCE IMAGE, and to display the cloud-free FIRST REFERENCE IMAGE to the GEE Map are listed.

e. Part 5: Parameters for Target Image Collections

In this part, the commands to display the duration of the TARGET IMAGES, to generate the cloud-free image collections for the TARGET IMAGES, and to display the cloud-free TARGET IMAGES to the GEE Map are listed.

f. Part 6: Parameters for Continuous Reference Image Collections

This part comprises the commands to generate the list of cloud-free image pairs in the investigation period (i.e., the pair of REFERENCE IMAGE and TARGET IMAGE) for each weekly forest loss analysis.

g. Part 7: Forest Loss Analysis

This part comprises functions to analyze forest loss by utilizing the forest loss detection methods. On this script, two forest loss detection methods are defined, i.e., the combination of NDVI, NDWI, and NBR method and the integration of SMA and NDFI method. The earlier-mentioned method analyzes the difference between NDVI, NDWI, and NBR images for a given reference and target images so that a decreasing value of those three indices at a given area or pixel that is greater than the given threshold value (tIndex) would be considered as forest loss. This method is adapted from the forest loss detection method derived by Hansen et al. (2016). Meanwhile, the later-mentioned method utilizes SMA-derived fraction images for generating NDFI image for a given reference and target image so that a decreasing value of NDFI at a given area or pixel that is greater than the given threshold value (tIndex) would be considered as forest loss. This method is initially proposed by Souza et al. (2003), Souza et al. (2005), and Souza et al. (2013). Lastly, the command to display the loss-image collection for each analysis to the GEE Map is listed.

h. Part 8: Loss Area Calculation

In this part, the function to calculate the loss areas is listed. On this script, the loss areas are calculated per 250 meters grid to accommodate a speedy computation. Furthermore, the unit of the loss areas is converted to square kilometers. At the end of this part, the command to print the loss-area for each analysis to the GEE Console is provided.

i. Part 9: Parameters for Export Images.

This part collects conditional functions for exporting the loss-image collection to user's Assets in GEE and user's Google Drive account. Each exported loss-image would have a pixel size of 10 meters and a UTM WGS84 projection. The naming structure of each lost-image is described as follows:

(AOI**)**_S2weeklyLossImage_(targetStart)_week_**(**n**)**

The (AOI) defines as the name of the area of interest of the image; 'AMANAB' for Amanab Consolidated Concession and 'ROTTOCK' for Rottock Bay Consolidated Concession. Meanwhile, the (targetStart) is the START DATE of the TARGET IMAGES DURATION with a 'YEAR-MONTH-DATE' format. Lastly, the (n) is the sequence of the week that is being analyzed, e.g., the first sequence (n = 1) defined as the loss-image for the first week counted from the START DATE of the TARGET IMAGES DURATION; the second sequence (n = 2) defined as the loss-image for the second week counted from the START DATE of the TARGET IMAGES DURATION; and so on until the sequence ends. To better understand the naming structure, please kindly have a look at these examples:

1. AMANAB_S2weeklyLossImage_2018-6-3_week_1
   The AOI of this weekly lost-image is the Amanab Consolidated Concession for the first week counted from '2018-6-3,' or from the '2018-6-3' to '2018-6-10.'
2. AMANAB_S2weeklyLossImage_2018-6-3_week_2
   The AOI of this weekly lost-image is the Amanab Consolidated Concession for the second week counted from '2018-6-3,' or from the '2018-6-10' to '2018-6-17.'
3. AMANAB_S2weeklyLossImage_2018-6-3_week_3
   The AOI of this weekly lost-image is the Amanab Consolidated Concession for the third week counted from '2018-6-3,' or from the '2018-6-17' to '2018-6-24.'
4. AMANAB_S2weeklyLossImage_2018-6-3_week_4
   The AOI of this weekly lost-image is the Amanab Consolidated Concession for the fourth week counted from '2018-6-3,' or from the '2018-6-24' to '2018-7-1.'
5. ROTTOCK_S2weeklyLossImage_2018-8-5_week_1
   The AOI of this weekly lost-image is the Rottock Bay Consolidated Concession for the first week counted from '2018-8-5,' or from the '2018-8-5' to '2018-8-12.'
6. ROTTOCK_S2weeklyLossImage_2018-8-5_week_2
   The AOI of this weekly lost-image is the Rottock Bay Consolidated Concession for the second week counted from '2018-8-5,' or from the '2018-8-12' to '2018-8-19.'
7. ROTTOCK_S2weeklyLossImage_2018-8-5_week_3
   The AOI of this weekly lost-image is the Rottock Bay Consolidated Concession for the third week counted from '2018-8-5,' or from the '2018-8-19' to '2018-8-26.'

8. ROTTOCK_S2weeklyLossImage_2018-8-5_week_4
   The AOI of this weekly lost-image is the Rottock Bay Consolidated Concession for the fourth week counted from '2018-8-5,' or from the '2018-8-26' to '2018-9-2.'

6.3.2.2 Script Guidelines

The primary objective of this script is to monitor the weekly logging activities inside boundaries of logging concessions in Papua New Guinea. Therefore, the following script guidelines are intended to instruct the users for utilizing the Sentinel-2 Weekly Forest Loss Detection (v2018.12.11).

a. Step-by-step instructions

To obtain the best advantage of the script, the users are kindly requested to follow the step-by-step instructions on how to use this script that are described as follows:

1. Navigate to the Google Earth Engine (GEE) Code Editor in Google Chrome, log in with a GEE-registered Google account, and open a forest loss detection script.
2. Prior to run the script, users are requested to read the input command's instructions and fill out the input commands (14 in total) that are available in the "Part 1:Input Commands."
3. Proceed with the COMMAND-1 and COMMAND-2 to define the period (i.e., the start date and the end date) of the FIRST REFERENCE IMAGE for the analysis. Each command includes three variables to assign the year, the month, and the date separately. Please kindly consider that the duration from the START DATE to the END DATE of the FIRST REFERENCE IMAGE is an ONE-WEEK duration counted from the LAST SUNDAY of a given MONTH to the following SUNDAY of the following MONTH. Please type the preferred period as shown below:

```
// [COMMAND-1] FIRST REFERENCE IMAGE - Start Date
/*  Instruction:
(a) Define the Start Date of the FIRST REFERENCE IMAGE.
(b) The Start Date of the FIRST REFERENCE IMAGE is the date of
    the LAST SUNDAY of a MONTH.
(c) Insert the YEAR, MONTH, and DATE on separate variables.
*/
var firstRefStart_YEAR = 2018;
var firstRefStart_MONTH = 5;
var firstRefStart_DATE = 27;


// [COMMAND-2] FIRST REFERENCE IMAGE - End Date
/*  Instruction:
(a) Define the End Date of the FIRST REFERENCE IMAGE.
(b) The End Date of the FIRST REFERENCE IMAGE is the date of the following SUNDAY from
    the Start Date of the FIRST REFERENCE IMAGE.
(c) For FIRST REFERENCE IMAGE, from Start Date to End Date is a ONE-WEEK duration from
    the LAST SUNDAY of a MONTH to the following SUNDAY of the following MONTH.
(d) The End Date of the FIRST REFERENCE IMAGE should be the same date as the
    Start Date of the TARGET IMAGES DURATION.
(e) Insert the YEAR, MONTH, and DATE on separate variables.
*/
var firstRefEnd_YEAR = 2018;
var firstRefEnd_MONTH = 6;
var firstRefEnd_DATE = 3;
```

4. Proceed with the COMMAND-3 and COMMAND-4 to define the period (i.e., the start date and the end date) of the TARGET IMAGES DURATION for the analysis. Each command includes three variables to

assign the year, the month, and the date separately. The users are recommended to assign the same date for the START DATE of the TARGET IMAGES DURATION (COMMAND-3) and the END DATE of the FIRST REFERENCE IMAGE (COMMAND-2). Please kindly consider that the duration from the START DATE to the END DATE of the TARGET IMAGES DURATION is an ONE-MONTH duration counted from the date of the FIRST SUNDAY of a MONTH to the FIRST SUNDAY of the following MONTH. Please type the preferred period as shown below:

```
// [COMMAND-3] TARGET IMAGES DURATION - Start Date
/*  Instruction:
(a) Define the Start Date of the TARGET IMAGES DURATION.
(b) The Start Date of the TARGET IMAGES DURATION is the FIRST SUNDAY of a MONTH.
(c) The Start Date of the TARGET IMAGES DURATION should be the same date as the
    End Date of the FIRST REFERENCE IMAGE.
(d) Insert the YEAR, MONTH, and DATE on separate variables.
*/
var targetStart_YEAR = 2018;
var targetStart_MONTH = 6;
var targetStart_DATE = 3;


// [COMMAND-4] TARGET IMAGES DURATION - End Date
/*  Instruction:
(a) Define the End Date of the TARGET IMAGES DURATION.
(b) The End Date of the TARGET IMAGES DURATION is the FIRST SUNDAY of the following MONTH from
    the Start Date of the TARGET IMAGES DURATION.
(c) For TARGET IMAGES DURATION, from Start Date to End Date is a ONE-MONTH duration from
    a FIRST SUNDAY of a month to the FIRST SUNDAY of the following month.
(d) Insert the YEAR, MONTH, and DATE on separate variables.
*/
var targetEnd_YEAR = 2018;
var targetEnd_MONTH = 7;
var targetEnd_DATE = 1;
```

5. Proceed with the COMMAND-5 to define the TOTAL WEEKS of the TARGET IMAGES DURATION to be used for analysis. An ONE-WEEK is counted from a given SUNDAY to the following SUNDAY. Please type the amount as shown below:

```
// [COMMAND-5] TOTAL WEEKS
/*  Instruction:
Define the TOTAL WEEKS of the TARGET IMAGES DURATION.
*/
var totalWeeks = 4;
```

6. Proceed with the COMMAND-6 to select the area of interest (AOI) to be used for forest loss detection. This script is supported weekly forest loss detection for two AOIs that are the Amanab Consolidated Concession ('AMANAB') and the Rottock Bay Consolidated Concession ('ROTTOCK'). Please type the preferred AOI as shown below:

```
// [COMMAND-6] AREA OF INTEREST
/*  Instruction:
Select the Area of interest (AOI) to be calculated:
(a) Type 'AMANAB' for Amanab Consolidated Concession.
(b) Type 'ROTTOCK' for Rottock Bay Consolidated Concession.
*/
var aoi_select = 'AMANAB';
```

7. Proceed with the COMMAND-7 to select the method to be used for cloud/haze elimination purposes. On this script, two cloud/haze elimination methods are available to be used, i.e., the QA band method and the FMASK-algorithm method. The recommended method to be used for cloud/haze elimination is listed for the user's convenience. Please type the preferred cloud/haze elimination method as shown below:

```
// [COMMAND-7] CLOUD/HAZE ELIMINATION METHOD
/*  Instruction:
Select the method to be used for cloud/haze elimination.
(a) Type 'QA_BAND' for using the QAband method.
(b) Type 'FMASK' for using the FMASK-algorithm method.
----------------------------
RECOMMENDED METHOD: 'FMASK'
----------------------------
*/
var getImageFunction = 'FMASK';
```

8. Proceed with the COMMAND-8 to select whether to display the cloud-free images to the GEE Map or not. Please type the preferred option as shown below:

```
// [COMMAND-8] CLOUD-FREE IMAGES
/*  Instruction:
Do you want to display cloud-free images to the GEE Map?
(a) Type 'YES' to display.
(b) Type 'NO' to not display.
*/
var showCloudFree = 'YES';
```

9. Proceed with the COMMAND-9 to select the method to be used for forest loss detection purposes. On this script, two forest loss detection methods are available to be selected, i.e., the combination of NDVI, NDWI, and NBR method and the integration of SMA and NDFI method. Please type the forest loss detection method as shown below:

```
// [COMMAND-9] FOREST LOSS DETECTION METHOD
/*  Instruction:
Select the method to be used for forest loss detection.
(a) Type 'NDVI_NDWI_NBR' for using the combination of NDVI, NDWI, and NBR.
(b) Type 'SMA_NDFI' for using the integration of SMA and NDFI.
*/
var methodOfAnalysis = 'NDVI_NDWI_NBR';
```

10. Proceed with the COMMAND-10 to assign the threshold value to define a unit of forest loss in the analysis (so-called the tIndex). The recommended tIndex to be applied to each AOI and on each forest loss detection method is listed for the user's convenience. Please type the preferred tIndex as shown below:

```
// [COMMAND-10] THRESHOLD VALUE
/*  Instruction:
Set a threshold value to define a unit of forest loss in the analysis.
----------------------------------------------
RECOMMENDED THRESHOLD VALUE:
(1) 'AMANAB'
    (a) For 'NDVI_NDWI_NBR' set tIndex to 0.190
    (b) For 'SMA_NDFI' set tIndex to 1.945
(2) 'ROTTOCK'
    (a) For 'NDVI_NDWI_NBR' set tIndex to 0.275
    (b) For 'SMA_NDFI' set tIndex to 1.975
----------------------------------------------
*/
var tIndex = 0.190;
```


11. Proceed with the COMMAND-11 to select whether to display the loss images to the GEE Map or not. Please type the preferred option as shown below:

```
// [COMMAND-11] LOSS IMAGES
/*  Instruction:
Do you want to display loss-images to the GEE Map?
(a) Type 'YES' to display.
(b) Type 'NO' to not display.
*/
var showLossImages = 'YES';
```

12. Proceed with the COMMAND-12 to select whether to calculate the loss areas in square kilometers and print it to the GEE Console or not. Please type the preferred option as shown below:

```
// [COMMAND-12] LOSS AREA CALCULATION
/*  Instruction:
Do you want to calculate loss area and print it to the GEE Console?
(a) Type 'YES' to proceed.
(b) Type 'NO' to not proceed.
*/
var calLossArea = 'YES';
```

13. Proceed with the COMMAND-13 and COMMAND-14 to select whether to export the loss images to user's Assets in GEE or not and to export the loss images to user's Google Drive account or not, respectively. Please type the preferred option as shown below:

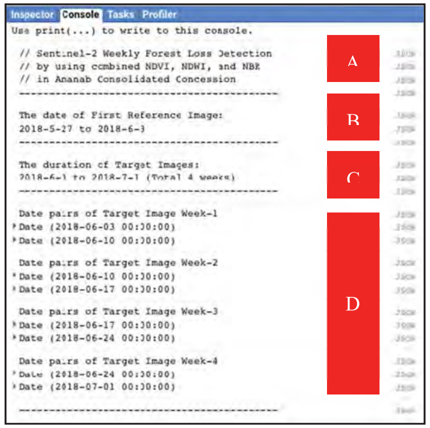
```
// [COMMAND-13] EXPORT LOSS IMAGES TO ASSET
/*  Instruction:
Do you want to export loss-images to user's Asset?
(a) Type 'YES' to export.
(b) Type 'NO' to not export.
*/
var exportLossToAsset = 'YES';


// [COMMAND-14] EXPORT LOSS IMAGES TO GOOGLE DRIVE
/*  Instruction:
Do you want to export loss-images to user's Google Drive?
(a) Type 'YES' to export.
(b) Type 'NO' to not export.
*/
var exportLossToDrive = 'YES';
```

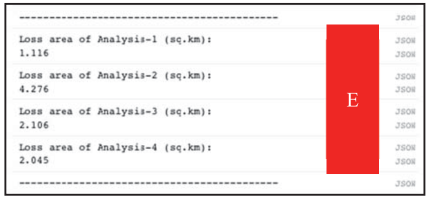
14. Finally, please kindly check that all input commands have been filled correctly by following each instruction and click 'Run' button on the top-side of the GEE Code Editor to start the forest loss analysis.

b. <u>Description of the printed results and displayed outputs.</u>

To understand the printed results in the GEE Console and the displayed outputs in the GEE Map, the users are kindly recommended to have a look at the following descriptions:

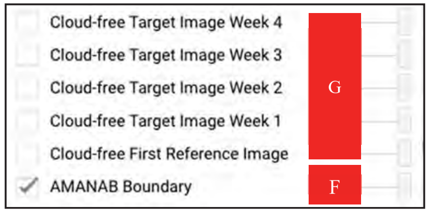
1. The printed results in the GEE Console are shown as follows:

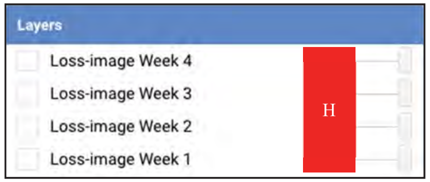




The A section displays the title of the script that includes the name of the sensor being used, the information about the selected forest loss detection method, and the name of the AOI being analyzed. Afterward, the B section shows the duration of the FIRST REFERENCE IMAGE for the analysis. Meanwhile, the C section is the duration of TARGET IMAGES for the analysis including the information of the TOTAL WEEKS. Next, the D section displays the weekly date pair within the TARGET IMAGES duration. On each weekly date pair, the upper date is the start date of a weekly TARGET IMAGE (on a given SUNDAY), and the lower date is its end date (the following SUNDAY). The number of the weekly date pair depends on the number of TOTAL WEEKS. Finally, the E section shows the calculated loss areas for all analysis in square kilometers (sq. km).

2. The displayed outputs in the GEE Map that are listed in the 'Layers' tab are shown as follows:

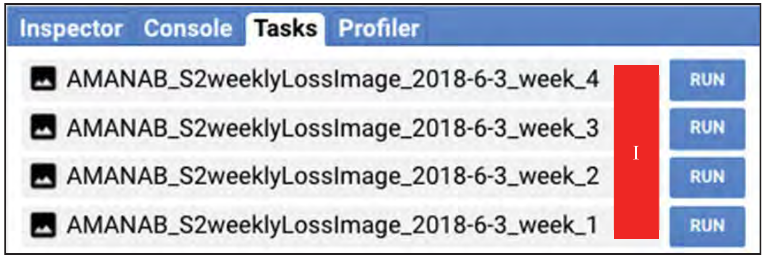


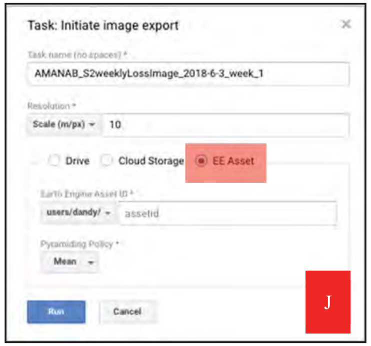


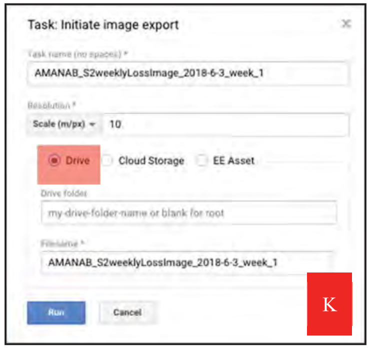
The F section is the layer of the boundary of the selected area of interest (AOI_name Boundary). Afterward, the G section is the cloud-free image collection for the FIRST REFERENCE IMAGE and each TARGET IMAGE; please check the box to display a cloud-free image to the GEE Map (R: SWIR1;

G: NIR; B: RED). Lastly, the H section is associated with the loss-image collection for each forest loss analysis; please check the box to display a loss-image to the GEE Map. On a loss-image, the detected forest loss areas are shown in red color.

3. Finally, to proceed the export options to user's Assets in GEE and or to user's Google Drive account, please navigate to the GEE 'Tasks' tab for validating export as shown below:







The I section is the list of the loss-image collection waited to be exported to either user's Assets in GEE or user's Google Drive account; the users are kindly requested to click the 'Run' button to proceed the export. By clicking the 'Run' button, the J section would appear for exporting to user's Assets in GEE option, while the K section would appear for exporting to user's Google Drive account option. Please kindly check and confirm the details and click the 'Run' button on the pop-up window to start the export.

6.3.2.3 Conclusion and remarks

The Sentinel-2 Weekly Forest Loss Detection (v2018.12.11) script is developed to monitor the weekly logging activities inside of logging concessions in Papua New Guinea. This script is supported the weekly forest loss detection for two AOIs, which are the Amanab Consolidated Concession and the Rottock Bay Consolidated Concession. In this script, two forest loss detection methods are available to be selected, i.e., the combination of NDVI, NDWI, and NBR method and the integration of SMA and NDFI method.

The outputs of this script are: (a) The weekly forest loss areas calculated in square kilometers unit for each analysis and (b) The forest loss image for each analysis in TIFF format that could be displayed in the GEE Map and or exported to the user's Assets in GEE or Google Drive account. Furthermore, the primary advantage of using this script is the ability to obtain the weekly forest lost areas by using the Sentinel-2 images so that this script could provide a rapid and reliable forest monitoring technique, especially for monitoring the logging activities inside of logging concessions in Papua New Guinea. Moreover, the dynamic trend of the logging activities in both AOIs could be understood in greater detail (i.e., weekly) so that might help stakeholders to advance both the short-term and the long-term decision-making actions, especially from the viewpoint of geospatial analysis.

In this script, the users are allowed to select the preferred methods for cloud/haze elimination (The QA band method and the FMASK-algorithm method) and forest loss detection (The combination of NDVI, NDWI, and NBR method and the integration of SMA and NDFI method), as well as to define the preferred threshold value for describing a unit of forest loss in the analysis (the tIndex). Therefore, the result of the forest loss detection highly depends on the selected methods and threshold values. For the user's convenience, the recommended methods and threshold values are listed on the script. Moreover, the performance of these recommendations has been analyzed and validated with the Global Land Analysis & Discovery (GLAD) alerts data (https://www.globalforestwatch.org/map).

Finally, as quick-start guidance for using the script, the users are kindly requested to follow the default settings for filling the input commands as listed below:

Table 3.1 Sentinel-2 Weekly Forest loss Detection

Input Commands

Command	Variable	Value	Remark
COMMAND-1	firstRefStart_YEAR firstRefStart_MONTH firstRefStart_DATE	Please refer to the Input Commands (COMMAND-1 to COMMAND-5) column of Weekly Analysis for each month.	Please define the year, month, and date separately as the following example: COMMAND-1 firstRefStart = yyyy-mm-*dd* firstRefStart_YEAR = yyyy firstRefStart_MONTH = mm firstRefStart_DATE = *dd*
COMMAND-2	firstRefEnd_YEAR firstRefEnd_MONTH firstRefEnd_DATE	Please refer to the Input Commands (COMMAND-1 to COMMAND-5) column of Weekly Analysis for each month.	Please define the year, month, and date separately as the following example: COMMAND-2 firstRefEnd = yyyy-mm-*dd* firstRefEnd_YEAR = yyyy firstRefEnd_MONTH = mm firstRefEnd_DATE = *dd*
COMMAND-3	targetStart_YEAR targetStart_MONTH targetStart_DATE	Please refer to the Input Commands (COMMAND-1 to COMMAND-5) column of Weekly Analysis for each month.	Please define the year, month, and date separately as the following example: COMMAND-3 targetStart = yyyy-mm-*dd* targetStart_YEAR = yyyy targetStart_MONTH = mm targetStart_DATE = *dd*
COMMAND-4	targetEnd_YEAR targetEnd_MONTH targetEnd_DATE	Please refer to the Input Commands (COMMAND-1 to COMMAND-5) column of Weekly Analysis for each month.	Please define the year, month, and date separately as the following example: COMMAND-4 targetEnd = yyyy-mm-*dd* targetEnd_YEAR = yyyy targetEnd_MONTH = mm targetEnd_DATE = *dd*
COMMAND-5	totalWeeks	Please refer to the Input Commands (COMMAND-1 to COMMAND-5) column of Weekly Analysis for each month.	The TOTAL WEEKS is the number of week within the TARGET IMAGES DURATION to be used for analysis

COMMAND-6	aoi_select	'AMANAB'	For forest loss detection in Amanab Consolidated Concession
	aoi_select	'ROTTOCK'	For forest loss detection in Rottock Bay Consolidated Concession
COMMAND-7	getImageFunction	'FMASK'	
COMMAND-8	showCloudFree	'YES'	
COMMAND-9	methodOfAnalysis	'NDVI_NDWI_NBR'	Using the combination of NDVI. NDWI, and NBR method.
	methodOfAnalysis	'SMA_NDFI'	Using the integration of SMA and NDFI method.
COMMAND-10	tIndex	0.190	For COMMAND-6 = 'AMANAB' and COMMAND-7 = 'NDVI_NDWI_NBR'
	tIndex	1.945	For COMMAND-6 = 'AMANAB' and COMMAND-7 = 'SMA_NDFI'
	tIndex	0.275	For COMMAND-6 = 'ROTTOCK' and COMMAND-7 = 'NDVI_NDWI_NBR'
	tIndex	1.975	For COMMAND-6 = 'ROTTOCK' and COMMAND-7 = 'SMA_NDFI'
COMMAND-11	showLossImages	'YES'	
COMMAND-12	calLossArea	'YES'	
COMMAND-13	exportLossToAsset	'YES'	Exporting all loss images to user's Assets in GEE.
COMMAND-14	exportLossToDrive	'YES'	Exporting all loss images to user's Google Drive account.

Results for Amanab Consolidated Concession

Forest Loss Detection

Input Commands (COMMAND-1 to COMMAND-5)	Analysis	Weekly Forest Loss (sq. Km) for NDVI, NDWI, and NBR Method	Weekly Forest Loss (sq. Km) for SMA and NDFI Method
Weekly Analysis For January 2018 COMMAND-1 firstRefStart = 2017-12-31 COMMAND-2 firstRefEnd = 2018-1-7 COMMAND-3 targetStart = 2018-1-7 COMMAND-4 targetEnd = 2018-2-4 COMMAND-5 totalWeeks = 4	Forest Loss in Week-1	3.222	2.912
	Forest Loss in Week-2	0.620	0.558
	Forest Loss in Week-3	1.673	2.788
	Forest Loss in Week-4	0.124	0.000
Weekly Analysis For February 2018 COMMAND-1 firstRefStart = 2018-1-28 COMMAND-2 firstRefEnd = 2018-2-4 COMMAND-3 targetStart = 2018-2-4 COMMAND-4 targetEnd = 2018-3-4 COMMAND-5 totalWeeks = 4	Forest Loss in Week-1	5.142	12.763
	Forest Loss in Week-2	1.673	3.160
	Forest Loss in Week-3	0.744	1.115
	Forest Loss in Week-4	0.496	0.000
Weekly Analysis For March 2018 COMMAND-1 firstRefStart = 2018-2-25 COMMAND-2 firstRefEnd = 2018-3-4 COMMAND-3 targetStart = 2018-3-4 COMMAND-4 targetEnd = 2018-4-1 COMMAND-5 totalWeeks = 4	Forest Loss in Week-1	0.867	1.673
	Forest Loss in Week-2	1.735	4.522
	Forest Loss in Week-3	5.204	5.885
	Forest Loss in Week-4	1.053	0.991
Weekly Analysis For April 2018 COMMAND-1 firstRefStart = 2018-3-25 COMMAND-2 firstRefEnd = 2018-4-1 COMMAND-3 targetStart = 2018-4-1 COMMAND-4 targetEnd = 2018-5-6 COMMAND-5 totalWeeks = 5	Forest Loss in Week-1	0.062	0.062
	Forest Loss in Week-2	4.586	6.259
	Forest Loss in Week-3	1.673	1.859
	Forest Loss in Week-4	3.780	4.276
	Forest Loss in Week-5	2.788	4.028
Weekly Analysis For May 2018 COMMAND-1 firstRefStart = 2018-4-29 COMMAND-2 firstRefEnd = 2018-5-6 COMMAND-3 targetStart = 2018-5-6 COMMAND-4 targetEnd = 2018-6-3	Forest Loss in Week-1	2.231	1.053
	Forest Loss in Week-2	2.371	2.185
	Forest Loss in Week-3	2.107	2.292

COMMAND-5 totalWeeks = 4	Forest Loss in Week-4	1.178	2.231
Weekly Analysis For June 2018 COMMAND-1 firstRefStart = 2018-5-27 COMMAND-2 firstRefEnd = 2018-6-3 COMMAND-3 targetStart = 2018-6-3 COMMAND-4 targetEnd = 2018-7-1 COMMAND-5 totalWeeks = 4	Forest Loss in Week-1	1.116	1.425
	Forest Loss in Week-2	4.276	4.338
	Forest Loss in Week-3	2.106	2.106
	Forest Loss in Week-4	2.045	1.983
Weekly Analysis For July 2018 COMMAND-1 firstRefStart = 2018-6-24 COMMAND-2 firstRefEnd = 2018-7-1 COMMAND-3 targetStart = 2018-7-1 COMMAND-4 targetEnd = 2018-8-5 COMMAND-5 totalWeeks = 5	Forest Loss in Week-1	7.622	7.499
	Forest Loss in Week-2	3.904	8.056
	Forest Loss in Week-3	6.196	7.560
	Forest Loss in Week-4	0.868	1.363
	Forest Loss in Week-5	3.036	2.727
Weekly Analysis For August 2018 COMMAND-1 firstRefStart = 2018-7-29 COMMAND-2 firstRefEnd = 2018-8-5 COMMAND-3 targetStart = 2018-8-5 COMMAND-4 targetEnd = 2018-9-2 COMMAND-5 totalWeeks = 4	Forest Loss in Week-1	1.259	1.259
	Forest Loss in Week-2	0.496	0.558
	Forest Loss in Week-3	1.588	1.135
	Forest Loss in Week-4	3.036	2.664
Weekly Analysis For September 2018 COMMAND-1 firstRefStart = 2018-8-26 COMMAND-2 firstRefEnd = 2018-9-2 COMMAND-3 targetStart = 2018-9-2 COMMAND-4 targetEnd = 2018-10-7 COMMAND-5 totalWeeks = 5	Forest Loss in Week-1	4.275	4.709
	Forest Loss in Week-2	0.372	1.115
	Forest Loss in Week-3	0.000	0.000
	Forest Loss in Week-4	0.372	0.929
	Forest Loss in Week-5	3.470	7.002
Weekly Analysis For October 2018 COMMAND-1 firstRefStart = 2018-9-30 COMMAND-2 firstRefEnd = 2018-10-7 COMMAND-3 targetStart = 2018-10-7 COMMAND-4 targetEnd = 2018-11-4 COMMAND-5 totalWeeks = 4	Forest Loss in Week-1	5.081	1.921
	Forest Loss in Week-2	0.248	0.124
	Forest Loss in Week-3	0.000	0.000
	Forest Loss in Week-4	0.000	0.000
Weekly Analysis For November 2018 COMMAND-1 firstRefStart = 2018-10-28 COMMAND-2 firstRefEnd = 2018-11-4 COMMAND-3 targetStart = 2018-11-4 COMMAND-4 targetEnd = 2018-12-2 COMMAND-5 totalWeeks = 4	Forest Loss in Week-1	0.620	0.558
	Forest Loss in Week-2	6.506	6.630
	Forest Loss in Week-3	18.342	10.782
	Forest Loss in Week-4	0.124	0.682

Results for Rottock Bay Consolidated Concession			
Forest Loss Detection			
Input Commands (COMMAND-1 to COMMAND-5)	**Analysis**	**Weekly Forest Loss (sq. Km) for NDVI, NDWI, and NBR Method**	**Weekly Forest Loss (sq. Km) for SMA and NDFI Method**
Weekly Analysis For January 2018 COMMAND-1 firstRefStart = 2017-12-31 COMMAND-2 firstRefEnd = 2018-1-7 COMMAND-3 targetStart = 2018-1-7 COMMAND-4 targetEnd = 2018-2-4 COMMAND-5 totalWeeks = 4	Forest Loss in Week-1	0.000	0.000
	Forest Loss in Week-2	0.000	0.000
	Forest Loss in Week-3	0.000	0.124
	Forest Loss in Week-4	0.000	0.000
Weekly Analysis For February 2018 COMMAND-1 firstRefStart = 2018-1-28 COMMAND-2 firstRefEnd = 2018-2-4 COMMAND-3 targetStart = 2018-2-4 COMMAND-4 targetEnd = 2018-3-4 COMMAND-5 totalWeeks = 4	Forest Loss in Week-1	0.000	0.000
	Forest Loss in Week-2	0.000	0.000
	Forest Loss in Week-3	0.000	0.000
	Forest Loss in Week-4	0.000	0.000
Weekly Analysis For March 2018 COMMAND-1 firstRefStart = 2018-2-25 COMMAND-2 firstRefEnd = 2018-3-4 COMMAND-3 targetStart = 2018-3-4 COMMAND-4 targetEnd = 2018-4-1 COMMAND-5 totalWeeks = 4	Forest Loss in Week-1	0.000	0.000
	Forest Loss in Week-2	0.000	0.000
	Forest Loss in Week-3	0.000	0.000
	Forest Loss in Week-4	0.062	0.247
Weekly Analysis For April 2018 COMMAND-1 firstRefStart = 2018-3-25 COMMAND-2 firstRefEnd = 2018-4-1	Forest Loss in Week-1	0.247	0.309
	Forest Loss in Week-2	0.000	0.000

COMMAND-3 targetStart = 2018-4-1 COMMAND-4 targetEnd = 2018-5-6 COMMAND-5 totalWeeks = 5	Forest Loss in Week-3	0.000	0.000
	Forest Loss in Week-4	0.124	0.741
	Forest Loss in Week-5	0.000	0.185
Weekly Analysis For May 2018 COMMAND-1 firstRefStart = 2018-4-29 COMMAND-2 firstRefEnd = 2018-5-6 COMMAND-3 targetStart = 2018-5-6 COMMAND-4 targetEnd = 2018-6-3 COMMAND-5 totalWeeks = 4	Forest Loss in Week-1	0.865	0.371
	Forest Loss in Week-2	0.062	0.000
	Forest Loss in Week-3	0.989	0.309
	Forest Loss in Week-4	0.000	0.000
Weekly Analysis For June 2018 COMMAND-1 firstRefStart = 2018-5-27 COMMAND-2 firstRefEnd = 2018-6-3 COMMAND-3 targetStart = 2018-6-3 COMMAND-4 targetEnd = 2018-7-1 COMMAND-5 totalWeeks = 4	Forest Loss in Week-1	0.000	0.000
	Forest Loss in Week-2	0.000	0.000
	Forest Loss in Week-3	0.000	0.000
	Forest Loss in Week-4	0.000	0.000
Weekly Analysis For July 2018 COMMAND-1 firstRefStart = 2018-6-24 COMMAND-2 firstRefEnd = 2018-7-1 COMMAND-3 targetStart = 2018-7-1 COMMAND-4 targetEnd = 2018-8-5 COMMAND-5 totalWeeks = 5	Forest Loss in Week-1	0.185	0.062
	Forest Loss in Week-2	0.000	0.000
	Forest Loss in Week-3	0.000	0.000
	Forest Loss in Week-4	0.000	0.000
	Forest Loss in Week-5	0.000	0.000
Weekly Analysis For August 2018 COMMAND-1 firstRefStart = 2018-7-29 COMMAND-2 firstRefEnd = 2018-8-5 COMMAND-3 targetStart = 2018-8-5 COMMAND-4 targetEnd = 2018-9-2 COMMAND-5 totalWeeks = 4	Forest Loss in Week-1	0.000	0.000
	Forest Loss in Week-2	0.185	0.062
	Forest Loss in Week-3	0.185	0.185
	Forest Loss in Week-4	0.309	0.185
Weekly Analysis For September 2018 COMMAND-1 firstRefStart = 2018-8-26 COMMAND-2 firstRefEnd = 2018-9-2 COMMAND-3 targetStart = 2018-9-2 COMMAND-4 targetEnd = 2018-10-7 COMMAND-5 totalWeeks = 5	Forest Loss in Week-1	0.309	0.247
	Forest Loss in Week-2	0.000	0.000
	Forest Loss in Week-3	0.000	0.000
	Forest Loss in Week-4	0.000	0.000
	Forest Loss in Week-5	0.247	0.556
Weekly Analysis For October 2018 COMMAND-1 firstRefStart = 2018-9-30 COMMAND-2 firstRefEnd = 2018-10-7 COMMAND-3 targetStart = 2018-10-7 COMMAND-4 targetEnd = 2018-11-4 COMMAND-5 totalWeeks = 4	Forest Loss in Week-1	0.000	0.000
	Forest Loss in Week-2	0.000	0.000
	Forest Loss in Week-3	0.000	0.000
	Forest Loss in Week-4	0.000	0.000
Weekly Analysis For November 2018 COMMAND-1 firstRefStart = 2018-10-28 COMMAND-2 firstRefEnd = 2018-11-4 COMMAND-3 targetStart = 2018-11-4 COMMAND-4 targetEnd = 2018-12-2 COMMAND-5 totalWeeks = 4	Forest Loss in Week-1	0.000	0.000
	Forest Loss in Week-2	0.062	0.124
	Forest Loss in Week-3	0.000	0.000
	Forest Loss in Week-4	0.000	0.000

6.3.3 The final report

The final report is the present document that describes the methods applied to each task for the development of the annual and weekly forest loss detection system by using Google Earth Engine technology in Papua New Guinea as well as provides the results of each task that listed on each chapter.

6.4 Conclusion

The present chapter has been successfully established the user manuals to instruct the users for utilizing the developed annual and weekly forest loss detection systems for monitoring logging activities inside of logging concession in Papua New Guinea and compiled the final report that describes the methods applied and the results of each task that listed on each chapter. The conclusion of this chapter is listed as follows:

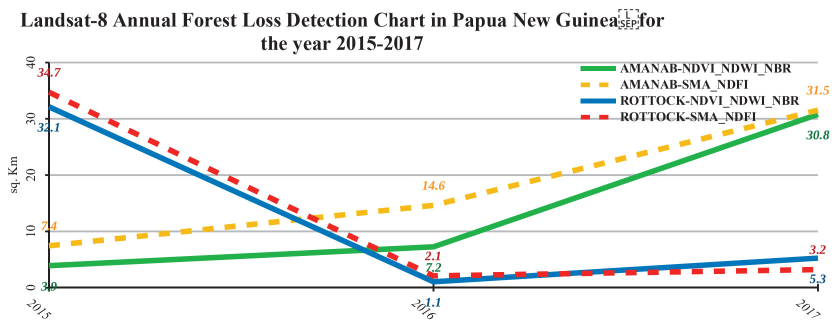
a. The user manual of the Landsat-8 and Sentinel-2 annual forest loss detection systems for monitoring logging activities inside of logging concession in Papua New Guinea is established.
b. The user manual of the Sentinel-2 weekly forest loss detection systems for monitoring logging activities inside of logging concession in Papua New Guinea is composed.
c. The final report outlining methods applied and the results of the forest loss detection systems for monitoring logging activities inside of logging concession in Papua New Guinea is compiled.

Chapter 7
General Conclusion and Remarks

The present work has developed the annual and weekly forest loss detection system by using the Google Earth Engine Technology for Papua New Guinea. This work serves as a step to update forest information for grasping forest situations regularly, which is further supporting the management and wise utilization of the forest resources of Papua New Guinea that is being promoted by the Papua New Guinea Forest Authority (PNGFA). This work was addressed to complete the following tasks: (1) to check the capabilities of forest loss detection systems developed in the third country for applying in Papua New Guinea, (2) to update the annual and weekly forest loss detection system for adapting to circumstances in Papua New Guinea based on the clarified issues, (3) to develop a monitoring system for selective logging concessions utilizing the Google Earth Engine technology, (4) to develop a system for monitoring logging activities inside logging concessions in Papua New Guinea using Google Earth Engine technology, and (5) to prepare the documents of user manuals to instruct the users for utilizing the developed forest loss detection systems. Therefore, the following descriptions are presented to serve as the general conclusion for the present work:

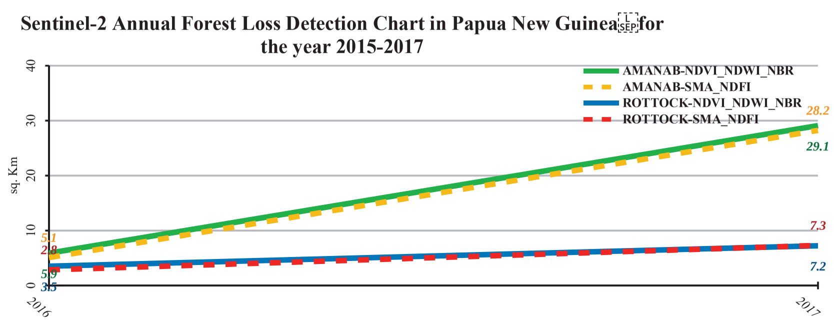
a. For both AOIs (i.e., Amanab Consolidated Concession and Rottock Bay Consolidated Concession), the CFMASK-derived QA band method and the FMASK-algorithm method are set as the default cloud/haze elimination method for the Landsat-8 and Sentinel-2 forest loss detection systems, respectively, due to their better performances (i.e., a higher Producer's Accuracy for cloudy class and/or a higher User's Accuracy) as compared to the other method. Therefore, these methods are listed as the recommended cloud/haze elimination method in the annual and weekly forest loss detection systems for the users to obtain the best advantage of the systems.
b. The optimum threshold values for defining a unit of forest loss (so-called the tIndex) were obtained by comparing the generated forest loss areas with the truth data. For the Landsat-8 and Sentinel-2 annual forest loss detection systems, the Hansen Forest Change v1.5 is served as the truth data, whereas for the Sentinel-2 weekly forest loss detection systems, the GLAD (Global Land Analysis & Discovery) data is served as the truth data. The optimum threshold values yielded the lowest mean absolute difference as compared with the truth data so that these threshold values are listed as the recommended threshold value (tIndex) in the forest loss detection systems for the users to obtain the best advantage of the systems.
c. The optimum threshold values for defining a unit of tree-cover loss (so-called the tTreecover) were obtained by comparing the generated forest loss areas with the truth data. The Hansen Forest Change v1.5 is served as the truth data for the tree-cover loss accumulation function that is added in the Landsat-8 and Sentinel-2 annual forest loss detection systems. The optimum threshold values produced the lowest mean absolute difference as compared with the truth data so that these threshold values are listed as the recommended threshold value (tTreecover) in the tree-cover loss accumulation function that is attached in the Landsat-8 and Sentinel-2 forest loss detection systems for the users to obtain the best advantage of the systems.

d. The result of the Landsat-8 annual forest loss detection in Papua New Guinea for the year 2015-2017 is presented as follow:



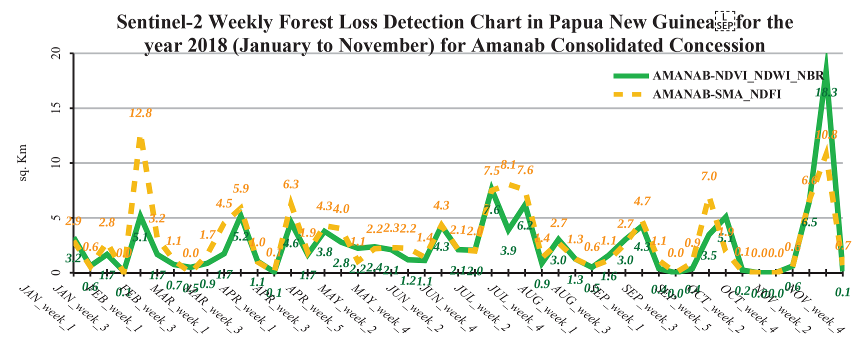
For the Landsat-8 annual forest loss detection system in Amanab Consolidated Concession, both forest loss analysis methods (i.e., the combination of NDVI, NDWI, and NBR and the integration of SMA and NDFI) produced a similar trend of forest loss areas during the year of 2015 to 2017, which is an increasing trend of forest loss areas. However, the result from the integration of SMA and NDFI methods yielded a higher forest lost areas as compared with the other method. Meanwhile, for the Landsat-8 annual forest loss detection system in Rottock Bay Consolidated Concession, both forest loss analysis methods (i.e., the combination of NDVI, NDWI, and NBR and the integration of SMA and NDFI) produced almost similar trend of forest loss areas during the year of 2015 to 2017, which is a decreasing trend of forest loss areas. The result from the integration of SMA and NDFI methods yielded a higher forest lost areas as compared with the other method, except that in the year 2017.

e. The result of the Sentinel-2 annual forest loss detection in Papua New Guinea for the year 2016-2017 is presented as follow:

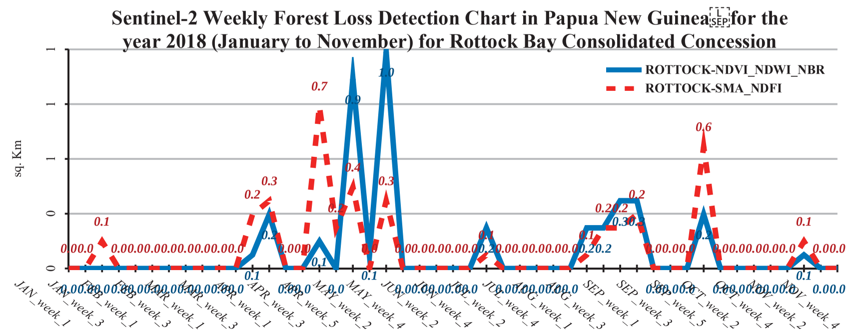


For the Sentinel-2 annual forest loss detection system in Amanab Consolidated Concession, both forest loss analysis methods (i.e., the combination of NDVI, NDWI, and NBR and the integration of SMA and NDFI) produced a similar trend of forest loss areas during the year of 2016 to 2017, which is an increasing trend of forest loss areas. However, the result from the combination of NDVI, NDWI, and NBR methods yielded a slightly higher forest lost areas as compared with the other method. Meanwhile, for the Sentinel-2 annual forest loss detection system in Rottock Bay Consolidated Concession, both forest loss analysis methods (i.e., the combination of NDVI, NDWI, and NBR and the integration of SMA and NDFI) produced almost similar trend of forest loss areas during the year of 2015 to 2017, which is a gentle increasing trend of forest loss areas. The result from the combination of NDVI, NDWI, and NBR methods yielded a slightly higher forest lost areas in the year 2016, however, produced a slightly lower forest lost areas in the year 2017 as compared with the other method.

f. The result of the Sentinel-2 weekly forest loss detection in Papua New Guinea for the year 2018 (January to November) is presented as follow:



For the Sentinel-2 weekly forest loss detection system in Amanab Consolidated Concession, both forest loss analysis methods (i.e., the combination of NDVI, NDWI, and NBR and the integration of SMA and NDFI) produced a similar trend of forest loss areas during the year of 2018 (January to November), which is a random trend of forest loss areas. However, the weekly forest loss areas in February, March, April, June, July, September, October, and November are above the average (2.745 sq. Km).



For the Sentinel-2 weekly forest loss detection system in Rottock Bay Consolidated Concession, both forest loss analysis methods (i.e., the combination of NDVI, NDWI, and NBR and the integration of SMA and NDFI) produced a similar trend of forest loss areas during the year of 2018 (January to November), which is a periodically increasing trend of forest loss areas. The weekly forest loss areas in April, May, July, September, and October are above the average (0.08 sq. Km). However, the weekly forest loss areas in Rottock Bay Consolidated Concession are significantly below the weekly forest loss areas in Amanab Bay Consolidated Concession.

g. The final version (version 2018.12.11) of the Landsat-8 annual forest loss detection script is provided in **Appendix A** and the URL as follows:
https://code.earthengine.google.com/005d2c3c19e24f0131ae4be3f25643d5

h. The final version (version 2018.12.11) of the Sentinel-2 annual forest loss detection script is provided in **Appendix B** and the URL as follows:
https://code.earthengine.google.com/ae4b5744b697b36ae7fd6c198f29bdae

i. The final version (version 2018.12.11) of the Sentinel-2 weekly forest loss detection script is provided in **Appendix C** and the URL as follows:
https://code.earthengine.google.com/42d01e399cd3efa364f12ca1cb690773

j. Finally, this work might serve as a step for updating forest information to grasp forest situations regularly, which is further supporting the management and wise utilization of the forest resources of Papua New Guinea that is being promoted by the Papua New Guinea Forest Authority (PNGFA). Therefore, by considering the potential of the developed annual and weekly forest loss detection systems, they could provide rapid and reliable forest monitoring technique, especially for monitoring the logging activities inside of logging concessions in Papua New Guinea. Moreover, the dynamic trend of the logging activities in both target areas could be understood in better detail (i.e., annual and weekly) so that might help stakeholders to advance both the short-term and the long-term decision-making actions, especially from the viewpoint of geospatial analysis.

Appendix A
The final version (version 2018.12.11) of the Landsat-8 annual forest loss detection script

```
// Landsat-8 annual forest loss detection for monitoring
// logging activities inside logging concession in Papua New Guinea.
// Version 2018.12.11 (FINAL)


// Part 1: Input Commands.
//==============================================================================START:
// PLEASE KINDLY READ EACH INSTRUCTION AND FILL OUT THE INPUT COMMANDS BELOW.


// [COMMAND-1] FIRST REFERENCE IMAGE - Start Date
/*  Instruction:
(a) Define the Start Date of the FIRST REFERENCE IMAGE.
(b) Insert the YEAR, MONTH, and DATE on separate variables.
*/
var firstRefStart_YEAR = 2014;
var firstRefStart_MONTH = 1;
var firstRefStart_DATE = 1;


// [COMMAND-2] FIRST REFERENCE IMAGE - End Date
/*  Instruction:
(a) Define the End Date of the FIRST REFERENCE IMAGE.
(b) Insert the YEAR, MONTH, and DATE on separate variables.
*/
var firstRefEnd_YEAR = 2014;
var firstRefEnd_MONTH = 12;
var firstRefEnd_DATE = 31;


// [COMMAND-3] FIRST TARGET IMAGE - Start Date
/*  Instruction:
(a) Define the Start Date of the FIRST TARGET IMAGE.
(b) Insert the YEAR, MONTH, and DATE on separate variables.
*/
var firstTargetStart_YEAR = 2015;
var firstTargetStart_MONTH = 1;
var firstTargetStart_DATE = 1;


// [COMMAND-4] FIRST TARGET IMAGE - End Date
/*  Instruction:
(a) Define the End Date of the FIRST TARGET IMAGE.
(b) Insert the YEAR, MONTH, and DATE on separate variables.
*/
var firstTargetEnd_YEAR = 2015;
var firstTargetEnd_MONTH = 12;
var firstTargetEnd_DATE = 31;


// [COMMAND-5] TARGET IMAGES
/*  Instruction:
Define the amount of TARGET IMAGES to be used for analysis,
which INCLUDING the FIRST TARGET IMAGE.
*/
var totalTarget = 3;


// [COMMAND-6] AREA OF INTEREST
/*  Instruction:
Select the Area of interest (AOI) to be calculated:
(a) Type 'AMANAB' for Amanab Consolidated Concession.
(b) Type 'ROTTOCK' for Rottock Bay Consolidated Concession.
*/
var aoi_select = 'AMANAB';


// [COMMAND-7] CLOUD/HAZE ELIMINATION METHOD
/*  Instruction:
Select the method to be used for cloud/haze elimination.
```

```
(a) Type 'QA_BAND' for using the QAband method.
(b) Type 'CFMASK' for using the CFMASK-derived QAband method.
----------------------------
RECOMMENDED METHOD: 'CFMASK'
----------------------------
*/
var getImageFunction = 'CFMASK';


// [COMMAND-8] CLOUD-FREE IMAGES
/*  Instruction:
Do you want to display cloud-free images to the GEE Map?
(a) Type 'YES' to display.
(b) Type 'NO' to not display.
*/
var showCloudFree = 'YES';


// [COMMAND-9] FOREST LOSS DETECTION METHOD
/*  Instruction:
Select the method to be used for forest loss detection.
(a) Type 'NDVI_NDWI_NBR' for using the combination of NDVI, NDWI, and NBR.
(b) Type 'SMA_NDFI' for using the integration of SMA and NDFI.
*/
var methodOfAnalysis = 'NDVI_NDWI_NBR';


// [COMMAND-10] THRESHOLD VALUE
/*  Instruction:
Set a threshold value to define a unit of forest loss in the analysis.
-----------------------------------------------
RECOMMENDED THRESHOLD VALUE:
(1) 'AMANAB'
    (a) For 'NDVI_NDWI_NBR' set tIndex to 0.215
    (b) For 'SMA_NDFI' set tIndex to 1.925
(2) 'ROTTOCK'
    (a) For 'NDVI_NDWI_NBR' set tIndex to 0.180
    (b) For 'SMA_NDFI' set tIndex to 1.900
-----------------------------------------------
*/
var tIndex = 0.215;


// [COMMAND-11] LOSS IMAGES
/*  Instruction:
Do you want to display loss-images to the GEE Map?
(a) Type 'YES' to display.
(b) Type 'NO' to not display.
*/
var showLossImages = 'YES';


// [COMMAND-12] LOSS AREA CALCULATION
/*  Instruction:
Do you want to calculate loss area and print it to the GEE Console?
(a) Type 'YES' to proceed.
(b) Type 'NO' to not proceed.
*/
var calLossArea = 'YES';


// [COMMAND-13] EXPORT LOSS IMAGES TO ASSET
/*  Instruction:
Do you want to export loss-images to user's Asset?
(a) Type 'YES' to export.
(b) Type 'NO' to not export.
*/
var exportLossToAsset = 'NO';


// [COMMAND-14] EXPORT LOSS IMAGES TO GOOGLE DRIVE
/*  Instruction:
Do you want to export loss-images to user's Google Drive?
(a) Type 'YES' to export.
(b) Type 'NO' to not export.
*/
var exportLossToDrive = 'NO';
```



```
// [COMMAND-15] TREE-COVER LOSS ACCUMULATION
/*  Instruction:
Do you want to generate greenest and least-greenest images,
and calculate tree-cover loss accumulation for each year?
(a) Type 'YES' and define the threshold value to define a unit of tree-cover loss.
(b) Type 'NO' to not proceed.
-----------------------------------------
RECOMMENDED THRESHOLD VALUE:
(1) For 'AMANAB' set tTreecover to 0.845
(2) For 'ROTTOCK' set tTreecover to 0.585
-----------------------------------------
*/
var showTreecoverAccum = 'NO';
var tTreecover = 0.845;


// PLEASE CHECK ALL INPUT COMMANDS HAVE BEEN FILLED CORRECTLY, AND CLICK RUN.
//===================================================================================END.



// Part 2: Parameters Collections.
//=================================================================================START:
// Image Collections.
var l8CollectionRAW = ee.ImageCollection('LANDSAT/LC08/C01/T1');
var l8CollectionSR = ee.ImageCollection('LANDSAT/LC08/C01/T1_SR');
var l8CollectionTOA = ee.ImageCollection('LANDSAT/LC08/C01/T1_RT_TOA');

// Date Format: 'YYYY-MM-DD'
var firstRefStart = ee.Date.fromYMD
                    (firstRefStart_YEAR,firstRefStart_MONTH,firstRefStart_DATE);
var firstRefEnd = ee.Date.fromYMD
                  (firstRefEnd_YEAR,firstRefEnd_MONTH,firstRefEnd_DATE);
var firstTargetStart = ee.Date.fromYMD
                       (firstTargetStart_YEAR,firstTargetStart_MONTH,firstTargetStart_DATE);
var firstTargetEnd = ee.Date.fromYMD
                     (firstTargetEnd_YEAR,firstTargetEnd_MONTH,firstTargetEnd_DATE);

// Conditional function for study area.
if (aoi_select === 'AMANAB') {
  var aoi_name = 'Amanab Consolidated Concession';
  var aoi = ee.FeatureCollection('ft:1qHYNSz7H0mwm4tfP0LG9BUSTxdtDR_9-Hu29CGpE','geometry');
  Map.centerObject(aoi, 9);
}
if (aoi_select === 'ROTTOCK') {
  var aoi_name = 'Rottock Bay Consolidated Concession';
  var aoi = ee.FeatureCollection('ft:1MHGkkEQCDtCLhSMdz5EefLU97UPkeT1Vg4-yGefZ','geometry');
  Map.centerObject(aoi, 10);
}

// Conditional function for forest loss analysis method.
if (methodOfAnalysis === 'NDVI_NDWI_NBR') {
  var printMethod = 'combined NDVI, NDWI, and NBR';
}
if (methodOfAnalysis === 'SMA_NDFI') {
  var printMethod = 'the integration of SMA and NDFI';
}

// Print title.
print('// Landsat-8 Annual Forest Loss Detection',
      '// by using '+printMethod,
      '// in '+aoi_name,
      '------------------------------------------'
     );

// Custom mask for tree cover.
var gfc2017 = ee.Image('UMD/hansen/global_forest_change_2017_v1_5');
var gfc2017Clip = gfc2017.clip(aoi);
var treeCover = gfc2017Clip.select(['treecover2000']);
var setMaskTreeCover30 = treeCover.lt(30);
var createMaskTreeCover30 = setMaskTreeCover30.eq(0);

// Visual parameters collections.
var visParamsTrue = {bands: 'B4,B3,B2', min:0, max:0.3};// True color RGB.
var visParamsFalse = {bands: 'B5,B4,B3', min:0, max:0.3};// False color RGB.
var visParamsIR = {bands: 'B6,B5,B4', min:0, max:0.3};// Color Infrared RGB.
var visParamsIndex = {palette:['Black','White','Green'], min: -1, max:1}; // Index pallete.
var visParamsLoss = {palette: ['Black','Red'], min:0, max:1}; // Loss-image palette.
```

```
// Display the AOI to the Map.
Map.addLayer(aoi, {'color': 'Black'}, aoi_select+' Boundary', true, 1);
//==============================================================================END.



// Part 3: Parameters for Investigation Periods.
//==============================================================================START:
// Function for creating a list of the Start date of TARGET IMAGES.
var targetStartList = ee.List.sequence(0, ee.Number(totalTarget).subtract(1));
var targetStartListFunction = targetStartList.map(
  function (number) {
  return ee.Date(firstTargetStart).advance(number, 'year');
});

// Function for creating a list of the End date of TARGET IMAGES.
var targetEndList = ee.List.sequence(0, ee.Number(totalTarget).subtract(1));
var targetEndListFunction = targetEndList.map(
  function (number) {
  return ee.Date(firstTargetEnd).advance(number, 'year');
});

// Combine the list of Start and End date of TARGET IMAGES.
var targetList = targetStartListFunction.zip(targetEndListFunction);

// Create a list of Start and End date of REFERENCE IMAGES.
var firstRefStartList = [ee.Date(firstRefStart)];
var firstRefEndList = [ee.Date(firstRefEnd)];
var firstRefList = ee.List(firstRefStartList).zip(firstRefEndList);

// Modified the last element of the target list.
var deleteLast = targetList.splice(-1,1);

// Insert FIRST REFERENCE IMAGE to be the first element of the modified target list.
var refList = deleteLast.insert(0, firstRefList.flatten());

// Print the list of date pairs for each analysis.
for (var a = 0; a < totalTarget; a++) {
  var trueA = a+1;
  var startDatePairs = ee.List(refList.get(a));
  var endDatePairs = ee.List(targetList.get(a));
  print('Date pairs of Analysis-'+trueA, startDatePairs, endDatePairs);
}
print('------------------------------------------');
//==============================================================================END.



// Part 4: Cloud/Haze Elimination Functions.
//==============================================================================START:
// QAband function.
if (getImageFunction === 'QA_BAND') {
  // Function to generate a cloud-free image by using
  // QA band method for Landsat.
  var getImageFunction = function (element) {

    var getImageFilter = element.map(
      function (date_list) {

        // Define local variables for the function.
        var aList = ee.List(date_list);
        var startDate = aList.get(0);
        var endDate = aList.get(1);

        // Set conditions for image filter.
        var imageFilter = ee.ImageCollection(l8CollectionTOA
                                .filterDate(startDate,endDate)
                                .filterBounds(aoi));

        // Topographic Correction for TOA.
        var illuminationCorr_TOA = imageFilter.map(
          function (image) {
          // Define local variables.
          var terrain = ee.call('Terrain', ee.Image('USGS/SRTMGL1_003'));

          var sunElev_deg = ee.Number((image.get("SUN_ELEVATION")));
          var solar_zenith = ee.Number(90).subtract(sunElev_deg);

          var solar_azimuth = ee.Number(image.get("SUN_AZIMUTH"));
```



```
          var degree2radian = 0.017453292519943295; // PI/180
          var solar_zenith_radians = solar_zenith.multiply(degree2radian);
          var slope_radians = terrain.select(['slope']).multiply(degree2radian);
          var aspect = terrain.select(['aspect']);

          // Slope part of the illumination condition.
          var cosZ = solar_zenith_radians.cos();

          var cosS = slope_radians.cos();
          var slope_illumination = cosS.multiply(cosZ);

          // Aspect part of the illumination condition
          var sinZ = solar_zenith_radians.sin();
          var sinS = slope_radians.sin();
          var azimuth_diff_radians = (aspect.subtract(solar_azimuth)).multiply(degree2radian);

          var cosPhi = azimuth_diff_radians.cos();
          var aspect_illumination = cosPhi.multiply(sinS).multiply(sinZ);

          // Illumination condition.
          var ic = slope_illumination.add(aspect_illumination);

          // Apply the cosine correction.
          var cos_output = image.expression("((image*cosZ)/ic) ", {
            'image': image.select(['B1','B2','B3','B4','B5','B6','B7']),
            'cosZ': cosZ,
            'ic': ic,
          });

        // Generate output.
        return ee.Image(cos_output
              .float()
              .addBands(image.select(['B10', 'B11','BQA']))
              .copyProperties(image)
              .copyProperties(image, ['system:time_start']));
        });

        // Get cloud-free image for each image in the collection.
        var QAcloudFree = ee.ImageCollection(illuminationCorr_TOA).map(
          function (image) {
            var qa = image.select('BQA');
            /// Check that the cloud bit is off.
            // See https://landsat.usgs.gov/collectionqualityband
            var mask = qa.bitwiseAnd(1 << 4).eq(0);
          return image.updateMask(mask);
        });

        // Apply DOS radiometric normalization.
        var QAcloudFreeDOS = ee.ImageCollection(QAcloudFree).map(getDOSl8);

        // Take the median and clip to AOI.
        var QAcloudFreeDOSMosaic = ee.ImageCollection(QAcloudFreeDOS)
                                                      .median()
                                                      .clip(aoi)
                                                      .updateMask(createMaskTreeCover30);

        // Generate other indices.
        var ndvi = ee.Image(QAcloudFreeDOSMosaic.normalizedDifference(['B5','B4']));
        var ndwi = ee.Image(QAcloudFreeDOSMosaic.normalizedDifference(['B5','B6']));
        var nbr = ee.Image(QAcloudFreeDOSMosaic.normalizedDifference(['B5','B7']));

      return QAcloudFreeDOSMosaic.addBands(ndvi.select([0],['ndvi']))
                          .addBands(ndwi.select([0],['ndwi']))
                          .addBands(nbr.select([0],['nbr']));

    });

  return getImageFilter;
  };
}

// CFMASK-derived QAband function.
if (getImageFunction === 'CFMASK') {
  // Function to generate a cloud-free image by using
  // CFMASK-derived QA band method for Landsat.
  var getImageFunction = function (element) {

    var getImageFilter = element.map(
      function (date_list) {
```

```
  // Define local variables for the function.
  var aList = ee.List(date_list);
  var startDate = aList.get(0);
  var endDate = aList.get(1);

  // Set conditions for image filter.
  var imageFilter = ee.ImageCollection(l8CollectionSR
                              .filterDate(startDate,endDate)
                              .filterBounds(aoi));

  // Topographic Correction for SR.
  var illuminationCorr_SR = imageFilter.map(
    function (image) {
    // Define local variables.
    var terrain = ee.call('Terrain', ee.Image('USGS/SRTMGL1_003'));
    var solar_zenith = ee.Number((image.get("SOLAR_ZENITH_ANGLE")));
    var solar_azimuth = ee.Number(image.get("SOLAR_AZIMUTH_ANGLE"));
    var degree2radian = 0.017453292519943295; // PI/180
    var solar_zenith_radians = solar_zenith.multiply(degree2radian);
    var slope_radians = terrain.select(['slope']).multiply(degree2radian);
    var aspect = terrain.select(['aspect']);

    // Slope part of the illumination condition.
    var cosZ = solar_zenith_radians.cos();

    var cosS = slope_radians.cos();
    var slope_illumination = cosS.multiply(cosZ);

    // Aspect part of the illumination condition
    var sinZ = solar_zenith_radians.sin();
    var sinS = slope_radians.sin();
    var azimuth_diff_radians = (aspect.subtract(solar_azimuth)).multiply(degree2radian);

    var cosPhi = azimuth_diff_radians.cos();
    var aspect_illumination = cosPhi.multiply(sinS).multiply(sinZ);

    // Illumination condition.
    var ic = slope_illumination.add(aspect_illumination);

    // Apply the cosine correction.
    var cos_output = image.expression("((image*cosZ)/ic) ", {
       'image': image.select(['B1','B2','B3','B4','B5','B6','B7']),
       'cosZ': cosZ,
       'ic': ic,
    });

  // Generate output.
  return ee.Image(cos_output
          .uint16()
          .addBands(image.select(['B10', 'B11','pixel_qa']))
          .copyProperties(image)
          .copyProperties(image, ['system:time_start']));
  });

  // Get cloud-free image for each image in the collection.
  var CFMASKcloudFree = ee.ImageCollection(illuminationCorr_SR).map(
    function (image) {
      // Bits 3 and 5 are cloud shadow and cloud, respectively.
      var cloudShadowBitMask = 1 << 3;
      var cloudsBitMask = 1 << 5;

      // Get the pixel QA band.
      var qa = image.select('pixel_qa');

      // Both flags should be set to zero, indicating clear conditions.
      var mask = qa.bitwiseAnd(cloudShadowBitMask).eq(0)
                 .and(qa.bitwiseAnd(cloudsBitMask).eq(0));

// Return the masked image, scaled to TOA reflectance, without the QA bands.
return image.updateMask(mask).divide(10000)
          .select("B[0-9]*")
          .copyProperties(image, ["system:time_start"]);
});

  // Take the median and clip to AOI.
  var CFMASKcloudFreeMosaic = ee.ImageCollection(CFMASKcloudFree)
                                        .median()
                                        .clip(aoi)
```



```
                                        .updateMask(createMaskTreeCover30);

      // Generate other indices.
      var ndvi = ee.Image(CFMASKcloudFreeMosaic.normalizedDifference(['B5','B4']));
      var ndwi = ee.Image(CFMASKcloudFreeMosaic.normalizedDifference(['B5','B6']));
      var nbr = ee.Image(CFMASKcloudFreeMosaic.normalizedDifference(['B5','B7']));

    return CFMASKcloudFreeMosaic.addBands(ndvi.select([0],['ndvi']))
                              .addBands(ndwi.select([0],['ndwi']))
                              .addBands(nbr.select([0],['nbr']));

    });

  return getImageFilter;
  };
}

// DOS radiometric normalization function.
/* Notes:
Dark Object Subtraction (DOS) only applied on cloud/haze elimination methods
for TOA reflectance images, which is the QAband method.
*/
function getDOSl8 (imageTOA) {

  // Define ESUN for B2, B3, B4, B5, B6, B7.
  var esunDict = [2067, 1893, 1603, 972.6, 245.0, 79.72];

  // Extract solar zenith angle and take it cos.
  var sunElev_deg = imageTOA.get('SUN_ELEVATION');
  var solarZenith_deg = ee.Number(90).subtract(sunElev_deg);
  var solarZenith_rad = ee.Number(solarZenith_deg).multiply(Math.PI).divide(180.0);
  var cosZen = solarZenith_rad.cos();

  // Define Earth-Sun Distance.
  var earthSunDis = imageTOA.get('EARTH_SUN_DISTANCE');
  var earthSunDisPow2 = ee.Number(earthSunDis).pow(2);
  var piEarthSunDisPow2 = earthSunDisPow2.multiply(Math.PI);

  // Calculate dark object on each band.
  var doB2 = ee.Number(cosZen.divide(piEarthSunDisPow2)).multiply(esunDict[0]).multiply(1e-4);
  var doB3 = ee.Number(cosZen.divide(piEarthSunDisPow2)).multiply(esunDict[1]).multiply(1e-4);
  var doB4 = ee.Number(cosZen.divide(piEarthSunDisPow2)).multiply(esunDict[2]).multiply(1e-4);
  var doB5 = ee.Number(cosZen.divide(piEarthSunDisPow2)).multiply(esunDict[3]).multiply(1e-4);
  var doB6 = ee.Number(cosZen.divide(piEarthSunDisPow2)).multiply(esunDict[4]).multiply(1e-4);
  var doB7 = ee.Number(cosZen.divide(piEarthSunDisPow2)).multiply(esunDict[5]).multiply(1e-4);
  var doDict = [doB2, doB3, doB4, doB5, doB6, doB7];

  // Apply DOS.
  var dosB2 = imageTOA.select('B2').subtract(doDict[0]).max(0);
  var dosB3 = imageTOA.select('B3').subtract(doDict[1]).max(0);
  var dosB4 = imageTOA.select('B4').subtract(doDict[2]).max(0);
  var dosB5 = imageTOA.select('B5').subtract(doDict[3]).max(0);
  var dosB6 = imageTOA.select('B6').subtract(doDict[4]).max(0);
  var dosB7 = imageTOA.select('B7').subtract(doDict[5]).max(0);
  var imageDOS = ee.Image(dosB2).addBands(ee.Image(dosB3)).addBands(ee.Image(dosB4))
                         .addBands(ee.Image(dosB5)).addBands(ee.Image(dosB6))
                         .addBands(ee.Image(dosB7));
  imageDOS = ee.Image(imageDOS).toFloat();

return imageDOS;
}
//=========================================================================================END.



// Part 5: Image Collections.
//=======================================================================================START:
// Collect cloud-free images for all analysis.
var refCollection = getImageFunction(refList);
var targetCollection = getImageFunction(targetList);
var allAnalysis = refCollection.zip(targetCollection);

// Display the cloud-free image collections to the GEE Map.
if (showCloudFree === 'YES') {
  Map.addLayer(ee.Image(refCollection.get(0)),
                    visParamsIR, 'Cloud-free First Reference', false);

  for (var b = 0; b < totalTarget; b++) {
    var trueB = b+1;
```

```
   var cloudFreeImageB = ee.Image(targetCollection.get(b));
   Map.addLayer(cloudFreeImageB, visParamsIR, 'Cloud-free Target '+trueB, false);
  }
}
//==================================================================================END.



// Part 6: Forest Loss Analysis.
//================================================================================START:
// Forest Loss Analysis using the combination of NDVI, NDWI, and NBR.
if (methodOfAnalysis === 'NDVI_NDWI_NBR') {
  // Create a function for analyzing Forest loss.
  var lossCollections = allAnalysis.map(
   function (list_of_image_pair) {

     // Define local variables for the function.
     var imagePair = ee.List(list_of_image_pair);
     var imageRef = ee.Image(imagePair.get(0));
     var imageTarget = ee.Image(imagePair.get(1));

     // Define delta NDVI, NDWI, and NBR for a pair of Reference-Target.
     var deltaNDVI = (imageRef.select(['ndvi'])).subtract(imageTarget.select(['ndvi']));
     var deltaNDWI = (imageRef.select(['ndwi'])).subtract(imageTarget.select(['ndwi']));
     var deltaNBR = (imageRef.select(['nbr'])).subtract(imageTarget.select(['nbr']));

     // Apply threshold value to all indices.
     var setThreshold = deltaNDVI.gt(tIndex)
                               .and(deltaNDWI.gt(tIndex))
                               .and(deltaNBR.gt(tIndex));

     // Masking out pixels that having a value less than tIndex.
     var maskThreshold = setThreshold.neq(0);
     var lossAreas = maskThreshold.updateMask(maskThreshold);

     // Indicate loss image.
    var lossImage = lossAreas.select([0], ['loss']);

  return lossImage.uint8();
 });
}

// Forest Loss Analysis using the integration of SMA and NDFI.
if (methodOfAnalysis === 'SMA_NDFI') {
  // Create a function for analyzing Forest loss.
  var lossCollections = allAnalysis.map(
    function (list_of_image_pair) {

      // Define local variables for the function.
      var imagePair = ee.List(list_of_image_pair);
      var imageRef = ee.Image(imagePair.get(0));
      var imageTarget = ee.Image(imagePair.get(1));

      // Create a function to get deforestation image.
      var getNDFI = function (image) {

        // Define cloud-free image collection for spectral unmix.
        var imageCloudFreeUnmix = image.select('B[2-7]');

        // Define spectral endmembers.
        var soil = [20, 30, 34, 58, 60, 58];
        var gv = [5, 9, 4, 61, 30, 10];
        var npv = [14, 17, 22, 30, 55, 30];
        var shade = [0, 0, 0, 0, 0, 0];
        var cloud = [90, 96, 80, 78, 72, 65];

        // Unmix the image.
        var fractions = imageCloudFreeUnmix.unmix([gv,shade,npv,soil,cloud],true,true)
                                    .rename(['gv', 'shade', 'npv','soil','cloud']);

        // Define additional cloud mask using cloud fraction.
        var fractionCloudMask = fractions.select('cloud').lt(0.1);

        // Calculate NDFI.
        var ndfi = ee.Image(fractions).expression(
             '((GV / (100 - SHADE)) - (NPV + SOIL)) / ((GV / (100 - SHADE)) + NPV + SOIL)', {
             'GV': ee.Image(fractions).select('gv'),
             'SHADE': ee.Image(fractions).select('shade'),
             'NPV': ee.Image(fractions).select('npv'),
```



```
             'SOIL': ee.Image(fractions).select('soil')
             }).rename('NDFI').updateMask(fractionCloudMask);

      return ndfi;
      };

      // Generate NDFI for a pair of Reference-Target.
      var ndfiRef = getNDFI(imageRef);
      var ndfiTarget = getNDFI(imageTarget);

      // Define delta NDFI for a pair of Reference-Target.
      var deltaNDFI = ndfiRef.subtract(ndfiTarget);

      // Apply threshold value to delta NDFI.
      var setThreshold = deltaNDFI.gt(tIndex);

      // Masking out pixels that having a value less than tIndex.
      var maskThreshold = setThreshold.neq(0);
      var lossAreas = maskThreshold.updateMask(maskThreshold);

      // Indicate loss image.
      var lossImage = lossAreas.select([0], ['loss']);

   return lossImage.uint8();
  });
}

// Display the loss-image collections to Map.
if (showLossImages === 'YES') {

 for (var c = 0; c < totalTarget; c++) {
  var trueC = c+1;
  var lossImageC = ee.Image(lossCollections.get(c)).select('loss');
  Map.addLayer(lossImageC, visParamsLoss, 'Loss-image Analysis '+trueC, false);
  }

}
//==================================================================================END.



// Part 7: Loss Area Calculation.
//================================================================================START:
// Function to calculate loss area.
var lossAreaCal = function (lossImage) {

  // Generate pixel area image.
  var imagePixArea=lossImage.multiply(ee.Image.pixelArea());

  // Calculate loss areas in sq. meter.
  var imageLossArea = imagePixArea.reduceRegion({
   reducer:ee.Reducer.sum(),
   geometry: aoi.geometry().bounds(),
   crs: 'EPSG:4326',
   scale: 250,
   // Scale pixel resolution to 250m for calculation purpose.
   maxPixels:1e10,
   tileScale:4
  });

  // Converts areas to sq. km.
  var sqKmImageLossArea = ee.Number(imageLossArea.get('loss'))
                              .divide(1e6).format('%.3f');

return sqKmImageLossArea;
};

if (calLossArea === 'YES') {

  // Calculate loss area for each analysis.
  for (var e = 0; e < totalTarget; e++) {
   var trueE = e+1;

   if (methodOfAnalysis === 'NDVI_NDWI_NBR'){
   var lossImageE = ee.Image(lossCollections.get(e));
   }
   if (methodOfAnalysis === 'SMA_NDFI'){
   var lossImageE = ee.Image(lossCollections.get(e)).select('loss');
   }
```

```
    // Calculate loss area for each analysis.
    var lossImageE_grid = lossAreaCal(lossImageE);

    // Display loss-area to Console.
    print('Loss area of Analysis-'+trueE+' (sq.km): ', lossImageE_grid);
  }

  print('-------------------------------------------');
}
//=================================================================================END.



// Part 8: Parameters for Export Images.
//================================================================================START:
// Selection to export loss-image collections to user's Asset.
if (exportLossToAsset === 'YES') {
  for (var f = 0; f < totalTarget; f++) {
    var trueF = f+1;

    if (methodOfAnalysis === 'NDVI_NDWI_NBR'){
    var lossImageF = ee.Image(lossCollections.get(f));
    }
    if (methodOfAnalysis === 'SMA_NDFI'){
    var lossImageF = ee.Image(lossCollections.get(f)).select('loss');
    }

    Export.image.toAsset({
    image: lossImageF,
    description: aoi_select+'_L8annualLossImage_analysis_'+trueF,
    region: aoi.geometry().bounds(),
    crs: 'EPSG:4326',
    scale: 30,
    maxPixels: 1e10,
    });
  }
}

// Selection to export loss-image collections to user's Google Drive.
if (exportLossToDrive === 'YES') {
  for (var g = 0; g < totalTarget; g++) {
    var trueG = g+1;

    if (methodOfAnalysis === 'NDVI_NDWI_NBR'){
    var lossImageG = ee.Image(lossCollections.get(g));
    }
    if (methodOfAnalysis === 'SMA_NDFI'){
    var lossImageG = ee.Image(lossCollections.get(g)).select('loss');
    }

    Export.image.toDrive({
    image: lossImageG,
    description: aoi_select+'_L8annualLossImage_analysis_'+trueG,
    region: aoi.geometry().bounds(),
    crs: 'EPSG:4326',
    scale: 30,
    maxPixels: 1e10,
    });
  }
}
//=================================================================================END.



// Part 9: Tree-cover loss accumulation for Landsat-8 (v2018.11.19).
//================================================================================START:
if (showTreecoverAccum === 'YES') {

  // Function to generate the tree-cover loss accumulation
  // by using cloud-free greenest and the least-greenest images.
  var accumTreecoverLossFunction = function (element) {

    var getAccumTreecoverLoss = element.map(
      function (date_list) {

        // Define local variables for the function.
        var aList = ee.List(date_list);
        var startDate = aList.get(0);
```



```
        var endDate = aList.get(1);

        // Set conditions for image filter.
        var imageFilter = ee.ImageCollection(l8CollectionSR
                              .filterDate(startDate,endDate)
                              .filterBounds(aoi));

        // Topographic Correction for SR.
        var illuminationCorr_SR = imageFilter.map(
          function (image) {
          // Define local variables.
          var terrain = ee.call('Terrain', ee.Image('USGS/SRTMGL1_003'));
          var solar_zenith = ee.Number((image.get("SOLAR_ZENITH_ANGLE")));
          var solar_azimuth = ee.Number(image.get("SOLAR_AZIMUTH_ANGLE"));
          var degree2radian = 0.017453292519943295; // PI/180
          var solar_zenith_radians = solar_zenith.multiply(degree2radian);
          var slope_radians = terrain.select(['slope']).multiply(degree2radian);
          var aspect = terrain.select(['aspect']);

          // Slope part of the illumination condition.
          var cosZ = solar_zenith_radians.cos();

          var cosS = slope_radians.cos();
          var slope_illumination = cosS.multiply(cosZ);

          // Aspect part of the illumination condition
          var sinZ = solar_zenith_radians.sin();
          var sinS = slope_radians.sin();
          var azimuth_diff_radians = (aspect.subtract(solar_azimuth)).multiply(degree2radian);

          var cosPhi = azimuth_diff_radians.cos();
          var aspect_illumination = cosPhi.multiply(sinS).multiply(sinZ);

          // Illumination condition.
          var ic = slope_illumination.add(aspect_illumination);

          // Apply the cosine correction.
          var cos_output = image.expression("((image*cosZ)/ic) ", {
              'image': image.select(['B1','B2','B3','B4','B5','B6','B7']),
              'cosZ': cosZ,
              'ic': ic,
          });

        // Generate output.
        return ee.Image(cos_output
                .uint16()
                .addBands(image.select(['B10', 'B11','pixel_qa']))
                .copyProperties(image)
                .copyProperties(image, ['system:time_start']));
        });

        // Get cloud-free image for each image in the collection.
        var CFMASKcloudFree = ee.ImageCollection(illuminationCorr_SR).map(
          function (image) {
            // Bits 3 and 5 are cloud shadow and cloud, respectively.
            var cloudShadowBitMask = 1 << 3;
            var cloudsBitMask = 1 << 5;

            // Get the pixel QA band.
            var qa = image.select('pixel_qa');

            // Both flags should be set to zero, indicating clear conditions.
            var mask = qa.bitwiseAnd(cloudShadowBitMask).eq(0)
                      .and(qa.bitwiseAnd(cloudsBitMask).eq(0));

       // Return the masked image, scaled to TOA reflectance, without the QA bands.
       return image.updateMask(mask).divide(10000)
                  .select("B[0-9]*")
                  .copyProperties(image, ["system:time_start"]);
       });

        // Generate and add a VI to the image collection.
        var VICollection = ee.ImageCollection(CFMASKcloudFree).map(
        function(image) {
          // NDVI
          var vi = image.normalizedDifference(['B5','B4']);
        return vi.select([0], ['vi']);
        });
```

```
    // Generate greenest and least greenest image from the image collection and clip to AOI.
    var greenest = ee.ImageCollection(VICollection)
                            .max()
                            .clip(aoi)
                            .updateMask(createMaskTreeCover30)
                            .select([0],['greenest']);
    var leastGreenest = ee.ImageCollection(VICollection)
                            .min()
                            .clip(aoi)
                            .updateMask(createMaskTreeCover30)
                            .select([0],['leastGreenest']);

    // Calculate the tree-cover loss accumulation image.
    var subtractGLG = greenest.subtract(leastGreenest);
    var lossGLG = ee.Image(subtractGLG).gt(tTreecover);
    var nonzeroLossGLG = lossGLG.updateMask(lossGLG);
    var accumTreecoverLoss = nonzeroLossGLG.rename('loss');

   return accumTreecoverLoss.uint8();
   });

 return getAccumTreecoverLoss;
 };

 // Display and calculate the tree-cover loss accumulation for each year.
  if (firstRefStart_YEAR === 2013) {
   var accumTarget = accumTreecoverLossFunction(targetList);
   // There is no Landsat-8 image archive prior to February 11, 2013.
   // Thus, the analysis for the year 2013 is excluded.
  }

  if (firstRefStart_YEAR !== 2013) {
   var accumRef = accumTreecoverLossFunction(refList);
   var accumTarget = accumTreecoverLossFunction(targetList);

   // Display tree-cover loss accumulation image to Map.
   Map.addLayer(ee.Image(accumRef.get(0)).select('loss'), visParamsLoss,
            'Treecover loss accum. First Reference', false);

   // Calculate tree-cover loss accumulation area.
   var accumRef_grid = lossAreaCal(ee.Image(accumRef.get(0)).select('loss'));

   // Display tree-cover loss accumulation area to Console.
   print('Treecover loss accum. of First Reference (sq.km): ', accumRef_grid);
  }

 for (var d = 0; d < totalTarget; d++) {
  var trueD = d+1;
  var accumD = ee.Image(accumTarget.get(d)).select('loss');

  // Display tree-cover loss accumulation image to Map.
  Map.addLayer(accumD, visParamsLoss, 'Treecover loss accum. Target '+trueD, false);

  // Calculate tree-cover loss accumulation area.
  var accumTargetD_grid = lossAreaCal(accumD);

  // Display tree-cover loss accumulation to Console.
  print('Treecover loss accum. of Target-'+trueD+' (sq.km): ', accumTargetD_grid);
 }
 print('------------------------------------------');


}
//==============================================================================END.


// End of script.
```


Appendix B
The final version (version 2018.12.11) of the Sentinel-2 annual forest loss detection script

```
// Sentinel-2 annual forest loss detection for monitoring
// logging activities inside logging concession in Papua New Guinea.
// Version 2018.12.11 (FINAL)


// Part 1: Input Commands.
//==============================================================================START:
// PLEASE KINDLY READ EACH INSTRUCTION AND FILL OUT THE INPUT COMMANDS BELOW.


// [COMMAND-1] FIRST REFERENCE IMAGE - Start Date
/*  Instruction:
(a) Define the Start Date of the FIRST REFERENCE IMAGE.
(b) Insert the YEAR, MONTH, and DATE on separate variables.
*/
var firstRefStart_YEAR = 2015;
var firstRefStart_MONTH = 1;
var firstRefStart_DATE = 1;


// [COMMAND-2] FIRST REFERENCE IMAGE - End Date
/*  Instruction:
(a) Define the End Date of the FIRST REFERENCE IMAGE.
(b) Insert the YEAR, MONTH, and DATE on separate variables.
*/
var firstRefEnd_YEAR = 2015;
var firstRefEnd_MONTH = 12;
var firstRefEnd_DATE = 31;


// [COMMAND-3] FIRST TARGET IMAGE - Start Date
/*  Instruction:
(a) Define the Start Date of the FIRST TARGET IMAGE.
(b) Insert the YEAR, MONTH, and DATE on separate variables.
*/
var firstTargetStart_YEAR = 2016;
var firstTargetStart_MONTH = 1;
var firstTargetStart_DATE = 1;


// [COMMAND-4] FIRST TARGET IMAGE - End Date
/*  Instruction:
(a) Define the End Date of the FIRST TARGET IMAGE.
(b) Insert the YEAR, MONTH, and DATE on separate variables.
*/
var firstTargetEnd_YEAR = 2016;
var firstTargetEnd_MONTH = 12;
var firstTargetEnd_DATE = 31;


// [COMMAND-5] TARGET IMAGES
/*  Instruction:
Define the amount of TARGET IMAGES to be used for analysis,
which INCLUDING the FIRST TARGET IMAGE.
*/
var totalTarget = 2;


// [COMMAND-6] AREA OF INTEREST
/*  Instruction:
Select the Area of interest (AOI) to be calculated:
(a) Type 'AMANAB' for Amanab Consolidated Concession.
(b) Type 'ROTTOCK' for Rottock Bay Consolidated Concession.
*/
var aoi_select = 'AMANAB';


// [COMMAND-7] CLOUD/HAZE ELIMINATION METHOD
/*  Instruction:
Select the method to be used for cloud/haze elimination.
```

```
(a) Type 'QA_BAND' for using the QAband method.
(b) Type 'FMASK' for using the FMASK-algorithm method.
---------------------------
RECOMMENDED METHOD: 'FMASK'
---------------------------
*/
var getImageFunction = 'FMASK';


// [COMMAND-8] CLOUD-FREE IMAGES
/*  Instruction:
Do you want to display cloud-free images to the GEE Map?
(a) Type 'YES' to display.
(b) Type 'NO' to not display.
*/
var showCloudFree = 'YES';


// [COMMAND-9] FOREST LOSS DETECTION METHOD
/*  Instruction:
Select the method to be used for forest loss detection.
(a) Type 'NDVI_NDWI_NBR' for using the combination of NDVI, NDWI, and NBR.
(b) Type 'SMA_NDFI' for using the integration of SMA and NDFI.
*/
var methodOfAnalysis = 'NDVI_NDWI_NBR';


// [COMMAND-10] THRESHOLD VALUE
/*  Instruction:
Set a threshold value to define a unit of forest loss in the analysis.
-----------------------------------------------
RECOMMENDED THRESHOLD VALUE:
(1) 'AMANAB'
   (a) For 'NDVI_NDWI_NBR' set tIndex to 0.190
   (b) For 'SMA_NDFI' set tIndex to 1.955
(2) 'ROTTOCK'
   (a) For 'NDVI_NDWI_NBR' set tIndex to 0.140
   (b) For 'SMA_NDFI' set tIndex to 1.905
-----------------------------------------------
*/
var tIndex = 0.190;


// [COMMAND-11] LOSS IMAGES
/*  Instruction:
Do you want to display loss-images to the GEE Map?
(a) Type 'YES' to display.
(b) Type 'NO' to not display.
*/
var showLossImages = 'YES';


// [COMMAND-12] LOSS AREA CALCULATION
/*  Instruction:
Do you want to calculate loss area and print it to the GEE Console?
(a) Type 'YES' to proceed.
(b) Type 'NO' to not proceed.
*/
var calLossArea = 'YES';


// [COMMAND-13] EXPORT LOSS IMAGES TO ASSET
/*  Instruction:
Do you want to export loss-images to user's Asset?
(a) Type 'YES' to export.
(b) Type 'NO' to not export.
*/
var exportLossToAsset = 'NO';


// [COMMAND-14] EXPORT LOSS IMAGES TO GOOGLE DRIVE
/*  Instruction:
Do you want to export loss-images to user's Google Drive?
(a) Type 'YES' to export.
(b) Type 'NO' to not export.
*/
var exportLossToDrive = 'NO';
```



```
// [COMMAND-15] TREE-COVER LOSS ACCUMULATION
/*  Instruction:
Do you want to generate greenest and least-greenest images,
and calculate tree-cover loss accumulation for each year?
(a) Type 'YES' and define the threshold value to define a unit of tree-cover loss.
(b) Type 'NO' to not proceed.
-----------------------------------------
RECOMMENDED THRESHOLD VALUE:
(1) For 'AMANAB' set tTreecover to 0.740
(2) For 'ROTTOCK' set tTreecover to 0.715
-----------------------------------------
*/
var showTreecoverAccum = 'NO';
var tTreecover = 0.740;


// PLEASE CHECK ALL INPUT COMMANDS HAVE BEEN FILLED CORRECTLY, AND CLICK RUN.
//==============================================================================END.



// Part 2: Parameters Collections.
//==============================================================================START:
// Image Collections.
var s2Collection = ee.ImageCollection('COPERNICUS/S2');

// Date Format: 'YYYY-MM-DD'
var firstRefStart = ee.Date.fromYMD
                  (firstRefStart_YEAR,firstRefStart_MONTH,firstRefStart_DATE);
var firstRefEnd = ee.Date.fromYMD
                 (firstRefEnd_YEAR,firstRefEnd_MONTH,firstRefEnd_DATE);
var firstTargetStart = ee.Date.fromYMD
                    (firstTargetStart_YEAR,firstTargetStart_MONTH,firstTargetStart_DATE);
var firstTargetEnd = ee.Date.fromYMD
                  (firstTargetEnd_YEAR,firstTargetEnd_MONTH,firstTargetEnd_DATE);

// Conditional function for study area.
if (aoi_select === 'AMANAB') {
  var aoi_name = 'Amanab Consolidated Concession';
  var aoi = ee.FeatureCollection('ft:1qHYNSz7H0mwm4tfP0LG9BUSTxdtDR_9-Hu29CGpE','geometry');
  Map.centerObject(aoi, 9);
}
if (aoi_select === 'ROTTOCK') {
  var aoi_name = 'Rottock Bay Consolidated Concession';
  var aoi = ee.FeatureCollection('ft:1MHGkkEQCDtCLhSMdz5EefLU97UPkeT1Vg4-yGefZ','geometry');
  Map.centerObject(aoi, 10);
}

// Conditional function for forest loss analysis method.
if (methodOfAnalysis === 'NDVI_NDWI_NBR') {
  var printMethod = 'combined NDVI, NDWI, and NBR';
}
if (methodOfAnalysis === 'SMA_NDFI') {
  var printMethod = 'the integration of SMA and NDFI';
}

// Print title.
print('// Sentinel-2 Annual Forest Loss Detection',
     '// by using '+printMethod,
     '// in '+aoi_name,
     '-----------------------------------------'
    );

// Custom mask for tree cover.
var gfc2017 = ee.Image('UMD/hansen/global_forest_change_2017_v1_5');
var gfc2017Clip = gfc2017.clip(aoi);
var treeCover = gfc2017Clip.select(['treecover2000']);
var setMaskTreeCover30 = treeCover.lt(30);
var createMaskTreeCover30 = setMaskTreeCover30.eq(0);

// Visual parameters collections.
var visParamsTrue = {bands: 'B4,B3,B2', min:0, max:3000}; // True color RGB.
var visParamsFalse = {bands: 'B8,B4,B3', min:0, max:3000};// False color RGB.
var visParamsIR = {bands: 'B11,B8,B4', min:0, max:3000}; // Color Infrared RGB.
var visParamsIndex = {palette:['Black','White','Green'], min: -1, max:1}; // Index pallete.
var visParamsLoss = {palette: ['Black','Red'], min:0, max:1}; // Loss-image palette.

// Display the AOI to the Map.
Map.addLayer(aoi, {'color': 'Black'}, aoi_select+' Boundary', true, 1);
```

```
//=================================================================================END.


// Part 3: Parameters for Investigation Periods.
//=================================================================================START:
// Function for creating a list of the Start date of TARGET IMAGES.
var targetStartList = ee.List.sequence(0, ee.Number(totalTarget).subtract(1));
var targetStartListFunction = targetStartList.map(
  function (number) {
  return ee.Date(firstTargetStart).advance(number, 'year');
});

// Function for creating a list of the End date of TARGET IMAGES.
var targetEndList = ee.List.sequence(0, ee.Number(totalTarget).subtract(1));
var targetEndListFunction = targetEndList.map(
  function (number) {
  return ee.Date(firstTargetEnd).advance(number, 'year');
});

// Combine the list of Start and End date of TARGET IMAGES.
var targetList = targetStartListFunction.zip(targetEndListFunction);

// Create a list of Start and End date of REFERENCE IMAGES.
var firstRefStartList = [ee.Date(firstRefStart)];
var firstRefEndList = [ee.Date(firstRefEnd)];
var firstRefList = ee.List(firstRefStartList).zip(firstRefEndList);

// Modified the last element of the target list.
var deleteLast = targetList.splice(-1,1);

// Insert FIRST REFERENCE IMAGE to be the first element of the modified target list.
var refList = deleteLast.insert(0, firstRefList.flatten());

// Print the list of date pairs for each analysis.
for (var a = 0; a < totalTarget; a++) {
  var trueA = a+1;
  var startDatePairs = ee.List(refList.get(a));
  var endDatePairs = ee.List(targetList.get(a));
  print('Date pairs of Analysis-'+trueA, startDatePairs, endDatePairs);
}
print('-------------------------------------------');
//=================================================================================END.


// Part 4: Cloud/Haze Elimination Functions.
//=================================================================================START:
// QA band function.
if (getImageFunction === 'QA_BAND') {
   // Function to generate a cloud-free image by using QA band method.
   var getImageFunction = function(element) {

     var getImageFilter = element.map(
       function(date_list) {

         // Define local variables for the function.
         var aList = ee.List(date_list);
         var startDate = aList.get(0);
         var endDate = aList.get(1);

        // Set conditions for image filter.
        var imageFilter = ee.ImageCollection(s2Collection
                                .filterDate(startDate,endDate)
                                .filterBounds(aoi));

        // Topographic Correction for Sentinel-2.
        var imageFilter_topo = imageFilter.map(illuminationCorrS2);

        // Get cloud-free image for each image in the collection.
        var QAcloudFree = ee.ImageCollection(imageFilter_topo).map(
          function(image) {
            var qa = image.select('QA60');

            // Bits 10 and 11 are clouds and cirrus, respectively.
            var cloudBitMask = Math.pow(2, 10);
            var cirrusBitMask = Math.pow(2, 11);

            // Both flags should be set to zero, indicating clear conditions.
```



```
            var mask = qa.bitwiseAnd(cloudBitMask).eq(0).and(
                     qa.bitwiseAnd(cirrusBitMask).eq(0));

            // Return the masked and scaled data.
            var imageout = image.addBands(mask.select([0], ['QAmask']))
                          .updateMask(mask);
                         //.divide(10000);

          return imageout;
          });

        // Apply DOS radiometric normalization.
        var QAcloudFreeDOS = ee.ImageCollection(QAcloudFree).map(getDOSs2);

        // Take the median and clip to AOI.
        var QAcloudFreeDOSMosaic = ee.ImageCollection(QAcloudFreeDOS)
                                          .median()
                                          .clip(aoi)
                                          .updateMask(createMaskTreeCover30);

         // Generate indices.
         var ndvi = ee.Image(QAcloudFreeDOSMosaic.normalizedDifference(['B8','B4']));
         var ndwi = ee.Image(QAcloudFreeDOSMosaic.normalizedDifference(['B8','B11']));
         var nbr  = ee.Image(QAcloudFreeDOSMosaic.normalizedDifference(['B8','B12']));

        return QAcloudFreeDOSMosaic.addBands(ndvi.select([0],['ndvi']))
                               .addBands(ndwi.select([0],['ndwi']))
                               .addBands(nbr.select([0],['nbr']));
      });

    return getImageFilter;
    };
}

// FMASK-algoithm function.
if (getImageFunction === 'FMASK') {
  // Function to generate a cloud-free image by using
  // FMASK-algorithm method for Sentinel-2.
  var getImageFunction = function (element) {

    var getImageFilter = element.map(
      function(date_list) {

        // Define local variables for the function.
        var aList = ee.List(date_list);
        var startDate = aList.get(0);
        var endDate = aList.get(1);

        // Set conditions for image filter.
        var imageFilter = ee.ImageCollection(s2Collection
                               .filterDate(startDate,endDate)
                               .filterBounds(aoi));

        // Topographic Correction for Sentinel-2.
        var imageFilter_topo = imageFilter.map(illuminationCorrS2);

        // Get cloud-free image for each image in the collection.
        var FMASKcloudFree = ee.ImageCollection(imageFilter_topo).map(
          function(image) {

            // Declare local variables.
            var toa = sentinel2toa(image);
            var cloud = sentinelCloudScore(toa);
            var shadow = shadowMask(toa,cloud);

            var cloud_buffer = 10;
            // Cloud buffer is defined to reduced cloud/haze residues.
            var ee_cloud_buffer = ee.Image(cloud_buffer);
            var mask = cloud.or(shadow).fastDistanceTransform(cloud_buffer,'pixels').gt(ee_cloud_buffer);
            var image1 = image.addBands(mask.select([0],['Fmaskcloudmask']));

          return image1.updateMask(mask);

          // Subfunction to derive unscaled Sentinel-2 TOA bands.
          function sentinel2toa(image) {
            var toa = image.select(['B2','B8','B9','B11','B12'])
                     .divide(10000)
                     .set('solar_azimuth',image.get('MEAN_SOLAR_AZIMUTH_ANGLE'))
                     .set('solar_zenith', image.get('MEAN_SOLAR_ZENITH_ANGLE'));
```

```
        return toa;
        }

        // Subfunction to apply the cloud and shadow masking.
        function sentinelCloudScore(toa) {
          var score = toa.select('B2').multiply(toa.select('B9')).multiply(1e4);
          var cloudScoreThreshold = 135;
          var cloud = score.gt(cloudScoreThreshold);
        return cloud;
        }

        // Subfunction to derive shadow mask.
        function shadowMask(toa,cloud){
          var azi = ee.Number(toa.get('solar_azimuth'));
          var zen = ee.Number(toa.get('solar_zenith')).multiply(1.6);
          var azimuth =azi.multiply(Math.PI).divide(180.0).add(ee.Number(0.5).multiply(Math.PI));
          var zenith  =ee.Number(0.5).multiply(Math.PI ).subtract(zen.multiply(Math.PI).divide(180.0));
          var nominalScale = cloud.projection().nominalScale();
          var cloudHeights = ee.List.sequence(200,5000,500);
          function cloudH (cloudHeight){
            cloudHeight = ee.Number(cloudHeight);
            var shadowVector = zenith.tan().multiply(cloudHeight);
            var x = azimuth.cos().multiply(shadowVector).divide(nominalScale).round();
            var y = azimuth.sin().multiply(shadowVector).divide(nominalScale).round();
          return cloud.changeProj(cloud.projection(), cloud.projection().translate(x, y));
          }
          var shadows = cloudHeights.map(cloudH);
          var potentialShadow = ee.ImageCollection.fromImages(shadows).max();
          var potentialShadow1 = potentialShadow.and(cloud.not());
          var darkPixels = toa.select(['B8','B11','B12']).reduce(ee.Reducer.sum()).multiply(1e3).lt(250).rename(['dark_pixels']);
          var shadow = potentialShadow1.and(darkPixels).rename('shadows');
        return shadow;
        }

        });

      // Apply DOS radiometric normalization.
      var FMASKcloudFreeDOS = ee.ImageCollection(FMASKcloudFree).map(getDOSs2);

      // Take the median and clip to AOI.
      var FMASKcloudFreeDOSMosaic = ee.ImageCollection(FMASKcloudFreeDOS)
                                              .median()
                                              .clip(aoi)
                                              .updateMask(createMaskTreeCover30);

      // Generate other indices.
      var ndvi = ee.Image(FMASKcloudFreeDOSMosaic.normalizedDifference(['B8','B4']));
      var ndwi = ee.Image(FMASKcloudFreeDOSMosaic.normalizedDifference(['B8','B11']));
      var nbr  = ee.Image(FMASKcloudFreeDOSMosaic.normalizedDifference(['B8','B12']));

    return FMASKcloudFreeDOSMosaic.addBands(ndvi.select([0],['ndvi']))
                          .addBands(ndwi.select([0],['ndwi']))
                          .addBands(nbr.select([0],['nbr']));

    });

  return getImageFilter;
  };

}

// Topographic correction function.
function illuminationCorrS2 (image) {

  // Define local variables.
  var terrain = ee.call('Terrain', ee.Image('USGS/SRTMGL1_003'));
  var solar_zenith = ee.Number((image.get("MEAN_SOLAR_ZENITH_ANGLE")));
  var solar_azimuth = ee.Number(image.get("MEAN_SOLAR_AZIMUTH_ANGLE"));
  var degree2radian = 0.017453292519943295; // PI/180
  var solar_zenith_radians = solar_zenith.multiply(degree2radian);
  var slope_radians = terrain.select(['slope']).multiply(degree2radian);
  var aspect = terrain.select(['aspect']);

  // Slope part of the illumination condition.
  var cosZ = solar_zenith_radians.cos();

  var cosS = slope_radians.cos();
  var slope_illumination = cosS.multiply(cosZ);
```



```
  // Aspect part of the illumination condition
  var sinZ = solar_zenith_radians.sin();
  var sinS = slope_radians.sin();
  var azimuth_diff_radians = (aspect.subtract(solar_azimuth)).multiply(degree2radian);

  var cosPhi = azimuth_diff_radians.cos();
  var aspect_illumination = cosPhi.multiply(sinS).multiply(sinZ);

  // Illumination condition.
  var ic = slope_illumination.add(aspect_illumination);

  // Apply the cosine correction.
  var cos_output = image.expression("((image*cosZ)/ic) ", {
   'image': image.select(['B1','B2','B3','B4','B8','B11','B12']),
   'cosZ': cosZ,
   'ic': ic,
  });

// Generate output.
return ee.Image(cos_output
                .float()
                .addBands(image.select(['B9', 'B10','QA60']))
                .copyProperties(image)
                .copyProperties(image, ['system:time_start']));
}

// DOS radiometric normalization function.
/* Notes:
Dark Object Subtraction (DOS) only applied on cloud/haze elimination methods
for TOA reflectance images, i.e., the QAband method and the FMASK-algorithm method.
*/
function getDOSs2 (imageTOA) {

  // Define ESUN for B2, B3, B4, B8, B11, B12.
  var esunDict = [1941.63, 1822.61, 1512.79, 1036.39, 245.59, 85.25];

  // Extract solar zenith angle and take it cos.
  var solarZenith_deg = imageTOA.get('MEAN_SOLAR_ZENITH_ANGLE');
  var solarZenith_rad = ee.Number(solarZenith_deg).multiply(Math.PI).divide(180.0);
  var cosZen = solarZenith_rad.cos();

  // Define Earth-Sun Distance.
  var earthSunDis = imageTOA.get('REFLECTANCE_CONVERSION_CORRECTION');
  var earthSunDisPow2 = ee.Number(earthSunDis).pow(2);
  var piEarthSunDisPow2 = earthSunDisPow2.multiply(Math.PI);

  // Calculate dark object on each band.
  var doB2 = ee.Number(cosZen.divide(piEarthSunDisPow2)).multiply(esunDict[0]);
  var doB3 = ee.Number(cosZen.divide(piEarthSunDisPow2)).multiply(esunDict[1]);
  var doB4 = ee.Number(cosZen.divide(piEarthSunDisPow2)).multiply(esunDict[2]);
  var doB8 = ee.Number(cosZen.divide(piEarthSunDisPow2)).multiply(esunDict[3]);
  var doB11 = ee.Number(cosZen.divide(piEarthSunDisPow2)).multiply(esunDict[4]);
  var doB12 = ee.Number(cosZen.divide(piEarthSunDisPow2)).multiply(esunDict[5]);
  var doDict = [doB2, doB3, doB4, doB8, doB11, doB12];

  // Apply DOS.
  var dosB2 = imageTOA.select('B2').subtract(doDict[0]).max(0);
  var dosB3 = imageTOA.select('B3').subtract(doDict[1]).max(0);
  var dosB4 = imageTOA.select('B4').subtract(doDict[2]).max(0);
  var dosB8 = imageTOA.select('B8').subtract(doDict[3]).max(0);
  var dosB11 = imageTOA.select('B11').subtract(doDict[4]).max(0);
  var dosB12 = imageTOA.select('B12').subtract(doDict[5]).max(0);
  var imageDOS = ee.Image(dosB2).addBands(ee.Image(dosB3)).addBands(ee.Image(dosB4))
                          .addBands(ee.Image(dosB8)).addBands(ee.Image(dosB11))
                          .addBands(ee.Image(dosB12));
  imageDOS = ee.Image(imageDOS).toFloat();

return imageDOS;
}
//============================================================================END.



// Part 5: Image Collections.
//==========================================================================START:
// Collect cloud-free images for all analysis.
var refCollection = getImageFunction(refList);
var targetCollection = getImageFunction(targetList);
var allAnalysis = refCollection.zip(targetCollection);
```

```
// Display the cloud-free image collections to the GEE Map.
if (showCloudFree === 'YES') {
  Map.addLayer(ee.Image(refCollection.get(0)),
                     visParamsIR, 'Cloud-free First Reference', false);

  for (var b = 0; b < totalTarget; b++) {
    var trueB = b+1;
    var cloudFreeImageB = ee.Image(targetCollection.get(b));
    Map.addLayer(cloudFreeImageB, visParamsIR, 'Cloud-free Target '+trueB, false);
  }
}
//=============================================================================END.



// Part 6: Forest Loss Analysis.
//===========================================================================START:
// Forest Loss Analysis using the combination of NDVI, NDWI, and NBR.
if (methodOfAnalysis === 'NDVI_NDWI_NBR') {
// Create a function for analyzing Forest loss.
var lossCollections = allAnalysis.map(
   function (list_of_image_pair) {

     // Define local variables for the function.
     var imagePair = ee.List(list_of_image_pair);
     var imageRef = ee.Image(imagePair.get(0));
     var imageTarget = ee.Image(imagePair.get(1));

     // Define delta NDVI, NDWI, and NBR for a pair of Reference-Target.
     var deltaNDVI = (imageRef.select(['ndvi'])).subtract(imageTarget.select(['ndvi']));
     var deltaNDWI = (imageRef.select(['ndwi'])).subtract(imageTarget.select(['ndwi']));
     var deltaNBR = (imageRef.select(['nbr'])).subtract(imageTarget.select(['nbr']));

     // Apply threshold value to all indices.
     var setThreshold = deltaNDVI.gt(tIndex)
                              .and(deltaNDWI.gt(tIndex))
                              .and(deltaNBR.gt(tIndex));

     // Masking out pixels that having a value less than tIndex.
     var maskThreshold = setThreshold.neq(0);
     var lossAreas = maskThreshold.updateMask(maskThreshold);

     // Indicate loss image.
    var lossImage = lossAreas.select([0], ['loss']);

  return lossImage.uint8();
  });
}

// Forest Loss Analysis using the integration of SMA and NDFI.
if (methodOfAnalysis === 'SMA_NDFI') {
 // Create a function for analyzing Forest loss.
  var lossCollections = allAnalysis.map(
    function (list_of_image_pair) {

      // Define local variables for the function.
      var imagePair = ee.List(list_of_image_pair);
      var imageRef = ee.Image(imagePair.get(0));
      var imageTarget = ee.Image(imagePair.get(1));

      // Create a function to get deforestation image.
      var getNDFI = function (image) {

        // Define cloud-free image collection for spectral unmix.
        var imageCloudFreeUnmix = image.select(['B2','B3','B4','B8','B11','B12'])
                                  .divide(10000);

        // Define spectral endmembers.
        var soil = [20, 30, 34, 58, 60, 58];
        var gv = [5, 9, 4, 61, 30, 10];
        var npv = [14, 17, 22, 30, 55, 30];
        var shade = [0, 0, 0, 0, 0, 0];
        var cloud = [90, 96, 80, 78, 72, 65];

        // Unmix the image.
        var fractions = imageCloudFreeUnmix.unmix([gv,shade,npv,soil,cloud],true,true)
                                     .rename(['gv', 'shade', 'npv','soil','cloud']);
```



```
        // Define additional cloud mask using cloud fraction.
        var fractionCloudMask = fractions.select('cloud').lt(0.1);

        // Calculate NDFI.
        var ndfi = ee.Image(fractions).expression(
            '((GV / (100 - SHADE)) - (NPV + SOIL)) / ((GV / (100 - SHADE)) + NPV + SOIL)', {
            'GV': ee.Image(fractions).select('gv'),
            'SHADE': ee.Image(fractions).select('shade'),
            'NPV': ee.Image(fractions).select('npv'),
            'SOIL': ee.Image(fractions).select('soil')
            }).rename('NDFI').updateMask(fractionCloudMask);

      return ndfi;
      };

      // Generate NDFI for a pair of Reference-Target.
      var ndfiRef = getNDFI(imageRef);
      var ndfiTarget = getNDFI(imageTarget);

      // Define delta NDFI for a pair of Reference-Target.
      var deltaNDFI = ndfiRef.subtract(ndfiTarget);

      // Apply threshold value to delta NDFI.
      var setThreshold = deltaNDFI.gt(tIndex);

      // Masking out pixels that having a value less than tIndex.
      var maskThreshold = setThreshold.neq(0);
      var lossAreas = maskThreshold.updateMask(maskThreshold);

      // Indicate loss image.
      var lossImage = lossAreas.select([0], ['loss']);

    return lossImage.uint8();
   });
}

// Display the loss-image collections to Map.
if (showLossImages === 'YES') {

 for (var c = 0; c < totalTarget; c++) {
  var trueC = c+1;
  var lossImageC = ee.Image(lossCollections.get(c)).select('loss');
  Map.addLayer(lossImageC, visParamsLoss, 'Loss-image Analysis '+trueC, false);
 }

}
//=============================================================================END.



// Part 7: Loss Area Calculation.
//===========================================================================START:
// Function to calculate loss area.
var lossAreaCal = function (lossImage) {

  // Generate pixel area image.
  var imagePixArea=lossImage.multiply(ee.Image.pixelArea());

  // Calculate loss areas in sq. meter.
  var imageLossArea = imagePixArea.reduceRegion({
    reducer:ee.Reducer.sum(),
    geometry: aoi.geometry().bounds(),
    crs: 'EPSG:4326',
    scale: 250,
    // Scale pixel resolution to 250m for calculation purpose.
    maxPixels:1e10,
    tileScale:4
  });

  // Converts areas to sq. km.
  var sqKmImageLossArea = ee.Number(imageLossArea.get('loss'))
                                 .divide(1e6).format('%.3f');

return sqKmImageLossArea;
};

if (calLossArea === 'YES') {

  // Calculate loss area for each analysis.
```

```
  for (var e = 0; e < totalTarget; e++) {
    var trueE = e+1;

    if (methodOfAnalysis === 'NDVI_NDWI_NBR'){
    var lossImageE = ee.Image(lossCollections.get(e));
    }
    if (methodOfAnalysis === 'SMA_NDFI'){
    var lossImageE = ee.Image(lossCollections.get(e)).select('loss');
    }

    // Calculate loss area for each analysis.
    var lossImageE_grid = lossAreaCal(lossImageE);

    // Display loss-area to Console.
    print('Loss area of Analysis-'+trueE+' (sq.km): ', lossImageE_grid);
  }

  print('-------------------------------------------');
}
//=============================================================================END.



// Part 8: Parameters for Export Images.
//============================================================================START:
// Selection to export loss-image collections to user's Asset.
if (exportLossToAsset === 'YES') {
  for (var f = 0; f < totalTarget; f++) {
    var trueF = f+1;

    if (methodOfAnalysis === 'NDVI_NDWI_NBR'){
    var lossImageF = ee.Image(lossCollections.get(f));
    }
    if (methodOfAnalysis === 'SMA_NDFI'){
    var lossImageF = ee.Image(lossCollections.get(f)).select('loss');
    }

    Export.image.toAsset({
    image: lossImageF,
    description: aoi_select+'_S2annualLossImage_analysis_'+trueF,
    region: aoi.geometry().bounds(),
    crs: 'EPSG:4326',
    scale: 10,
    maxPixels: 1e10,
    });
  }
}

// Selection to export loss-image collections to user's Google Drive.
if (exportLossToDrive === 'YES') {
  for (var g = 0; g < totalTarget; g++) {
    var trueG = g+1;

    if (methodOfAnalysis === 'NDVI_NDWI_NBR'){
    var lossImageG = ee.Image(lossCollections.get(g));
    }
    if (methodOfAnalysis === 'SMA_NDFI'){
    var lossImageG = ee.Image(lossCollections.get(g)).select('loss');
    }

    Export.image.toDrive({
    image: lossImageG,
    description: aoi_select+'_S2annualLossImage_analysis_'+trueG,
    region: aoi.geometry().bounds(),
    crs: 'EPSG:4326',
    scale: 10,
    maxPixels: 1e10,
    });
  }
}
//=============================================================================END.



// Part 9: Tree-cover loss accumulation for Sentinel-2 (v2018.11.19).
//============================================================================START:
if (showTreecoverAccum === 'YES') {

  // Function to generate the tree-cover loss accumulation
```



```
// by using cloud-free greenest and the least-greenest images.
var accumTreecoverLossFunction = function (element) {

  var getAccumTreecoverLoss = element.map(
    function (date_list) {

      // Define local variables for the function.
      var aList = ee.List(date_list);
      var startDate = aList.get(0);
      var endDate = aList.get(1);

      // Set conditions for image filter.
      var imageFilter = ee.ImageCollection(s2Collection
                              .filterDate(startDate,endDate)
                              .filterBounds(aoi));

      // Topographic Correction for Sentinel-2.
      var imageFilter_topo = imageFilter.map(illuminationCorrS2);

      // Get cloud-free image for each image in the collection.
      var FMASKcloudFree = ee.ImageCollection(imageFilter_topo).map(
        function(image) {

          // Declare local variables.
          var toa = sentinel2toa(image);
          var cloud = sentinelCloudScore(toa);
          var shadow = shadowMask(toa,cloud);

          var cloud_buffer = 10;
          // Cloud buffer is defined to reduced cloud/haze residues.
          var ee_cloud_buffer = ee.Image(cloud_buffer);
          var mask = cloud.or(shadow).fastDistanceTransform(cloud_buffer,'pixels').gt(ee_cloud_buffer);
          var image1 = image.addBands(mask.select([0],['Fmaskcloudmask']));

        return image1.updateMask(mask);

        // Subfunction to derive unscaled Sentinel-2 TOA bands.
        function sentinel2toa(image) {
          var toa = image.select(['B2','B8','B9','B11','B12'])
                  .divide(10000)
                  .set('solar_azimuth',image.get('MEAN_SOLAR_AZIMUTH_ANGLE'))
                  .set('solar_zenith', image.get('MEAN_SOLAR_ZENITH_ANGLE'));
        return toa;
        }

        // Subfunction to apply the cloud and shadow masking.
        function sentinelCloudScore(toa) {
          var score = toa.select('B2').multiply(toa.select('B9')).multiply(1e4);
          var cloudScoreThreshold = 135;
          var cloud = score.gt(cloudScoreThreshold);
        return cloud;
        }

        // Subfunction to derive shadow mask.
        function shadowMask(toa,cloud){
          var azi = ee.Number(toa.get('solar_azimuth'));
          var zen = ee.Number(toa.get('solar_zenith')).multiply(1.6);
          var azimuth =azi.multiply(Math.PI).divide(180.0).add(ee.Number(0.5).multiply(Math.PI));
          var zenith  =ee.Number(0.5).multiply(Math.PI ).subtract(zen.multiply(Math.PI).divide(180.0));
          var nominalScale = cloud.projection().nominalScale();
          var cloudHeights = ee.List.sequence(200,5000,500);
          function cloudH (cloudHeight){
            cloudHeight = ee.Number(cloudHeight);
            var shadowVector = zenith.tan().multiply(cloudHeight);
            var x = azimuth.cos().multiply(shadowVector).divide(nominalScale).round();
            var y = azimuth.sin().multiply(shadowVector).divide(nominalScale).round();
          return cloud.changeProj(cloud.projection(), cloud.projection().translate(x, y));
          }
          var shadows = cloudHeights.map(cloudH);
          var potentialShadow = ee.ImageCollection.fromImages(shadows).max();
          var potentialShadow1 = potentialShadow.and(cloud.not());
          var darkPixels = toa.select(['B8','B11','B12']).reduce(ee.Reducer.sum()).multiply(1e3).lt(250).rename(['dark_pixels']);
          var shadow = potentialShadow1.and(darkPixels).rename('shadows');
        return shadow;
        }

        });

      // Apply DOS radiometric normalization.
```

```
    var FMASKcloudFreeDOS = ee.ImageCollection(FMASKcloudFree).map(getDOSs2);

    // Generate and add a VI to the image collection.
    var VICollection = ee.ImageCollection(FMASKcloudFreeDOS).map(
    function(image) {
      // NDVI
      var vi = image.normalizedDifference(['B8','B4']);
    return vi.select([0], ['vi']);
    });

    // Generate greenest and least greenest image from the image collection and clip to AOI.
    var greenest = ee.ImageCollection(VICollection)
                        .max()
                        .clip(aoi)
                        .updateMask(createMaskTreeCover30)
                        .select([0],['greenest']);
    var leastGreenest = ee.ImageCollection(VICollection)
                        .min()
                        .clip(aoi)
                        .updateMask(createMaskTreeCover30)
                        .select([0],['leastGreenest']);

    // Calculate the tree-cover loss accumulation image.
    var subtractGLG = greenest.subtract(leastGreenest);
    var lossGLG = ee.Image(subtractGLG).gt(tTreecover);
    var nonzeroLossGLG = lossGLG.updateMask(lossGLG);
    var accumTreecoverLoss = nonzeroLossGLG.rename('loss');

   return accumTreecoverLoss.uint8();
   });

 return getAccumTreecoverLoss;
 };

 // Display and calculate the tree-cover loss accumulation for each year.
 if (firstRefStart_YEAR === 2015) {
  var accumTarget = accumTreecoverLossFunction(targetList);
  // There is no Sentinel-2 image archive prior to June 23, 2015.
  // Thus, the analysis for the year 2015 is excluded.
 }

 if (firstRefStart_YEAR !== 2015) {
  var accumRef = accumTreecoverLossFunction(refList);
  var accumTarget = accumTreecoverLossFunction(targetList);

  // Display tree-cover loss accumulation image to Map.
  Map.addLayer(ee.Image(accumRef.get(0)).select('loss'), visParamsLoss,
           'Treecover loss accum. First Reference', false);

  // Calculate tree-cover loss accumulation area.
  var accumRef_grid = lossAreaCal(ee.Image(accumRef.get(0)).select('loss'));

  // Display tree-cover loss accumulation area to Console.
  print('Treecover loss accum. of First Reference (sq.km): ', accumRef_grid);
 }

 for (var d = 0; d < totalTarget; d++) {
  var trueD = d+1;
  var accumD = ee.Image(accumTarget.get(d)).select('loss');

  // Display tree-cover loss accumulation image to Map.
  Map.addLayer(accumD, visParamsLoss, 'Treecover loss accum. Target '+trueD, false);

  // Calculate tree-cover loss accumulation area.
  var accumTargetD_grid = lossAreaCal(accumD);

  // Display tree-cover loss accumulation to Console.
  print('Treecover loss accum. of Target-'+trueD+' (sq.km): ', accumTargetD_grid);
 }
 print('--------------------------------------------');


}
//==============================================================================END.


// End of script.
```

Appendix C
The final version (version 2018.12.11) of the Sentinel-2 weekly forest loss detection script

```
// Sentinel-2 weekly forest loss detection for monitoring
// logging activities inside logging concession in Papua New Guinea.
// Version 2018.12.11 (FINAL)


// Part 1: Input Commands.
//=========================================================================START:
// PLEASE KINDLY READ EACH INSTRUCTION AND FILL OUT THE INPUT COMMANDS BELOW.


// [COMMAND-1] FIRST REFERENCE IMAGE - Start Date
/*  Instruction:
(a) Define the Start Date of the FIRST REFERENCE IMAGE.
(b) The Start Date of the FIRST REFERENCE IMAGE is the date of
    the LAST SUNDAY of a MONTH.
(c) Insert the YEAR, MONTH, and DATE on separate variables.
*/
var firstRefStart_YEAR = 2018;
var firstRefStart_MONTH = 5;
var firstRefStart_DATE = 27;


// [COMMAND-2] FIRST REFERENCE IMAGE - End Date
/*  Instruction:
(a) Define the End Date of the FIRST REFERENCE IMAGE.
(b) The End Date of the FIRST REFERENCE IMAGE is the date of the following SUNDAY from
    the Start Date of the FIRST REFERENCE IMAGE.
(c) For FIRST REFERENCE IMAGE, from Start Date to End Date is a ONE-WEEK duration from
    the LAST SUNDAY of a MONTH to the following SUNDAY of the following MONTH.
(d) The End Date of the FIRST REFERENCE IMAGE should be the same date as the
    Start Date of the TARGET IMAGES DURATION.
(e) Insert the YEAR, MONTH, and DATE on separate variables.
*/
var firstRefEnd_YEAR = 2018;
var firstRefEnd_MONTH = 6;
var firstRefEnd_DATE = 3;


// [COMMAND-3] TARGET IMAGES DURATION - Start Date
/*  Instruction:
(a) Define the Start Date of the TARGET IMAGES DURATION.
(b) The Start Date of the TARGET IMAGES DURATION is the FIRST SUNDAY of a MONTH.
(c) The Start Date of the TARGET IMAGES DURATION should be the same date as the
    End Date of the FIRST REFERENCE IMAGE.
(d) Insert the YEAR, MONTH, and DATE on separate variables.
*/
var targetStart_YEAR = 2018;
var targetStart_MONTH = 6;
var targetStart_DATE = 3;


// [COMMAND-4] TARGET IMAGES DURATION - End Date
/*  Instruction:
(a) Define the End Date of the TARGET IMAGES DURATION.
(b) The End Date of the TARGET IMAGES DURATION is the FIRST SUNDAY of the following MONTH from
    the Start Date of the TARGET IMAGES DURATION.
(c) For TARGET IMAGES DURATION, from Start Date to End Date is a ONE-MONTH duration from
    a FIRST SUNDAY of a month to the FIRST SUNDAY of the following month.
(d) Insert the YEAR, MONTH, and DATE on separate variables.
*/
var targetEnd_YEAR = 2018;
var targetEnd_MONTH = 7;
var targetEnd_DATE = 1;


// [COMMAND-5] TOTAL WEEKS
/*  Instruction:
Define the TOTAL WEEKS of the TARGET IMAGES DURATION.
*/
var totalWeeks = 4;
```



```
// [COMMAND-6] AREA OF INTEREST
/*  Instruction:
Select the Area of interest (AOI) to be calculated:
(a) Type 'AMANAB' for Amanab Consolidated Concession.
(b) Type 'ROTTOCK' for Rottock Bay Consolidated Concession.
*/
var aoi_select = 'AMANAB';


// [COMMAND-7] CLOUD/HAZE ELIMINATION METHOD
/*  Instruction:
Select the method to be used for cloud/haze elimination.
(a) Type 'QA_BAND' for using the QAband method.
(b) Type 'FMASK' for using the FMASK-algorithm method.
----------------------------
RECOMMENDED METHOD: 'FMASK'
----------------------------
*/
var getImageFunction = 'FMASK';


// [COMMAND-8] CLOUD-FREE IMAGES
/*  Instruction:
Do you want to display cloud-free images to the GEE Map?
(a) Type 'YES' to display.
(b) Type 'NO' to not display.
*/
var showCloudFree = 'YES';


// [COMMAND-9] FOREST LOSS DETECTION METHOD
/*  Instruction:
Select the method to be used for forest loss detection.
(a) Type 'NDVI_NDWI_NBR' for using the combination of NDVI, NDWI, and NBR.
(b) Type 'SMA_NDFI' for using the integration of SMA and NDFI.
*/
var methodOfAnalysis = 'NDVI_NDWI_NBR';


// [COMMAND-10] THRESHOLD VALUE
/*  Instruction:
Set a threshold value to define a unit of forest loss in the analysis.
----------------------------------------------
RECOMMENDED THRESHOLD VALUE:
(1) 'AMANAB'
    (a) For 'NDVI_NDWI_NBR' set tIndex to 0.190
    (b) For 'SMA_NDFI' set tIndex to 1.945
(2) 'ROTTOCK'
    (a) For 'NDVI_NDWI_NBR' set tIndex to 0.275
    (b) For 'SMA_NDFI' set tIndex to 1.975
----------------------------------------------
*/
var tIndex = 0.190;


// [COMMAND-11] LOSS IMAGES
/*  Instruction:
Do you want to display loss-images to the GEE Map?
(a) Type 'YES' to display.
(b) Type 'NO' to not display.
*/
var showLossImages = 'YES';


// [COMMAND-12] LOSS AREA CALCULATION
/*  Instruction:
Do you want to calculate loss area and print it to the GEE Console?
(a) Type 'YES' to proceed.
(b) Type 'NO' to not proceed.
*/
var calLossArea = 'YES';


// [COMMAND-13] EXPORT LOSS IMAGES TO ASSET
/*  Instruction:
Do you want to export loss-images to user's Asset?
(a) Type 'YES' to export.
```

```
(b) Type 'NO' to not export.
*/
var exportLossToAsset = 'NO';


// [COMMAND-14] EXPORT LOSS IMAGES TO GOOGLE DRIVE
/*  Instruction:
Do you want to export loss-images to user's Google Drive?
(a) Type 'YES' to export.
(b) Type 'NO' to not export.
*/
var exportLossToDrive = 'NO';


// PLEASE CHECK ALL INPUT COMMANDS HAVE BEEN FILLED CORRECTLY, AND CLICK RUN.
//==============================================================================END.



// Part 2: Parameters Collections.
//============================================================================START:
// Image Collections.
var s2Collection = ee.ImageCollection('COPERNICUS/S2');

// Date Format: 'YYYY-MM-DD'
var firstRefStart = ee.Date.fromYMD
                    (firstRefStart_YEAR,firstRefStart_MONTH,firstRefStart_DATE);
var firstRefEnd = ee.Date.fromYMD
                   (firstRefEnd_YEAR,firstRefEnd_MONTH,firstRefEnd_DATE);
var targetStart = ee.Date.fromYMD
                     (targetStart_YEAR,targetStart_MONTH,targetStart_DATE);
var targetEnd = ee.Date.fromYMD
                    (targetEnd_YEAR,targetEnd_MONTH,targetEnd_DATE);

// Conditional function for study area.
if (aoi_select === 'AMANAB') {
  var aoi_name = 'Amanab Consolidated Concession';
  var aoi = ee.FeatureCollection('ft:1qHYNSz7H0mwm4tfP0LG9BUSTxdtDR_9-Hu29CGpE','geometry');
  Map.centerObject(aoi, 9);
}
if (aoi_select === 'ROTTOCK') {
  var aoi_name = 'Rottock Bay Consolidated Concession';
  var aoi = ee.FeatureCollection('ft:1MHGkkEQCDtCLhSMdz5EefLU97UPkeT1Vg4-yGefZ','geometry');
  Map.centerObject(aoi, 10);
}

// Conditional function for forest loss analysis method.
if (methodOfAnalysis === 'NDVI_NDWI_NBR') {
  var printMethod = 'combined NDVI, NDWI, and NBR';
}
if (methodOfAnalysis === 'SMA_NDFI') {
  var printMethod = 'the integration of SMA and NDFI';
}

// Print title.
print('// Sentinel-2 Weekly Forest Loss Detection',
      '// by using '+printMethod,
      '// in '+aoi_name,
      '------------------------------------------'
     );

// Custom mask for tree cover.
var gfc2017 = ee.Image('UMD/hansen/global_forest_change_2017_v1_5');
var gfc2017Clip = gfc2017.clip(aoi);
var treeCover = gfc2017Clip.select(['treecover2000']);
var setMaskTreeCover30 = treeCover.lt(30);
var createMaskTreeCover30 = setMaskTreeCover30.eq(0);

// Visual parameters collections.
var visParamsTrue = {bands: 'B4,B3,B2', min:0, max:3000}; // True color RGB.
var visParamsFalse = {bands: 'B8,B4,B3', min:0, max:3000};// False color RGB.
var visParamsIR = {bands: 'B11,B8,B4', min:0, max:3000}; // Color Infrared RGB.
var visParamsIndex = {palette:['Black','White','Green'], min: -1, max:1}; // Index pallete.
var visParamsLoss = {palette: ['Black','Red'], min:0, max:1}; // Loss-image palette.

// Display the AOI to the Map.
Map.addLayer(aoi, {'color': 'Black'}, aoi_select+' Boundary', true, 1);
//==============================================================================END.
```



```
// Part 3: Cloud/Haze Elimination Functions.
//============================================================================START:
// QA band function.
if (getImageFunction === 'QA_BAND') {
  // Function to generate a cloud-free image by using QA band method.
  var getImageFunction = function (element) {

    var getImageFilter = element.map(
      function (date_list) {

        // Define local variables for the function.
        var aList = ee.List(date_list);
        var startDate = aList.get(0);
        var endDate = aList.get(1);

        // Set conditions for image filter.
        var imageFilter = ee.ImageCollection(s2Collection
                              .filterDate(startDate,endDate)
                              .filterBounds(aoi));

        // Topographic Correction for Sentinel-2.
        var imageFilter_topo = imageFilter.map(illuminationCorrS2);

        // Get cloud-free image for each image in the collection.
        var QAcloudFree = ee.ImageCollection(imageFilter_topo).map(
          function (image) {
            var qa = image.select('QA60');

            // Bits 10 and 11 are clouds and cirrus, respectively.
            var cloudBitMask = Math.pow(2, 10);
            var cirrusBitMask = Math.pow(2, 11);

            // Both flags should be set to zero, indicating clear conditions.
            var mask = qa.bitwiseAnd(cloudBitMask).eq(0).and(
                       qa.bitwiseAnd(cirrusBitMask).eq(0));

            // Return the masked and scaled data.
            var imageout = image.addBands(mask.select([0], ['QAmask']))
                                .updateMask(mask);
                               //.divide(10000);

          return imageout;
        });

        // Apply DOS radiometric normalization.
        var QAcloudFreeDOS = ee.ImageCollection(QAcloudFree).map(getDOSs2);

        // Take the median and clip to AOI.
        var QAcloudFreeDOSMosaic = ee.ImageCollection(QAcloudFreeDOS)
                                              .median()
                                              .clip(aoi)
                                              .updateMask(createMaskTreeCover30);

        // Generate indices.
        var ndvi = ee.Image(QAcloudFreeDOSMosaic.normalizedDifference(['B8','B4']));
        var ndwi = ee.Image(QAcloudFreeDOSMosaic.normalizedDifference(['B8','B11']));
        var nbr  = ee.Image(QAcloudFreeDOSMosaic.normalizedDifference(['B8','B12']));

        return QAcloudFreeDOSMosaic.addBands(ndvi.select([0],['ndvi']))
                              .addBands(ndwi.select([0],['ndwi']))
                              .addBands(nbr.select([0],['nbr']));
      });

    return getImageFilter;
  };
}

// FMASK-algoithm function.
if (getImageFunction === 'FMASK') {
  // Function to generate a cloud-free image by using
  // FMASK-algorithm method for Sentinel-2.
  var getImageFunction = function (element) {

    var getImageFilter = element.map(
      function (date_list) {

        // Define local variables for the function.
```

```
var aList = ee.List(date_list);
var startDate = aList.get(0);
var endDate = aList.get(1);

// Set conditions for image filter.
var imageFilter = ee.ImageCollection(s2Collection
                        .filterDate(startDate,endDate)
                        .filterBounds(aoi));

// Topographic Correction for Sentinel-2.
var imageFilter_topo = imageFilter.map(illuminationCorrS2);

// Get cloud-free image for each image in the collection.
var FMASKcloudFree = ee.ImageCollection(imageFilter_topo).map(
  function (image) {

    // Declare local variables.
    var toa = sentinel2toa(image);
    var cloud = sentinelCloudScore(toa);
    var shadow = shadowMask(toa,cloud);

    var cloud_buffer = 10;
    // Cloud buffer is defined to reduced cloud/haze residues.
    var ee_cloud_buffer = ee.Image(cloud_buffer);
    var mask = cloud.or(shadow).fastDistanceTransform(cloud_buffer,'pixels').gt(ee_cloud_buffer);
    var image1 = image.addBands(mask.select([0],['Fmaskcloudmask']));

  return image1.updateMask(mask);

  // Subfunction to derive unscaled Sentinel-2 TOA bands.
  function sentinel2toa (image) {
    var toa = image.select(['B2','B8','B9','B11','B12'])
                .divide(10000)
                .set('solar_azimuth',image.get('MEAN_SOLAR_AZIMUTH_ANGLE'))
                .set('solar_zenith', image.get('MEAN_SOLAR_ZENITH_ANGLE'));
  return toa;
  }

  // Subfunction to apply the cloud and shadow masking.
  function sentinelCloudScore (toa) {
    var score = toa.select('B2').multiply(toa.select('B9')).multiply(1e4);
    var cloudScoreThreshold = 135;
    var cloud = score.gt(cloudScoreThreshold);
  return cloud;
  }

  // Subfunction to derive shadow mask.
  function shadowMask (toa,cloud) {
    var azi = ee.Number(toa.get('solar_azimuth'));
    var zen = ee.Number(toa.get('solar_zenith')).multiply(1.6);
    var azimuth =azi.multiply(Math.PI).divide(180.0).add(ee.Number(0.5).multiply(Math.PI));
    var zenith  =ee.Number(0.5).multiply(Math.PI ).subtract(zen.multiply(Math.PI).divide(180.0));
    var nominalScale = cloud.projection().nominalScale();
    var cloudHeights = ee.List.sequence(200,5000,500);
    function cloudH (cloudHeight) {
      cloudHeight = ee.Number(cloudHeight);
      var shadowVector = zenith.tan().multiply(cloudHeight);
      var x = azimuth.cos().multiply(shadowVector).divide(nominalScale).round();
      var y = azimuth.sin().multiply(shadowVector).divide(nominalScale).round();
    return cloud.changeProj(cloud.projection(), cloud.projection().translate(x, y));
    }
    var shadows = cloudHeights.map(cloudH);
    var potentialShadow = ee.ImageCollection.fromImages(shadows).max();
    var potentialShadow1 = potentialShadow.and(cloud.not());
    var darkPixels = toa.select(['B8','B11','B12']).reduce(ee.Reducer.sum()).multiply(1e3).lt(250).rename(['dark_pixels']);
    var shadow = potentialShadow1.and(darkPixels).rename('shadows');
  return shadow;
  }

  });

// Apply DOS radiometric normalization.
var FMASKcloudFreeDOS = ee.ImageCollection(FMASKcloudFree).map(getDOSs2);

// Take the median and clip to AOI.
var FMASKcloudFreeDOSMosaic = ee.ImageCollection(FMASKcloudFreeDOS)
                                        .median()
                                        .clip(aoi)
                                        .updateMask(createMaskTreeCover30);
```



```
      // Generate other indices.
      var ndvi = ee.Image(FMASKcloudFreeDOSMosaic.normalizedDifference(['B8','B4']));
      var ndwi = ee.Image(FMASKcloudFreeDOSMosaic.normalizedDifference(['B8','B11']));
      var nbr  = ee.Image(FMASKcloudFreeDOSMosaic.normalizedDifference(['B8','B12']));

    return FMASKcloudFreeDOSMosaic.addBands(ndvi.select([0],['ndvi']))
                              .addBands(ndwi.select([0],['ndwi']))
                              .addBands(nbr.select([0],['nbr']));

    });

  return getImageFilter;
  };

}

// Topographic correction function.
function illuminationCorrS2 (image) {

  // Define local variables.
  var terrain = ee.call('Terrain', ee.Image('USGS/SRTMGL1_003'));
  var solar_zenith = ee.Number((image.get("MEAN_SOLAR_ZENITH_ANGLE")));
  var solar_azimuth = ee.Number(image.get("MEAN_SOLAR_AZIMUTH_ANGLE"));
  var degree2radian = 0.01745329251994329 5; // PI/180
  var solar_zenith_radians = solar_zenith.multiply(degree2radian);
  var slope_radians = terrain.select(['slope']).multiply(degree2radian);
  var aspect = terrain.select(['aspect']);

  // Slope part of the illumination condition.
  var cosZ = solar_zenith_radians.cos();

  var cosS = slope_radians.cos();
  var slope_illumination = cosS.multiply(cosZ);

  // Aspect part of the illumination condition
  var sinZ = solar_zenith_radians.sin();
  var sinS = slope_radians.sin();
  var azimuth_diff_radians = (aspect.subtract(solar_azimuth)).multiply(degree2radian);

  var cosPhi = azimuth_diff_radians.cos();
  var aspect_illumination = cosPhi.multiply(sinS).multiply(sinZ);

  // Illumination condition.
  var ic = slope_illumination.add(aspect_illumination);

  // Apply the cosine correction.
  var cos_output = image.expression("((image*cosZ)/ic) ", {
    'image': image.select(['B1','B2','B3','B4','B8','B11','B12']),
    'cosZ': cosZ,
    'ic': ic,
  });

// Generate output.
return ee.Image(cos_output
                .float()
                .addBands(image.select(['B9', 'B10','QA60']))
                .copyProperties(image)
                .copyProperties(image, ['system:time_start']));
}

// DOS radiometric normalization function.
/* Notes:
Dark Object Subtraction (DOS) only applied on cloud/haze elimination methods
for TOA reflectance images, i.e., the QAband method and the FMASK-algorithm method.
*/
function getDOSs2 (imageTOA) {

  // Define ESUN for B2, B3, B4, B8, B11, B12.
  var esunDict = [1941.63, 1822.61, 1512.79, 1036.39, 245.59, 85.25];

  // Extract solar zenith angle and take it cos.
  var solarZenith_deg = imageTOA.get('MEAN_SOLAR_ZENITH_ANGLE');
  var solarZenith_rad = ee.Number(solarZenith_deg).multiply(Math.PI).divide(180.0);
  var cosZen = solarZenith_rad.cos();

  // Define Earth-Sun Distance.
  var earthSunDis = imageTOA.get('REFLECTANCE_CONVERSION_CORRECTION');
  var earthSunDisPow2 = ee.Number(earthSunDis).pow(2);
```

```
  var piEarthSunDisPow2 = earthSunDisPow2.multiply(Math.PI);

  // Calculate dark object on each band.
  var doB2 = ee.Number(cosZen.divide(piEarthSunDisPow2)).multiply(esunDict[0]);
  var doB3 = ee.Number(cosZen.divide(piEarthSunDisPow2)).multiply(esunDict[1]);
  var doB4 = ee.Number(cosZen.divide(piEarthSunDisPow2)).multiply(esunDict[2]);
  var doB8 = ee.Number(cosZen.divide(piEarthSunDisPow2)).multiply(esunDict[3]);
  var doB11 = ee.Number(cosZen.divide(piEarthSunDisPow2)).multiply(esunDict[4]);
  var doB12 = ee.Number(cosZen.divide(piEarthSunDisPow2)).multiply(esunDict[5]);
  var doDict = [doB2, doB3, doB4, doB8, doB11, doB12];

  // Apply DOS.
  var dosB2 = imageTOA.select('B2').subtract(doDict[0]).max(0);
  var dosB3 = imageTOA.select('B3').subtract(doDict[1]).max(0);
  var dosB4 = imageTOA.select('B4').subtract(doDict[2]).max(0);
  var dosB8 = imageTOA.select('B8').subtract(doDict[3]).max(0);
  var dosB11 = imageTOA.select('B11').subtract(doDict[4]).max(0);
  var dosB12 = imageTOA.select('B12').subtract(doDict[5]).max(0);
  var imageDOS = ee.Image(dosB2).addBands(ee.Image(dosB3)).addBands(ee.Image(dosB4))
                        .addBands(ee.Image(dosB8)).addBands(ee.Image(dosB11))
                        .addBands(ee.Image(dosB12));
  imageDOS = ee.Image(imageDOS).toFloat();

return imageDOS;
}
//==============================================================================END.



// Part 4: Parameters for First Reference Image.
//==============================================================================START:
// Display the duration of First Reference Image.
print('The date of First Reference Image:',
     firstRefStart_YEAR+'-'+firstRefStart_MONTH+'-'+firstRefStart_DATE+' to '
     +firstRefEnd_YEAR+'-'+firstRefEnd_MONTH+'-'+firstRefEnd_DATE,
     '------------------------------------------');

// Define variables to derive FIRST REFERENCE IMAGE.
var firstRefStartList = [ee.Date(firstRefStart)];
var firstRefEndList = [ee.Date(firstRefEnd)];
var firstRefList = ee.List(firstRefStartList).zip(firstRefEndList);
var firstRefCloudMasking = getImageFunction(firstRefList);
var firstRefCloudFreeImage = ee.Image(ee.List(firstRefCloudMasking).get(0));

// Display the selected FIRST REFERENCE IMAGE to Map.
if (showCloudFree === 'YES') {
  Map.addLayer(firstRefCloudFreeImage, visParamsIR,
           'Cloud-free First Reference Image', false);
}
//==============================================================================END.



// Part 5: Parameters for Target Images Collections.
//==============================================================================START:
// Print TARGET IMAGES duration.
print('The duration of Target Images:',
     targetStart_YEAR+'-'+targetStart_MONTH+'-'+targetStart_DATE+' to '
     +targetEnd_YEAR+'-'+targetEnd_MONTH+'-'+targetEnd_DATE+
     ' (Total '+totalWeeks+' weeks)', '------------------------------------------');

// Create a week list (including FIRST REFERENCE IMAGE date).
var firstWeekList = ee.List.sequence(0, ee.Number(totalWeeks).subtract(1));

// Create another week list (excluding FIRST REFERENCE IMAGE date).
var weekList = ee.List.sequence(1, totalWeeks);

// Create a function for filling week list with dates (including initial date).
var firstWeekList = firstWeekList.map(
  function (number) {
    return ee.Date(targetStart).advance(number, 'week');
  });

// Create a function for filling week list with dates (excluding initial date).
var weekList = weekList.map(
  function (number) {
    return ee.Date(targetStart).advance(number, 'week');
  });
```



```
// Create a new list of week pairs (start and end).
var allWeekList = firstWeekList.zip(weekList);

// Print the list of date pairs.
for (var a = 0; a < totalWeeks; a++) {
  var trueA = a+1;
  var startDatePairA = ee.List(allWeekList.get(a)).get(0);
  var endDatePairA = ee.List(allWeekList.get(a)).get(1);
  print('Date pair of Target Image Week-'+trueA, startDatePairA, endDatePairA);
}
print('------------------------------------------');

// Get cloud-free weekly image collection by using cloud-filter function.
var weeklyCollectionsCloudFreeImage = getImageFunction(allWeekList);

// Display the cloud-free weekly image collection to Map.
if (showCloudFree === 'YES') {
  for (var b = 0; b < totalWeeks; b++) {
    var trueB = b+1;
    var weekImageB = ee.Image(weeklyCollectionsCloudFreeImage.get(b));
    Map.addLayer(weekImageB, visParamsIR, 'Cloud-free Target Image Week '+trueB, false);
  }
}
//==============================================================================END.



// Part 6: Parameters for Continuous Reference Image Collections.
//==============================================================================START:
// Delete the last element of the cloud-free weekly image collection.
var deleteLast = weeklyCollectionsCloudFreeImage.splice(-1,1);

// Insert FIRST REFERENCE IMAGE to be the first element of refImageCollections.
var refImageCollections = deleteLast.insert(0, firstRefCloudFreeImage);

// Create a new list of all CONTINUOUS REFERENCE and TARGET images.
var allAnalysis = refImageCollections.zip(weeklyCollectionsCloudFreeImage);
//==============================================================================END.



// Part 7: Forest Loss Analysis.
//==============================================================================START:
// Forest Loss Analysis using the combination of NDVI, NDWI, and NBR.
if (methodOfAnalysis === 'NDVI_NDWI_NBR') {
// Create a function for analyzing Forest loss.
var lossCollections = allAnalysis.map(
   function (list_of_image_pair) {

     // Define local variables for the function.
     var imagePair = ee.List(list_of_image_pair);
     var imageRef = ee.Image(imagePair.get(0));
     var imageTarget = ee.Image(imagePair.get(1));

     // Define delta NDVI, NDWI, and NBR for a pair of Reference-Target.
     var deltaNDVI = (imageRef.select(['ndvi'])).subtract(imageTarget.select(['ndvi']));
     var deltaNDWI = (imageRef.select(['ndwi'])).subtract(imageTarget.select(['ndwi']));
     var deltaNBR = (imageRef.select(['nbr'])).subtract(imageTarget.select(['nbr']));

     // Apply threshold value to all indices.
     var setThreshold = deltaNDVI.gt(tIndex)
                           .and(deltaNDWI.gt(tIndex))
                           .and(deltaNBR.gt(tIndex));

     // Masking out pixels that having a value less than tIndex.
     var maskThreshold = setThreshold.neq(0);
     var lossAreas = maskThreshold.updateMask(maskThreshold);

     // Indicate loss image.
    var lossImage = lossAreas.select([0], ['loss']);

  return lossImage.uint8();
  });
}

// Forest Loss Analysis using the integration of SMA and NDFI.
if (methodOfAnalysis === 'SMA_NDFI') {
  // Create a function for analyzing Forest loss.
  var lossCollections = allAnalysis.map(
```

```
  function (list_of_image_pair) {

    // Define local variables for the function.
    var imagePair = ee.List(list_of_image_pair);
    var imageRef = ee.Image(imagePair.get(0));
    var imageTarget = ee.Image(imagePair.get(1));

    // Create a function to get deforestation image.
    var getNDFI = function (image) {

      // Define cloud-free image collection for spectral unmix.
      var imageCloudFreeUnmix = image.select(['B2','B3','B4','B8','B11','B12'])
                                .divide(10000);

      // Define spectral endmembers.
      var soil = [20, 30, 34, 58, 60, 58];
      var gv = [5, 9, 4, 61, 30, 10];
      var npv = [14, 17, 22, 30, 55, 30];
      var shade = [0, 0, 0, 0, 0, 0];
      var cloud = [90, 96, 80, 78, 72, 65];

      // Unmix the image.
      var fractions = imageCloudFreeUnmix.unmix([gv,shade,npv,soil,cloud],true,true)
                                  .rename(['gv', 'shade', 'npv','soil','cloud']);

      // Define additional cloud mask using cloud fraction.
      var fractionCloudMask = fractions.select('cloud').lt(0.1);

      // Calculate NDFI.
      var ndfi = ee.Image(fractions).expression(
           '((GV / (100 - SHADE)) - (NPV + SOIL)) / ((GV / (100 - SHADE)) + NPV + SOIL)', {
           'GV': ee.Image(fractions).select('gv'),
           'SHADE': ee.Image(fractions).select('shade'),
           'NPV': ee.Image(fractions).select('npv'),
           'SOIL': ee.Image(fractions).select('soil')
           }).rename('NDFI').updateMask(fractionCloudMask);

    return ndfi;
    };

    // Generate NDFI for a pair of Reference-Target.
    var ndfiRef = getNDFI(imageRef);
    var ndfiTarget = getNDFI(imageTarget);

    // Define delta NDFI for a pair of Reference-Target.
    var deltaNDFI = ndfiRef.subtract(ndfiTarget);

    // Apply threshold value to delta NDFI.
    var setThreshold = deltaNDFI.gt(tIndex);

    // Masking out pixels that having a value less than tIndex.
    var maskThreshold = setThreshold.neq(0);
    var lossAreas = maskThreshold.updateMask(maskThreshold);

    // Indicate loss image.
    var lossImage = lossAreas.select([0], ['loss']);

  return lossImage.uint8();
  });
}

// Display the loss-image collections to Map.
if (showLossImages === 'YES') {

 for (var c = 0; c < totalWeeks; c++) {
  var trueC = c+1;
  var lossImageC = ee.Image(lossCollections.get(c)).select('loss');
  Map.addLayer(lossImageC, visParamsLoss, 'Loss-image Week '+trueC, false);
 }

}
//=================================================================================END.


// Part 8: Loss Area Calculation.
//===============================================================================START:
// Function to calculate loss area.
var lossAreaCal = function (lossImage) {
```



```
  // Generate pixel area image.
  var imagePixArea=lossImage.multiply(ee.Image.pixelArea());

  // Calculate loss areas in sq. meter.
  var imageLossArea = imagePixArea.reduceRegion({
   reducer:ee.Reducer.sum(),
   geometry: aoi.geometry().bounds(),
   crs: 'EPSG:4326',
   scale: 250,
   // Scale pixel resolution to 250m for calculation purpose.
   maxPixels:1e10,
   tileScale:4
  });

  // Converts areas to sq. km.
  var sqKmImageLossArea = ee.Number(imageLossArea.get('loss'))
                              .divide(1e6).format('%.3f');

return sqKmImageLossArea;
};

if (calLossArea === 'YES') {

  // Calculate loss area for each analysis.
  for (var e = 0; e < totalWeeks; e++) {
    var trueE = e+1;

    if (methodOfAnalysis === 'NDVI_NDWI_NBR'){
    var lossImageE = ee.Image(lossCollections.get(e));
    }
    if (methodOfAnalysis === 'SMA_NDFI'){
    var lossImageE = ee.Image(lossCollections.get(e)).select('loss');
    }

    // Calculate loss area for each analysis.
    var lossImageE_grid = lossAreaCal(lossImageE);

    // Display loss-area to Console.
    print('Loss area of Analysis-'+trueE+' (sq.km): ', lossImageE_grid);
  }

  print('--------------------------------------------');
}
//=================================================================================END.


// Part 9: Parameters for Export Images.
//===============================================================================START:
// Selection to export loss-image collections to user's Asset.
if (exportLossToAsset === 'YES') {
  for (var f = 0; f < totalWeeks; f++) {
    var trueF = f+1;

    if (methodOfAnalysis === 'NDVI_NDWI_NBR'){
    var lossImageF = ee.Image(lossCollections.get(f));
    }
    if (methodOfAnalysis === 'SMA_NDFI'){
    var lossImageF = ee.Image(lossCollections.get(f)).select('loss');
    }

    Export.image.toAsset({
    image: lossImageF,
    description: aoi_select+'_S2weeklyLossImage_'
              +targetStart_YEAR+'-'+targetStart_MONTH+'-'+targetStart_DATE+'_week_'+trueF,
    region: aoi.geometry().bounds(),
    crs: 'EPSG:4326',
    scale: 10,
    maxPixels: 1e10,
    });
  }
}

// Selection to export loss-image collections to user's Google Drive.
if (exportLossToDrive === 'YES') {
  for (var g = 0; g < totalWeeks; g++) {
    var trueG = g+1;
```

```
if (methodOfAnalysis === 'NDVI_NDWI_NBR'){
var lossImageG = ee.Image(lossCollections.get(g));
}
if (methodOfAnalysis === 'SMA_NDFI'){
var lossImageG = ee.Image(lossCollections.get(g)).select('loss');
}

Export.image.toDrive({
image: lossImageG,
description: aoi_select+'_S2weeklyLossImage_'
        +targetStart_YEAR+'-'+targetStart_MONTH+'-'+targetStart_DATE+'_week_'+trueG,
region: aoi.geometry().bounds(),
crs: 'EPSG:4326',
scale: 10,
maxPixels: 1e10,
});
 }
}
//==========================================================================END.


// End of script.
```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添付資料 9

森林減少モニタリングツールマニュアル

年次森林減少モニタリングツールのマニュアル

週次森林減少モニタリングツールのマニュアル

User Manual:
Landsat-8 Annual Forest Loss Detection (v2018.12.11) and Sentinel-2 Annual Forest Loss Detection (v2018.12.11)

1. Introduction

The Landsat-8 Annual Forest Loss Detection (v2018.12.11) and the Sentinel-2 Annual Forest Loss Detection (v2018.12.11) are similar scripts that intended to monitor the annual logging activities inside of logging concessions in Papua New Guinea. In these scripts, two forest loss detection methods are available to be selected, i.e., the combination of Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), and Normalized Burn Ratio (NBR) method and the integration of Spectral Mixture Analysis (SMA) and Normalized Difference Fraction Index (NDFI) method. The only difference between these scripts is the sensor that is used to derive satellite images; thus user manuals for both scripts are combined for users' convenience. Each script is divided into nine parts, which are: (1) Input Commands, (2) Parameters Collections, (3) Parameters for Investigation Periods, (4) Cloud/Haze Elimination Functions, (5) Image Collections, (6) Forest Loss Analysis, (7) Loss Area Calculation, (8) Parameters for Export Images, and (9) Tree-cover loss accumulation.

a. Part 1: Input Commands

In this part, all input commands (15 in total) should be defined by the user prior to run the script. The first command (COMMAND-1) is to assign the START DATE of the FIRST REFERENCE IMAGE that includes three variables, i.e., firstRefStart_YEAR to define the year, firstRefStart_MONTH to define the month, and firstRefStart_DATE to define the date. The second command (COMMAND-2) is to assign the END DATE of the FIRST REFERENCE IMAGE that includes three variables, i.e., firstRefEnd_YEAR to define the year, firstRefEnd_MONTH to define the month, and firstRefEnd_DATE to define the date. The third command (COMMAND-3) is to assign the START DATE of the FIRST TARGET IMAGE that includes three variables, i.e., firstTargetStart_YEAR to define the year, firstTargetStart_MONTH to define the month, and firstTargetStart_DATE to define the date. The fourth command (COMMAND-4) is to assign the END DATE of the FIRST TARGET IMAGE that includes three variables, i.e., firstTargetEnd_YEAR to define the year, firstTargetEnd_MONTH to define the month, and firstTargetEnd_DATE to define the date. The fifth command (COMMAND-5) is to define the TOTAL amount of TARGET IMAGES to be used for analysis, which includes the FIRST TARGET IMAGE. The sixth command (COMMAND-6) is to select the area of interest (AOI) to be used for forest loss detection. These scripts are supported annual forest loss detection for two AOIs in Papua New Guinea that is the Amanab Consolidated Concession and the Rottock Bay Consolidated Concession. The seventh command (COMMAND-7) is to select the method to be used for cloud/haze elimination purposes. For the Landsat-8 based script, two cloud/haze elimination methods are available to be used, i.e., the QA band method and the CFMASK-derived QA band method. For the Sentinel-2 based script, two cloud/haze elimination methods are available to be used, i.e., the QA band method and the FMASK-algorithm method. On each script, the recommended method to be used for cloud/

haze elimination is listed for the user's convenience. The eighth command (COMMAND-8) is an option whether to display the cloud-free images to the Google Earth Engine (GEE) Map or not. The ninth command (COMMAND-9) is to select the method to be used for forest loss detection purposes. In these scripts, two forest loss detection methods are available to be selected, i.e., the combination of NDVI, NDWI, and NBR method and the integration of SMA and NDFI method. The tenth command (COMMAND-10) is to assign the threshold value to define a unit of forest loss in the analysis (so-called the tIndex). On each script, the recommended tIndex to be applied to each AOI and on each forest loss detection method is listed for the user's convenience. The eleventh command (COMMAND-11) is an option whether to display the loss images to the GEE Map or not. The twelfth command (COMMAND-12) is an option whether to calculate the loss areas in square kilometers and print it to the GEE Console or not. The thirteenth command (COMMAND-13) is an option whether to export the loss images to user's Assets in GEE or not. The fourteenth command (COMMAND-14) is an option whether to export the loss images to user's Google Drive account or not. The last command (COMMAND-15) is an option whether to generate the greenest and least-greenest images as well as calculate the tree-cover loss accumulation for each year. If the user selects 'YES,' the threshold value to define a unit of tree-cover loss in the analysis (so-called the tTreecover) should be defined. On each script, the recommended tTreecover to be applied to each AOI is listed for the user's convenience.

b. Part 2: Parameters Collections

This part comprises the collection of general parameters that are used on the scripts. These parameters include: (a) The definition of image collections, (b) The date formatting for the investigation period, (c) The conditional functions for the selected AOI, (d) The conditional functions for the selected method for forest loss detection, (e) A command to print the script's title to the GEE Console, (f) A command for masking the tree-cover in the selected AOI that is derived from the Hansen Global Forest Change v1.5 data, (g) A collection of visual parameters, and (h) A command to display the boundary of the selected AOI to the GEE Map.

c. Part 3: Parameters for Investigation Periods

In this part, the functions to automatically derive the START DATE and END DATE for each reference and target images are defined. Furthermore, these dates are grouped in the list for each pair of reference and target images. Lastly, there is a command to print out the list of the date-pairs for each analysis of forest loss detection to the GEE Console.

d. Part 4: Cloud/Haze Elimination Functions

This part collects functions to generate cloud-free images by using the cloud/haze elimination methods. For the Landsat-8 based script, two functions of cloud/haze elimination methods are defined, i.e., the QA band method and the CFMASK-derived QA band method. For the Sentinel-2 based script, two functions of cloud/haze elimination methods are defined, i.e., the QA band method and the FMASK-algorithm method. Basically, each cloud/haze elimination method follows the following workflow: (a) Define the local parameters to be used on the function, (b) Obtain the image collection from the image archive, (c) Apply the topographic correction function that is based on Teillet, P.M., et al. (1982), (d) Apply the cloud/haze elimination function for each image in the image collection, (e) Apply the Dark Object Subtraction (DOS) radiometric correction function that is based on Chavez (1988), (f) Generate the mosaic image of the annual cloud-free image by taking the median value of the image collection and clip it with the boundary of the selected AOI, (g) Generate the vegetation index images to be used for further image processing.

e. Part 5: Image Collections

In this part, the commands to obtain the cloud-free image for each reference and target images in the investigation period are listed. Furthermore, there is a conditional function to accommodate the option for displaying the cloud-free image collection to the GEE Map.

f. Part 6: Forest Loss Analysis

This part comprises functions to analyze forest loss by utilizing the forest loss detection methods. In these scripts, two forest loss detection methods are defined, i.e., the combination of NDVI, NDWI, and NBR method and the integration of SMA and NDFI method. The earlier-mentioned method analyzes the difference between NDVI, NDWI, and NBR images for a given reference and target images so that a decreasing value of those three indices at a given area or pixel that is greater than the given threshold value (tIndex) would be considered as forest loss. This method is adapted from the forest loss detection method derived by Hansen et al. (2016). Meanwhile, the later-mentioned method utilizes SMA-derived fraction images for generating NDFI image for a given reference and target image so that a decreasing value of NDFI at a given area or pixel that is greater than the given threshold value (tIndex) would be considered as forest loss. This method is initially proposed by Souza et al. (2003), Souza et al. (2005), and Souza et al. (2013). Lastly, the command to display the loss-image collection for each analysis to the GEE Map is listed.

g. Part 7: Loss Area Calculation

In this part, the function to calculate the loss areas is listed. In these scripts, the loss areas are calculated per 250 meters grid to accommodate a speedy computation. Furthermore, the unit of the loss areas is converted to square kilometers. At the end of this part, the command to print the loss-area for each analysis to the GEE Console is provided.

h. Part 8: Parameters for Export Images

This part collects conditional functions for exporting the loss-image collection to user's Assets in GEE and user's Google Drive account. Each exported loss-image would have a pixel size of 30 meters and 10 meters for Landsat-8 script and Sentinel-2 script, respectively, and a UTM WGS84 projection. The naming structure of each lost-image is described as follows:

For Landsat-8 Annual Forest Loss Detection (v2018.12.11)

(AOI**)**_L8annualLossImage_analysis_**(**n**)**

The (AOI) defines as the name of the area of interest of the image; 'AMANAB' for Amanab Consolidated Concession and 'ROTTOCK' for Rottock Bay Consolidated Concession. Meanwhile, the (n) defined as the sequence of the forest lost that is being analyzed, e.g., the first sequence (n = 1) is the annual forest lost image for the pair of FIRST REFERENCE IMAGE and the FIRST TARGET IMAGE, and so on until the end sequence of the analysis. To better understand the naming structure, please kindly have a look at these examples:

1. AMANAB_L8annualLossImage_analysis_1
   The AOI of this lost-image is the Amanab Consolidated Concession for the annual forest lost analysis in 2015 and is generated by subtracting the forest areas in 2014 (as the REFERENCE IMAGE; Start Date: 2014/01/01; End Date: 2014/12/31) with the forest areas in 2015 (as the TARGET IMAGE; Start Date: 2015/01/01; End Date: 2015/12/31).
2. AMANAB_L8annualLossImage_analysis_2
   The AOI of this lost-image is the Amanab Consolidated Concession for the annual forest lost analysis in 2016 and is generated by subtracting the forest areas in 2015 (as the REFERENCE IMAGE; Start Date: 2015/01/01; End Date: 2015/12/31) with the forest areas in 2016 (as the TARGET IMAGE; Start Date: 2016/01/01; End Date: 2016/12/31).
3. AMANAB_L8annualLossImage_analysis_3
   The AOI of this lost-image is the Amanab Consolidated Concession for the annual forest lost analysis in 2017 and is generated by subtracting the forest areas in 2016 (as the REFERENCE IMAGE; Start Date: 2016/01/01; End Date: 2016/12/31) with the forest areas in 2017 (as the TARGET IMAGE; Start Date: 2017/01/01; End Date: 2017/12/31).
4. ROTTOCK_L8annualLossImage_analysis_1
   The AOI of this lost-image is the Rottock Bay Consolidated Concession for the annual forest lost analysis in 2015 and is generated by subtracting the forest areas in 2014 (as the REFERENCE IMAGE; Start Date: 2014/01/01; End Date: 2014/12/31) with the forest areas in 2015 (as the TARGET IMAGE; Start Date: 2015/01/01; End Date: 2015/12/31).
5. ROTTOCK_L8annualLossImage_analysis_2
   The AOI of this lost-image is the Rottock Bay Consolidated Concession for the annual forest lost analysis in 2016 and is generated by subtracting the forest areas in 2015 (as the REFERENCE IMAGE; Start Date: 2015/01/01; End Date: 2015/12/31) with the forest areas in 2016 (as the TARGET IMAGE; Start Date: 2016/01/01; End Date: 2016/12/31).
6. ROTTOCK_L8annualLossImage_analysis_3
   The AOI of this lost-image is the Rottock Bay Consolidated Concession for the annual forest lost analysis in 2017 and is generated by subtracting the forest areas in 2016 (as the REFERENCE IMAGE; Start Date: 2016/01/01; End Date: 2016/12/31) with the forest areas in 2017 (as the TARGET IMAGE; Start Date: 2017/01/01; End Date: 2017/12/31).

For Sentinel-2 Annual Forest Loss Detection (v2018.12.11)

(AOI**)**_S2annualLossImage_analysis_**(**n**)**

The (AOI) defines as the name of the area of interest of the image; ‘AMANAB' for Amanab Consolidated Concession and ‘ROTTOCK’ for Rottock Bay Consolidated Concession. Meanwhile, the (n) defined as the sequence of the forest lost that is being analyzed, e.g., the first sequence (n = 1) is the annual forest lost image for the pair of FIRST REFERENCE IMAGE and the FIRST TARGET IMAGE, and so on until the end sequence of the analysis. To better understand the naming structure, please kindly have a look at these examples:

1. AMANAB_S2annualLossImage_analysis_1
   The AOI of this lost-image is the Amanab Consolidated Concession for the annual forest lost analysis in 2016 and is generated by subtracting the forest areas in 2015 (as the REFERENCE IMAGE; Start Date: 2015/01/01; End Date: 2015/12/31) with the forest areas in 2016 (as the TARGET IMAGE; Start Date: 2016/01/01; End Date: 2016/12/31).
2. AMANAB_S2annualLossImage_analysis_2
   The AOI of this lost-image is the Amanab Consolidated Concession for the annual forest lost analysis in 2017 and is generated by subtracting the forest areas in 2016 (as the REFERENCE IMAGE; Start Date: 2016/01/01; End Date: 2016/12/31) with the forest areas in 2017 (as the TARGET IMAGE; Start Date: 2017/01/01; End Date: 2017/12/31).
3. ROTTOCK_S2annualLossImage_analysis_1
   The AOI of this lost-image is the Rottock Bay Consolidated Concession for the annual forest lost analysis in 2016 and is generated by subtracting the forest areas in 2015 (as the REFERENCE IMAGE; Start Date: 2015/01/01; End Date: 2015/12/31) with the forest areas in 2016 (as the TARGET IMAGE; Start Date: 2016/01/01; End Date: 2016/12/31).
4. ROTTOCK_S2annualLossImage_analysis_2
   The AOI of this lost-image is the Rottock Bay Consolidated Concession for the annual forest lost analysis in 2017 and is generated by subtracting the forest areas in 2016 (as the REFERENCE IMAGE; Start Date: 2016/01/01; End Date: 2016/12/31) with the forest areas in 2017 (as the TARGET IMAGE; Start Date: 2017/01/01; End Date: 2017/12/31).

e. Part 9: Tree-cover loss accumulation.

This part collects the function to generate the tree-cover loss accumulation by utilizing the greenest and the least-greenest images. The tree-cover loss accumulation method follows the following workflow:

(i) Obtain an image collection for a given year in a given AOI,
(ii) Apply the topographic correction for each image in the image collection,
(iii) Generate the cloud-free image collection by using the CFMASK and FMASK cloud/haze elimination method for Landsat-8 based script and Sentinel-2 based script, respectively,
(iv) Derive the NDVI image for each image in the cloud-free image collection,
(v) Generate the greenest image by taking the highest (maximum) NDVI value on each pixel in the image collection, and the least-greenest image by taking the lowest (minimum) NDVI value on each pixel in the image collection,
(vi) Calculate the tree-cover loss accumulation by subtracting the greenest image with the least-greenest image and take all values that is greater than the threshold value (so called the tTreecover that is

describes as a user-defined threshold value that is used to determine a unit of tree-cover loss in the analysis),
(vii) Calculate the tree-cover loss accumulation areas, print them to the GEE Console, and display the tree-cover loss accumulation image to the GEE Map.

2. Script Guidelines

The primary objective of these scripts is to monitor the annual logging activities inside boundaries of logging concessions in Papua New Guinea. Therefore, the following script guidelines are intended to instruct the users for utilizing the Landsat-8 Annual Forest Loss Detection (v2018.12.11) and the Sentinel-2 Annual Forest Loss Detection (v2018.12.11).

a. Step-by-step instructions

To obtain the best advantage of these scripts, the users are kindly requested to follow the step-by-step instructions on how to use these scripts that are described as follows:

1. Navigate to the Google Earth Engine (GEE) Code Editor in Google Chrome, log in with a GEE-registered Google account, and open a forest loss detection script.
2. Prior to run the script, users are requested to read the input command's instructions and fill out the input commands (15 in total) that are available in the "Part 1:Input Commands."
3. Proceed with the COMMAND-1 and COMMAND-2 to define the period (i.e., the start date and the end date) of the FIRST REFERENCE IMAGE for the analysis. Each command includes three variables to assign the year, the month, and the date separately. Please type the preferred period as shown below:

For Landsat-8 Annual Forest Loss Detection (v2018.12.11)

```
// [COMMAND-1] FIRST REFERENCE IMAGE - Start Date
/*  Instruction:
(a) Define the Start Date of the FIRST REFERENCE IMAGE.
(b) Insert the YEAR, MONTH, and DATE on separate variables.
*/
var firstRefStart_YEAR = 2014;
var firstRefStart_MONTH = 1;
var firstRefStart_DATE = 1;


// [COMMAND-2] FIRST REFERENCE IMAGE - End Date
/*  Instruction:
(a) Define the End Date of the FIRST REFERENCE IMAGE.
(b) Insert the YEAR, MONTH, and DATE on separate variables.
*/
var firstRefEnd_YEAR = 2014;
var firstRefEnd_MONTH = 12;
var firstRefEnd_DATE = 31;
```

For Sentinel-2 Annual Forest Loss Detection (v2018.12.11)

```
// [COMMAND-1] FIRST REFERENCE IMAGE - Start Date
/*  Instruction:
(a) Define the Start Date of the FIRST REFERENCE IMAGE.
(b) Insert the YEAR, MONTH, and DATE on separate variables.
*/
var firstRefStart_YEAR = 2015;
var firstRefStart_MONTH = 1;
var firstRefStart_DATE = 1;


// [COMMAND-2] FIRST REFERENCE IMAGE - End Date
/*  Instruction:
(a) Define the End Date of the FIRST REFERENCE IMAGE.
(b) Insert the YEAR, MONTH, and DATE on separate variables.
*/
var firstRefEnd_YEAR = 2015;
var firstRefEnd_MONTH = 12;
var firstRefEnd_DATE = 31;
```

4. Proceed with the COMMAND-3 and COMMAND-4 to define the period (i.e., the start date and the end date) of the FIRST TARGET IMAGE for the analysis. Each command includes three variables to assign the year, the month, and the date separately. Please type the preferred period as shown below:

For Landsat-8 Annual Forest Loss Detection (v2018.12.11)

```
// [COMMAND-3] FIRST TARGET IMAGE - Start Date
/*  Instruction:
(a) Define the Start Date of the FIRST TARGET IMAGE.
(b) Insert the YEAR, MONTH, and DATE on separate variables.
*/
var firstTargetStart_YEAR = 2015;
var firstTargetStart_MONTH = 1;
var firstTargetStart_DATE = 1;


// [COMMAND-4] FIRST TARGET IMAGE - End Date
/*  Instruction:
(a) Define the End Date of the FIRST TARGET IMAGE.
(b) Insert the YEAR, MONTH, and DATE on separate variables.
*/
var firstTargetEnd_YEAR = 2015;
var firstTargetEnd_MONTH = 12;
var firstTargetEnd_DATE = 31;
```

For Sentinel-2 Annual Forest Loss Detection (v2018.12.11)

```
// [COMMAND-3] FIRST TARGET IMAGE - Start Date
/*  Instruction:
(a) Define the Start Date of the FIRST TARGET IMAGE.
(b) Insert the YEAR, MONTH, and DATE on separate variables.
*/
var firstTargetStart_YEAR = 2016;
var firstTargetStart_MONTH = 1;
var firstTargetStart_DATE = 1;


// [COMMAND-4] FIRST TARGET IMAGE - End Date
/*  Instruction:
(a) Define the End Date of the FIRST TARGET IMAGE.
(b) Insert the YEAR, MONTH, and DATE on separate variables.
*/
var firstTargetEnd_YEAR = 2016;
var firstTargetEnd_MONTH = 12;
var firstTargetEnd_DATE = 31;
```

5. Proceed with the COMMAND-5 to define the total amount of the TARGET IMAGES to be used for analysis, which includes the FIRST TARGET IMAGE. Please type the amount as shown below:

For Landsat-8 Annual Forest Loss Detection (v2018.12.11)

```
// [COMMAND-5] TARGET IMAGES
/*  Instruction:
Define the amount of TARGET IMAGES to be used for analysis,
which INCLUDING the FIRST TARGET IMAGE.
*/
var totalTarget = 3;
```

For Sentinel-2 Annual Forest Loss Detection (v2018.12.11)

```
// [COMMAND-5] TARGET IMAGES
/*  Instruction:
Define the amount of TARGET IMAGES to be used for analysis,
which INCLUDING the FIRST TARGET IMAGE.
*/
var totalTarget = 2;
```

6. Proceed with the COMMAND-6 to select the area of interest (AOI) to be used for forest loss detection. Both scripts are supported annual forest loss detection for two AOIs that are the Amanab Consolidated Concession ('AMANAB') and the Rottock Bay Consolidated Concession ('ROTTOCK'). Please type the preferred AOI as shown below, for both scripts:

```
// [COMMAND-6] AREA OF INTEREST
/*  Instruction:
Select the Area of interest (AOI) to be calculated:
(a) Type 'AMANAB' for Amanab Consolidated Concession.
(b) Type 'ROTTOCK' for Rottock Bay Consolidated Concession.
*/
var aoi_select = 'AMANAB';
```

7. Proceed with the COMMAND-7 to select the method to be used for cloud/haze elimination purposes. For the Landsat-8 based script, two cloud/haze elimination methods are available to be used, i.e., the QA band method and the CFMASK-derived QA band method. For the Sentinel-2 based script, two cloud/haze elimination methods are available to be used, i.e., the QA band method and the FMASK-algorithm method. On each script, the recommended method to be used for cloud/haze elimination is listed for the user's convenience. Please type the preferred cloud/haze elimination method as shown below:

<u>For Landsat-8 Annual Forest Loss Detection (v2018.12.11)</u>

```
// [COMMAND-7] CLOUD/HAZE ELIMINATION METHOD
/*  Instruction:
Select the method to be used for cloud/haze elimination.
(a) Type 'QA_BAND' for using the QAband method.
(b) Type 'CFMASK' for using the CFMASK-derived QAband method.
-----------------------------
RECOMMENDED METHOD: 'CFMASK'
-----------------------------
*/
var getImageFunction = 'CFMASK';
```

<u>For Sentinel-2 Annual Forest Loss Detection (v2018.12.11)</u>

```
// [COMMAND-7] CLOUD/HAZE ELIMINATION METHOD
/*  Instruction:
Select the method to be used for cloud/haze elimination.
(a) Type 'QA_BAND' for using the QAband method.
(b) Type 'FMASK' for using the FMASK-algorithm method.
-----------------------------
RECOMMENDED METHOD: 'FMASK'
-----------------------------
*/
var getImageFunction = 'FMASK';
```

8. Proceed with the COMMAND-8 to select whether to display the cloud-free images to the GEE Map or not. Please type the preferred option as shown below, for both scripts:

```
// [COMMAND-8] CLOUD-FREE IMAGES
/*  Instruction:
Do you want to display cloud-free images to the GEE Map?
(a) Type 'YES' to display.
(b) Type 'NO' to not display.
*/
var showCloudFree = 'YES';
```

9. Proceed with the COMMAND-9 to select the method to be used for forest loss detection purposes. For both scripts, two forest loss detection methods are available to be selected, i.e., the combination of NDVI, NDWI, and NBR method and the integration of SMA and NDFI method. Please type the forest loss detection method as shown below, for both scripts:

```
// [COMMAND-9] FOREST LOSS DETECTION METHOD
/*  Instruction:
Select the method to be used for forest loss detection.
(a) Type 'NDVI_NDWI_NBR' for using the combination of NDVI, NDWI, and NBR.
(b) Type 'SMA_NDFI' for using the integration of SMA and NDFI.
*/
var methodOfAnalysis = 'NDVI_NDWI_NBR';
```

10. Proceed with the COMMAND-10 to assign the threshold value to define a unit of forest loss in the analysis (so-called the tIndex). On each script, the recommended tIndex to be applied to each AOI and on each forest loss detection method is listed for the user's convenience. Please type the preferred tIndex as shown below:

<u>For Landsat-8 Annual Forest Loss Detection (v2018.12.11)</u>

```
// [COMMAND-10] THRESHOLD VALUE
/*  Instruction:
Set a threshold value to define a unit of forest loss in the analysis.
-----------------------------------------------
RECOMMENDED THRESHOLD VALUE:
(1) 'AMANAB'
    (a) For 'NDVI_NDWI_NBR' set tIndex to 0.215
    (b) For 'SMA_NDFI' set tIndex to 1.925
(2) 'ROTTOCK'
    (a) For 'NDVI_NDWI_NBR' set tIndex to 0.180
    (b) For 'SMA_NDFI' set tIndex to 1.900
-----------------------------------------------
*/
var tIndex = 0.215;
```

<u>For Sentinel-2 Annual Forest Loss Detection (v2018.12.11)</u>

```
// [COMMAND-10] THRESHOLD VALUE
/*  Instruction:
Set a threshold value to define a unit of forest loss in the analysis.
-----------------------------------------------
RECOMMENDED THRESHOLD VALUE:
(1) 'AMANAB'
    (a) For 'NDVI_NDWI_NBR' set tIndex to 0.190
    (b) For 'SMA_NDFI' set tIndex to 1.955
(2) 'ROTTOCK'
    (a) For 'NDVI_NDWI_NBR' set tIndex to 0.140
    (b) For 'SMA_NDFI' set tIndex to 1.905
-----------------------------------------------
*/
var tIndex = 0.190;
```

11. Proceed with the COMMAND-11 to select whether to display the loss images to the GEE Map or not. Please type the preferred option as shown below, for both scripts:

```
// [COMMAND-11] LOSS IMAGES
/*  Instruction:
Do you want to display loss-images to the GEE Map?
(a) Type 'YES' to display.
(b) Type 'NO' to not display.
*/
var showLossImages = 'YES';
```

12. Proceed with the COMMAND-12 to select whether to calculate the loss areas in square kilometers and print it to the GEE Console or not. Please type the preferred option as shown below, for both scripts:

```
// [COMMAND-12] LOSS AREA CALCULATION
/*  Instruction:
Do you want to calculate loss area and print it to the GEE Console?
(a) Type 'YES' to proceed.
(b) Type 'NO' to not proceed.
*/
var calLossArea = 'YES';
```

13. Proceed with the COMMAND-13 and COMMAND-14 to select whether to export the loss images to user's Assets in GEE or not and to export the loss images to user's Google Drive account or not, respectively. Please type the preferred option as shown below, for both scripts:

```
// [COMMAND-13] EXPORT LOSS IMAGES TO ASSET
/*  Instruction:
Do you want to export loss-images to user's Asset?
(a) Type 'YES' to export.
(b) Type 'NO' to not export.
*/
var exportLossToAsset = 'NO';


// [COMMAND-14] EXPORT LOSS IMAGES TO GOOGLE DRIVE
/*  Instruction:
Do you want to export loss-images to user's Google Drive?
(a) Type 'YES' to export.
(b) Type 'NO' to not export.
*/
var exportLossToDrive = 'NO';
```

14. Proceed with the COMMAND-15 to select whether to generate the greenest and least-greenest images as well as calculate the tree-cover loss accumulation for each year. If the user selects 'YES,' the threshold value to define a unit of tree-cover loss in the analysis (so-called the tTreecover) should also be defined. On each script, the recommended tTreecover to be applied to each AOI is listed for the user's convenience. Please type the preferred option and tTreecover (only defined if the preferred option is a 'YES') as shown below:

<u>For Landsat-8 Annual Forest Loss Detection (v2018.12.11)</u>

```
// [COMMAND-15] TREE-COVER LOSS ACCUMULATION
/* Instruction:
Do you want to generate greenest and least-greenest images,
and calculate tree-cover loss accumulation for each year?
(a) Type 'YES' and define the threshold value to define a unit of tree-cover loss.
(b) Type 'NO' to not proceed.
----------------------------------------------------
RECOMMENDED THRESHOLD VALUE:
(1) For 'AMANAB' set tTreecover to 0.845
(2) For 'ROTTOCK' set tTreecover to 0.585
----------------------------------------------------
*/
var showTreecoverAccum = 'NO';
var tTreecover = 0.845;
```

<u>For Sentinel-2 Annual Forest Loss Detection (v2018.12.11)</u>

```
// [COMMAND-15] TREE-COVER LOSS ACCUMULATION
/* Instruction:
Do you want to generate greenest and least-greenest images,
and calculate tree-cover loss accumulation for each year?
(a) Type 'YES' and define the threshold value to define a unit of tree-cover loss.
(b) Type 'NO' to not proceed.
----------------------------------------------------
RECOMMENDED THRESHOLD VALUE:
(1) For 'AMANAB' set tTreecover to 0.740
(2) For 'ROTTOCK' set tTreecover to 0.715
----------------------------------------------------
*/
var showTreecoverAccum = 'NO';
var tTreecover = 0.740;
```

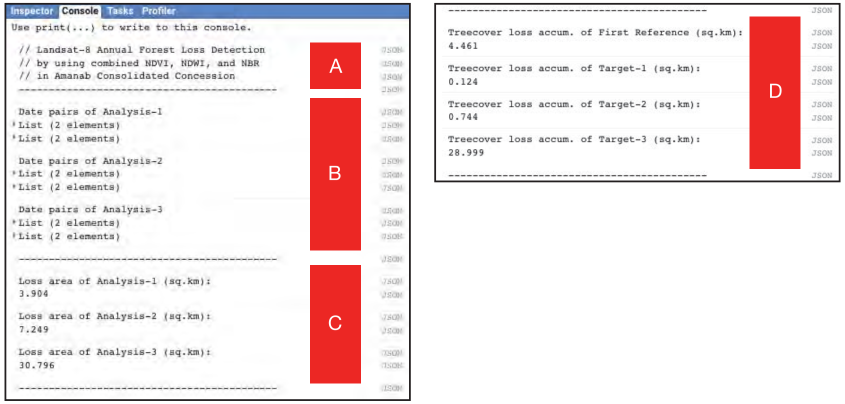
15. Finally, please kindly check that all input commands have been filled correctly by following each instruction and click 'Run' button on the top-side of the GEE Code Editor to start the forest loss analysis.

b. <u>Description of the printed results and displayed outputs.</u>

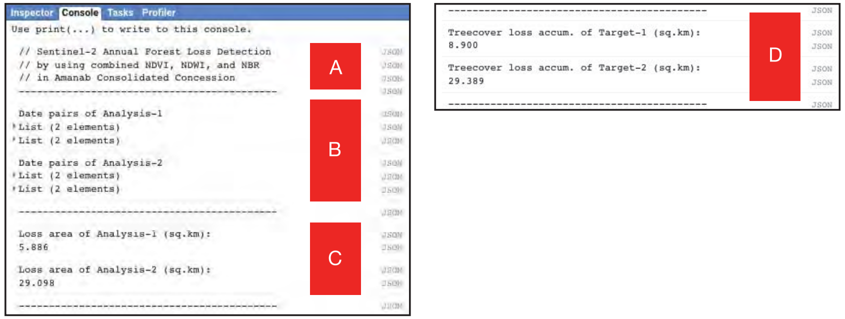
To understand the printed results in the GEE Console and the displayed outputs in the GEE Map, the users are kindly recommended to have a look at the following descriptions:

1. The printed results in the GEE Console are shown as follows:

<u>For Landsat-8 Annual Forest Loss Detection (v2018.12.11)</u>



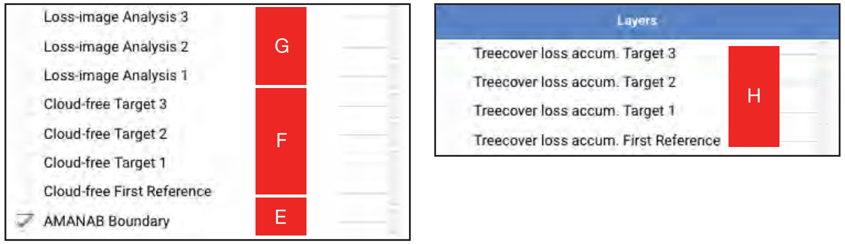
<u>For Sentinel-2 Annual Forest Loss Detection (v2018.12.11)</u>



For both scripts, the A section displays the title of the script that includes the name of the sensor being used, the information about the selected forest loss detection method, and the name of the AOI being analyzed. Afterward, the B section displays the lists of date pairs of the REFERENCE and TARGET IMAGE for all analyses. On each list of date-pairs, the upper list shows the date of the REFERENCE IMAGE (the start date and end date) and the lower list shows the date of the TARGET IMAGE (the start date and end date). The number of the lists of date pairs depends on the total amount of TARGET IMAGES. The users are recommended to click the zippy symbol (▸) to see the detail information of a list of date-pairs. Meanwhile, the C section shows the calculated loss areas for all analysis in square kilometers (sq. km). Finally, the D section shows the calculated tree-cover loss accumulation areas for all years (including the year of the FIRST REFERENCE IMAGE) in square kilometers (sq. km).

2. The displayed outputs in the GEE Map that are listed in the 'Layers' tab are shown as follows:

For Landsat-8 Annual Forest Loss Detection (v2018.12.11)

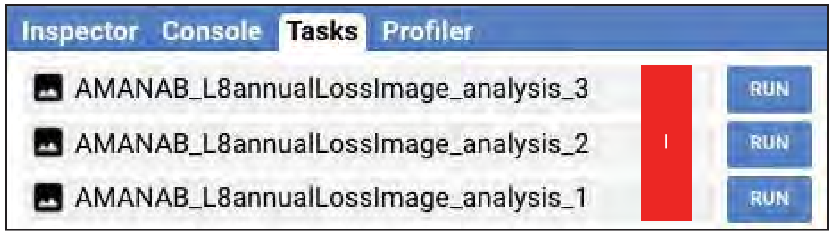


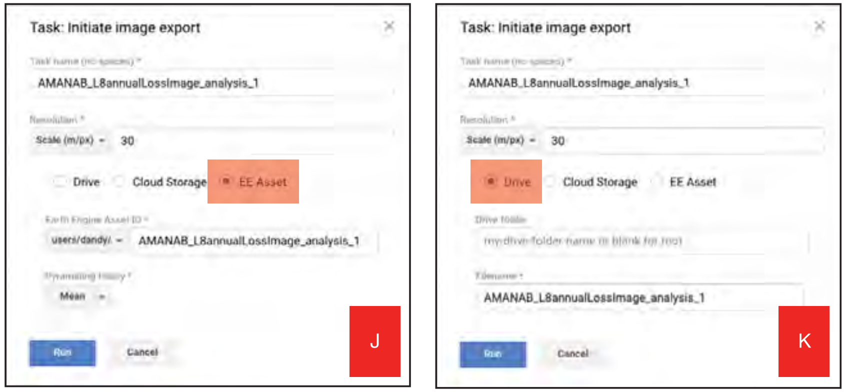
For Sentinel-2 Annual Forest Loss Detection (v2018.12.11)

For both scripts, the E section is the layer of the boundary of the selected area of interest (AOI_name Boundary). Afterward, the F section is the cloud-free image collection for the FIRST REFERENCE IMAGE and each TARGET IMAGE; please check the box to display a cloud-free image to the GEE Map (R: SWIR1; G: NIR; B: RED). Moreover, the G section is associated with the loss-image collection for each forest loss analysis; please check the box to display a loss-image to the GEE Map. On a loss-image, the detected forest loss areas are shown in red color. Lastly, the H section is related to the tree-cover loss accumulation image collection for all years in the investigation period (including the year of the FIRST REFERENCE IMAGE). On a tree-cover loss accumulation image, the detected tree-cover loss accumulation areas are shown in red color.

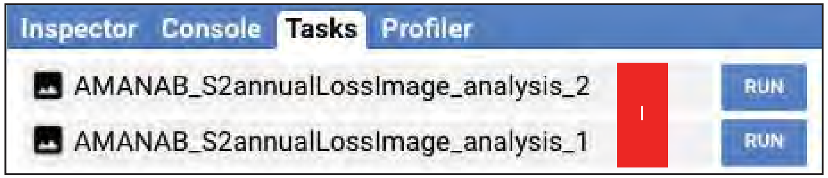
3. Finally, to proceed the export options to user's Assets in GEE and or to user's Google Drive account, please navigate to the GEE 'Tasks' tab for validating export as shown below:

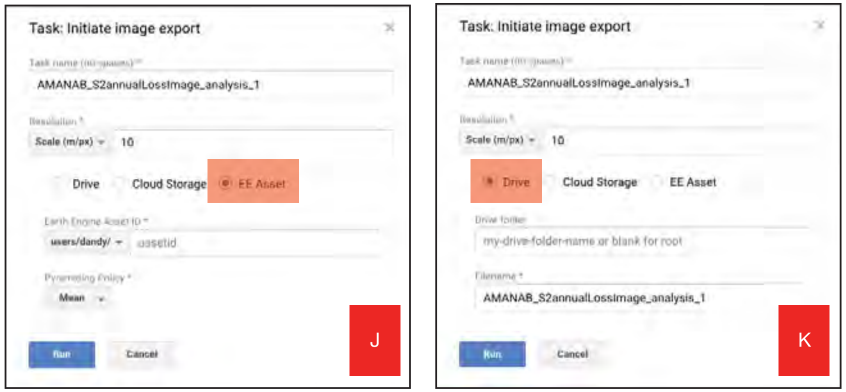
For Landsat-8 Annual Forest Loss Detection (v2018.12.11)





For Sentinel-2 Annual Forest Loss Detection (v2018.12.11)





For both scripts, the I section is the list of the loss-image collection waited to be exported to either user's Assets in GEE or user's Google Drive account; the users are kindly requested to click the 'Run' button to proceed the export. By clicking the 'Run' button, the J section would appear for exporting to user's Assets in GEE option, while the K section would appear for exporting to user's Google Drive account option. Please kindly check and confirm the details and click the 'Run' button on the pop-up window to start the export.

3. Conclusion and remarks

The Landsat-8 Annual Forest Loss Detection (v2018.12.11) and the Sentinel-2 Annual Forest Loss Detection (v2018.12.11) scripts are developed to monitor the annual logging activities inside of logging concessions in Papua New Guinea. These scripts are supported the annual forest loss detection for two AOIs, which are the Amanab Consolidated Concession and the Rottock Bay Consolidated Concession. On each script, two forest loss detection methods are available to be selected, i.e., the combination of NDVI, NDWI, and NBR method and the integration of SMA and NDFI method.

The outputs of these scripts are: (a) The annual forest loss areas calculated in square kilometers unit for each analysis, (b) The forest loss image for each analysis in TIFF format that could be displayed in the GEE Map and or exported to the user's Assets in GEE or Google Drive account, (c) The additional tree-cover loss accumulation areas calculated in square kilometers unit for each year in the investigation period, and (d) The additional tree-cover loss accumulation image for each year in the investigation period that could be displayed in the GEE Map. Furthermore, the main advantage of using these scripts is the potential to generate the annual forest lost areas by utilizing either Landsat-8 or Sentinel-2 images. This information could be used to monitor the annual logging activities inside of logging concessions in Papua New Guinea during a given investigation period. Moreover, the dynamic trend of the logging activities in both AOIs could be understood so that might help stakeholders to advance the decision-making actions, especially from the viewpoint of geospatial analysis.

On both scripts, the users are able to select the preferred methods for cloud/haze elimination (For the Landsat-8 based script: The QA band method and the CFMASK-derived QA band method; For the Sentinel-2 based script: The QA band method and the FMASK-algorithm method) and forest loss detection (The combination of NDVI, NDWI, and NBR method and the integration of SMA and NDFI method), as well as to define the preferred threshold value for defining a unit of forest loss in the analysis (the tIndex). Therefore, the result of the forest loss detection highly depends on the selected methods and threshold values. For the user's convenience, the recommended methods and threshold values are listed for both scripts. Moreover, the performance of these recommendations has been analyzed and validated with the Hansen Forest Change v1.5 data (http://earthenginepartners.appspot.com/science-2013-global-forest).

Finally, as quick-start guidance for using these scripts, the users are kindly requested to follow the default settings for filling the input commands on each script as listed below:

For Landsat-8 Annual Forest Loss Detection (v2018.12.11)

Table 3.1 Landsat-8 Annual Forest loss Detection

Input Commands			
Command	**Variable**	**Value**	**Remark**
COMMAND-1	firstRefStart_YEAR	2014	
	firstRefStart_MONTH	1	
	firstRefStart_DATE	1	
COMMAND-2	firstRefEnd_YEAR	2014	
	firstRefEnd_MONTH	12	
	firstRefEnd_DATE	31	
COMMAND-3	firstTargetStart_YEAR	2015	
	firstTargetStart_MONTH	1	
	firstTargetStart_DATE	1	
COMMAND-4	firstTargetEnd_YEAR	2015	
	firstTargetEnd_MONTH	12	
	firstTargetEnd_DATE	31	
COMMAND-5	totalTarget	3	The TARGET IMAGES are 2015, 2016, and 2017.
COMMAND-6	aoi_select	'AMANAB'	For forest loss detection in Amanab Consolidated Concession
	aoi_select	'ROTTOCK'	For forest loss detection in Rottock Bay Consolidated Concession
COMMAND-7	getImageFunction	'CFMASK'	
COMMAND-8	showCloudFree	'YES'	
COMMAND-9	methodOfAnalysis	'NDVI_NDWI_NBR'	Using the combination of NDVI. NDWI, and NBR method.
	methodOfAnalysis	'SMA_NDFI'	Using the integration of SMA and NDFI method.
COMMAND-10	tIndex	0.215	For COMMAND-6 = 'AMANAB' and COMMAND-7 = 'NDVI_NDWI_NBR'
	tIndex	1.925	For COMMAND-6 = 'AMANAB' and COMMAND-7 = 'SMA_NDFI'
	tIndex	0.180	For COMMAND-6 = 'ROTTOCK' and COMMAND-7 = 'NDVI_NDWI_NBR'
	tIndex	1.900	For COMMAND-6 = 'ROTTOCK' and COMMAND-7 = 'SMA_NDFI'
COMMAND-11	showLossImages	'YES'	
COMMAND-12	calLossArea	'YES'	
COMMAND-13	exportLossToAsset	'YES'	Exporting all loss images to user's Assets in GEE.
COMMAND-14	exportLossToDrive	'YES'	Exporting all loss images to user's Google Drive account.
COMMAND-15	showTreecoverAccum	'YES'	
	tTreecover	0.845	For COMMAND-6 = 'AMANAB' and showTreecoverAccum = 'YES'
	tTreecover	0.585	For COMMAND-6 = 'ROTTOCK' and showTreecoverAccum = 'YES'

Results for Amanab Consolidated Concession			
Forest Loss Detection			
Image ID	**Analysis**	**Annual Forest Loss (sq. Km) for NDVI, NDWI, and NBR Method**	**Annual Forest Loss (sq. Km) for SMA and NDFI Method**
AMANAB_L8annualLossImage_analysis_1	Forest Loss in 2015 (Forest Area 2014 - Forest Area 2015)	3.904	7.437
AMANAB_L8annualLossImage_analysis_2	Forest Loss in 2016 (Forest Area 2015- Forest Area 2016)	7.249	14.622
AMANAB_L8annualLossImage_analysis_3	Forest Loss in 2017 (Forest Area 2016- Forest Area 2017)	30.796	31.540
Tree-cover Loss Accumulation			
Year		**Tree-cover Loss Accumulation (sq. Km)**	
AMANAB Tree-cover Loss Accumulation in 2014		4.461	

AMANAB Tree-cover Loss Accumulation in 2015		0.124	
AMANAB Tree-cover Loss Accumulation in 2016		0.744	
AMANAB Tree-cover Loss Accumulation in 2017		28.999	
Results for Rottock Bay Consolidated Concession			
Forest Loss Detection			
Image ID	**Analysis**	**Annual Forest Loss (sq. Km) for NDVI, NDWI, and NBR Method**	**Annual Forest Loss (sq. Km) for SMA and NDFI Method**
ROTTOCK_L8annualLossImage_analysis_1	Forest Loss in 2015 (Forest Area 2014 - Forest Area 2015)	32.133	34.727
ROTTOCK_L8annualLossImage_analysis_2	Forest Loss in 2016 (Forest Area 2015- Forest Area 2016)	1.050	2.100
ROTTOCK_L8annualLossImage_analysis_3	Forest Loss in 2017 (Forest Area 2016- Forest Area 2017)	5.252	3.213
Tree-cover Loss Accumulation			
Year		**Tree-cover Loss Accumulation (sq. Km)**	
ROTTOCK Tree-cover Loss Accumulation in 2014		2.346	
ROTTOCK Tree-cover Loss Accumulation in 2015		28.415	
ROTTOCK Tree-cover Loss Accumulation in 2016		15.071	
ROTTOCK Tree-cover Loss Accumulation in 2017		20.568	

For Sentinel-2 Annual Forest Loss Detection (v2018.12.11)

Table 3.2 Sentinel-2 Annual Forest loss Detection			
Input Commands			
Command	**Variable**	**Value**	**Remark**
COMMAND-1	firstRefStart_YEAR	2015	
	firstRefStart_MONTH	1	
	firstRefStart_DATE	1	
COMMAND-2	firstRefEnd_YEAR	2015	
	firstRefEnd_MONTH	12	
	firstRefEnd_DATE	31	
COMMAND-3	firstTargetStart_YEAR	2016	
	firstTargetStart_MONTH	1	
	firstTargetStart_DATE	1	
COMMAND-4	firstTargetEnd_YEAR	2016	
	firstTargetEnd_MONTH	12	
	firstTargetEnd_DATE	31	
COMMAND-5	totalTarget	2	The TARGET IMAGES are 2016, and 2017.
COMMAND-6	aoi_select	'AMANAB'	For forest loss detection in Amanab Consolidated Concession
	aoi_select	'ROTTOCK'	For forest loss detection in Rottock Bay Consolidated Concession
COMMAND-7	getImageFunction	'FMASK'	

COMMAND-8	showCloudFree	'YES'	
COMMAND-9	methodOfAnalysis	'NDVI_NDWI_NBR'	Using the combination of NDVI. NDWI, and NBR method.
	methodOfAnalysis	'SMA_NDFI'	Using the integration of SMA and NDFI method.
COMMAND-10	tIndex	0.190	For COMMAND-6 = 'AMANAB' and COMMAND-7 = 'NDVI_NDWI_NBR'
	tIndex	1.955	For COMMAND-6 = 'AMANAB' and COMMAND-7 = 'SMA_NDFI'
	tIndex	0.140	For COMMAND-6 = 'ROTTOCK' and COMMAND-7 = 'NDVI_NDWI_NBR'
	tIndex	1.905	For COMMAND-6 = 'ROTTOCK' and COMMAND-7 = 'SMA_NDFI'
COMMAND-11	showLossImages	'YES'	
COMMAND-12	calLossArea	'YES'	
COMMAND-13	exportLossToAsset	'YES'	Exporting all loss images to user's Assets in GEE.
COMMAND-14	exportLossToDrive	'YES'	Exporting all loss images to user's Google Drive account.
COMMAND-15	showTreecoverAccum	'YES'	
	tTreecover	0.740	For COMMAND-6 = 'AMANAB' and showTreecoverAccum = 'YES'
	tTreecover	0.715	For COMMAND-6 = 'ROTTOCK' and showTreecoverAccum = 'YES'
Results for Amanab Consolidated Concession			
Forest Loss Detection			
Image ID	**Analysis**	**Annual Forest Loss (sq. Km) for NDVI, NDWI, and NBR Method**	**Annual Forest Loss (sq. Km) for SMA and NDFI Method**
AMANAB_S2annualLossImage_analysis_1	Forest Loss in 2016 (Forest Area 2015- Forest Area 2016)	5.886	5.081
AMANAB_S2annualLossImage_analysis_2	Forest Loss in 2017 (Forest Area 2016- Forest Area 2017)	29.098	28.230
Tree-cover Loss Accumulation			
Year		**Tree-cover Loss Accumulation (sq. Km)**	
AMANAB Tree-cover Loss Accumulation in 2016		8.900	
AMANAB Tree-cover Loss Accumulation in 2017		29.389	
Results for Rottock Bay Consolidated Concession			
Forest Loss Detection			
Image ID	**Analysis**	**Annual Forest Loss (sq. Km) for NDVI, NDWI, and NBR Method**	**Annual Forest Loss (sq. Km) for SMA and NDFI Method**
ROTTOCK_S2annualLossImage_analysis_1	Forest Loss in 2016 (Forest Area 2015- Forest Area 2016)	3.521	2.841
ROTTOCK_S2annualLossImage_analysis_1	Forest Loss in 2017 (Forest Area 2016- Forest Area 2017)	7.228	7.289
Tree-cover Loss Accumulation			
Year		**Tree-cover Loss Accumulation (sq. Km)**	
ROTTOCK Tree-cover Loss Accumulation in 2016		6.364	
ROTTOCK Tree-cover Loss Accumulation in 2017		6.487	

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User Manual:
Sentinel-2 Weekly Forest Loss Detection (v2018.12.11)

1. Introduction

The Sentinel-2 Weekly Forest Loss Detection (v2018.12.11) is a script intended to monitor the weekly logging activities inside of logging concessions in Papua New Guinea. Two forest loss detection methods are available to be selected, i.e., the combination of Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), and Normalized Burn Ratio (NBR) method and the integration of Spectral Mixture Analysis (SMA) and Normalized Difference Fraction Index (NDFI) method. This script is divided into nine parts, which are: (1) Input Commands, (2) Parameters Collections, (3) Cloud/Haze Elimination Functions, (4) Parameters for First Reference Image, (5) Parameters for Target Image Collections, (6) Parameters for Continuous Reference Image Collections, (7) Forest Loss Analysis, (8) Loss Area Calculation, and (9) Parameters for Export Images.

a. <u>Part 1: Input Commands</u>

In this part, all input commands (14 in total) should be defined by the user prior to run the script. The first command (COMMAND-1) is to assign the START DATE of the FIRST REFERENCE IMAGE that includes three variables, i.e., firstRefStart_YEAR to define the year, firstRefStart_MONTH to define the month, and firstRefStart_DATE to define the date. In this script, the START DATE of the FIRST REFERENCE IMAGE is the date of the LAST SUNDAY of a given MONTH. The second command (COMMAND-2) is to assign the END DATE of the FIRST REFERENCE IMAGE that includes three variables, i.e., firstRefEnd_YEAR to define the year, firstRefEnd_MONTH to define the month, and firstRefEnd_DATE to define the date. In this script, the END DATE of the FIRST REFERENCE IMAGE is the date of the following SUNDAY counted from the START DATE of the FIRST REFERENCE IMAGE. Therefore, the duration from the START DATE to the END DATE of the FIRST REFERENCE IMAGE is an ONE-WEEK duration counted from the LAST SUNDAY of a given MONTH to the following SUNDAY of the following MONTH. The third command (COMMAND-3) is to assign the START DATE of the TARGET IMAGES DURATION that includes three variables, i.e., targetStart_YEAR to define the year, targetStart_MONTH to define the month, and targetStart_DATE to define the date. In this script, the START DATE of the TARGET IMAGES DURATION is the date of the FIRST SUNDAY of a MONTH. The users are recommended to assign the same date for the START DATE of the TARGET IMAGES DURATION (COMMAND-3) and the END DATE of the FIRST REFERENCE IMAGE (COMMAND-2). The fourth command (COMMAND-4) is to assign the END DATE of the TARGET IMAGES DURATION that includes three variables, i.e., targetEnd_YEAR to define the year, targetEnd_MONTH to define the month, and targetEnd_DATE to define the date. In this script, the END DATE of the TARGET IMAGES DURATION is the date of the FIRST SUNDAY of the following MONTH counted from the START DATE of the TARGET IMAGES DURATION. Therefore, the duration from the START DATE to the END DATE of the TARGET IMAGES DURATION is an ONE-MONTH duration counted from the date of the FIRST SUNDAY of a MONTH to the FIRST SUNDAY of the following MONTH. The fifth command (COMMAND-5) is to define the TOTAL WEEKS of the TARGET IMAGES DURATION to be used for analysis. An ONE-WEEK is counted from a given SUNDAY to the following SUNDAY. The sixth command (COMMAND-6) is to select the area of interest (AOI) to be used for forest loss detection. This script is supported the weekly forest loss detection for two AOIs in Papua New Guinea that is the Amanab Consolidated Concession and the Rottock Bay Consolidated Concession. The seventh command (COMMAND-7) is to select the method to be used for cloud/haze elimination purposes. On this script, two cloud/haze elimination methods are available to be used, i.e., the QA band method and the FMASK-algorithm method. The recommended method to be used for cloud/haze elimination is listed for the user's convenience. The eighth command (COMMAND-8) is an option whether to display the cloud-free images to the Google Earth Engine (GEE) Map or not. The ninth command (COMMAND-9) is to select the method to be used for forest loss detection purposes. On this script, two forest loss detection methods are available to be selected, i.e., the combination of NDVI, NDWI, and NBR method and the integration of SMA and NDFI method. The tenth command (COMMAND-10) is to assign the threshold value to define a unit of forest loss in the analysis (so-called the tIndex). On this script, the recommended tIndex to be applied to each AOI and on each forest loss detection method is listed for the user's convenience. The eleventh command (COMMAND-11) is an option whether to display the loss images to the GEE Map or not. The twelfth command (COMMAND-12) is an option whether to calculate the loss areas in square kilometers and print it to the GEE Console or not. The thirteenth command (COMMAND-13) is an option whether to export the loss images to user's Assets in GEE or not. The fourteenth command (COMMAND-14) is an option whether to export the loss images to user's Google Drive account or not.

b. Part 2: Parameters Collections

This part comprises the collection of general parameters that are used on the script. These parameters include: (a) The definition of image collections, (b) The date formatting for the investigation period, (c) The conditional functions for the selected AOI, (d) The conditional functions for the selected method for forest loss detection, (e) A command to print the script's title to the GEE Console, (f) A command for masking the tree-cover in the selected AOI that is derived from the Hansen Global Forest Change v1.5 data, (g) A collection of visual parameters, and (h) A command to display the boundary of the selected AOI to the GEE Map.

c. Part 3: Cloud/Haze Elimination Functions

This part collects functions to generate cloud-free images by using the cloud/haze elimination methods. On this script, two functions of cloud/haze elimination methods are defined, i.e., the QA band method and the FMASK-algorithm method. Basically, each cloud/haze elimination method follows the following workflow: (a) Define the local parameters to be used on the function, (b) Obtain the image collection from the image archive, (c) Apply the topographic correction function that is based on Teillet, P.M., et al. (1982), (d) Apply the cloud/haze elimination function for each image in the image collection, (e) Apply the Dark Object Subtraction (DOS) radiometric correction function that is based on Chavez (1988), (f) Generate the mosaic image of the weekly cloud-free image by taking the median value of the image collection and clip it

with the boundary of the selected AOI, (g) Generate the vegetation index images to be used for further image processing.

d. Part 4: Parameters for First Reference Image

In this part, the commands to display the duration of the FIRST REFERENCE IMAGE, to generate the cloud-free image collection for the FIRST REFERENCE IMAGE, and to display the cloud-free FIRST REFERENCE IMAGE to the GEE Map are listed.

e. Part 5: Parameters for Target Image Collections

In this part, the commands to display the duration of the TARGET IMAGES, to generate the cloud-free image collections for the TARGET IMAGES, and to display the cloud-free TARGET IMAGES to the GEE Map are listed.

f. Part 6: Parameters for Continuous Reference Image Collections

This part comprises the commands to generate the list of cloud-free image pairs in the investigation period (i.e., the pair of REFERENCE IMAGE and TARGET IMAGE) for each weekly forest loss analysis.

g. Part 7: Forest Loss Analysis

This part comprises functions to analyze forest loss by utilizing the forest loss detection methods. On this script, two forest loss detection methods are defined, i.e., the combination of NDVI, NDWI, and NBR method and the integration of SMA and NDFI method. The earlier-mentioned method analyzes the difference between NDVI, NDWI, and NBR images for a given reference and target images so that a decreasing value of those three indices at a given area or pixel that is greater than the given threshold value (tIndex) would be considered as forest loss. This method is adapted from the forest loss detection method derived by Hansen et al. (2016). Meanwhile, the later-mentioned method utilizes SMA-derived fraction images for generating NDFI image for a given reference and target image so that a decreasing value of NDFI at a given area or pixel that is greater than the given threshold value (tIndex) would be considered as forest loss. This method is initially proposed by Souza et al. (2003), Souza et al. (2005), and Souza et al. (2013). Lastly, the command to display the loss-image collection for each analysis to the GEE Map is listed.

h. Part 8: Loss Area Calculation

In this part, the function to calculate the loss areas is listed. On this script, the loss areas are calculated per 250 meters grid to accommodate a speedy computation. Furthermore, the unit of the loss areas is converted to square kilometers. At the end of this part, the command to print the loss-area for each analysis to the GEE Console is provided.

i. Part 9: Parameters for Export Images.

This part collects conditional functions for exporting the loss-image collection to user's Assets in GEE and user's Google Drive account. Each exported loss-image would have a pixel size of 10 meters and a UTM WGS84 projection. The naming structure of each lost-image is described as follows:

(AOI**)**_S2weeklyLossImage_(targetStart)_week_**(n)**

The (AOI) defines as the name of the area of interest of the image; 'AMANAB' for Amanab Consolidated Concession and 'ROTTOCK' for Rottock Bay Consolidated Concession. Meanwhile, the (targetStart) is the START DATE of the TARGET IMAGES DURATION with a 'YEAR-MONTH-DATE' format. Lastly, the (n) is the sequence of the week that is being analyzed, e.g., the first sequence (n = 1) defined as the loss-image for the first week counted from the START DATE of the TARGET IMAGES DURATION; the second sequence (n = 2) defined as the loss-image for the second week counted from the START DATE of the TARGET IMAGES DURATION; and so on until the sequence ends. To better understand the naming structure, please kindly have a look at these examples:

1. AMANAB_S2weeklyLossImage_2018-6-3_week_1
   The AOI of this weekly lost-image is the Amanab Consolidated Concession for the first week counted from '2018-6-3,' or from the '2018-6-3' to '2018-6-10.'
2. AMANAB_S2weeklyLossImage_2018-6-3_week_2
   The AOI of this weekly lost-image is the Amanab Consolidated Concession for the second week counted from '2018-6-3,' or from the '2018-6-10' to '2018-6-17.'
3. AMANAB_S2weeklyLossImage_2018-6-3_week_3
   The AOI of this weekly lost-image is the Amanab Consolidated Concession for the third week counted from '2018-6-3,' or from the '2018-6-17' to '2018-6-24.'
4. AMANAB_S2weeklyLossImage_2018-6-3_week_4
   The AOI of this weekly lost-image is the Amanab Consolidated Concession for the fourth week counted from '2018-6-3,' or from the '2018-6-24' to '2018-7-1.'
5. ROTTOCK_S2weeklyLossImage_2018-8-5_week_1
   The AOI of this weekly lost-image is the Rottock Bay Consolidated Concession for the first week counted from '2018-8-5,' or from the '2018-8-5' to '2018-8-12.'
6. ROTTOCK_S2weeklyLossImage_2018-8-5_week_2
   The AOI of this weekly lost-image is the Rottock Bay Consolidated Concession for the second week counted from '2018-8-5,' or from the '2018-8-12' to '2018-8-19.'
7. ROTTOCK_S2weeklyLossImage_2018-8-5_week_3
   The AOI of this weekly lost-image is the Rottock Bay Consolidated Concession for the third week counted from '2018-8-5,' or from the '2018-8-19' to '2018-8-26.'
8. ROTTOCK_S2weeklyLossImage_2018-8-5_week_4
   The AOI of this weekly lost-image is the Rottock Bay Consolidated Concession for the fourth week counted from '2018-8-5,' or from the '2018-8-26' to '2018-9-2.'

2. Script Guidelines

The primary objective of this script is to monitor the weekly logging activities inside boundaries of logging concessions in Papua New Guinea. Therefore, the following script guidelines are intended to instruct the users for utilizing the Sentinel-2 Weekly Forest Loss Detection (v2018.12.11).

a. <u>Step-by-step instructions</u>

To obtain the best advantage of the script, the users are kindly requested to follow the step-by-step instructions on how to use this script that are described as follows:

1. Navigate to the Google Earth Engine (GEE) Code Editor in Google Chrome, log in with a GEE-registered Google account, and open a forest loss detection script.
2. Prior to run the script, users are requested to read the input command's instructions and fill out the input commands (14 in total) that are available in the "Part 1:Input Commands."
3. Proceed with the COMMAND-1 and COMMAND-2 to define the period (i.e., the start date and the end date) of the FIRST REFERENCE IMAGE for the analysis. Each command includes three variables to assign the year, the month, and the date separately. Please kindly consider that the duration from the START DATE to the END DATE of the FIRST REFERENCE IMAGE is an ONE-WEEK duration counted from the LAST SUNDAY of a given MONTH to the following SUNDAY of the following MONTH. Please type the preferred period as shown below:

```
// [COMMAND-1] FIRST REFERENCE IMAGE - Start Date
/*  Instruction:
(a) Define the Start Date of the FIRST REFERENCE IMAGE.
(b) The Start Date of the FIRST REFERENCE IMAGE is the date of
    the LAST SUNDAY of a MONTH.
(c) Insert the YEAR, MONTH, and DATE on separate variables.
*/
var firstRefStart_YEAR = 2018;
var firstRefStart_MONTH = 5;
var firstRefStart_DATE = 27;


// [COMMAND-2] FIRST REFERENCE IMAGE - End Date
/*  Instruction:
(a) Define the End Date of the FIRST REFERENCE IMAGE.
(b) The End Date of the FIRST REFERENCE IMAGE is the date of the following SUNDAY from
    the Start Date of the FIRST REFERENCE IMAGE.
(c) For FIRST REFERENCE IMAGE, from Start Date to End Date is a ONE-WEEK duration from
    the LAST SUNDAY of a MONTH to the following SUNDAY of the following MONTH.
(d) The End Date of the FIRST REFERENCE IMAGE should be the same date as the
    Start Date of the TARGET IMAGES DURATION.
(e) Insert the YEAR, MONTH, and DATE on separate variables.
*/
var firstRefEnd_YEAR = 2018;
var firstRefEnd_MONTH = 6;
var firstRefEnd_DATE = 3;
```

4. Proceed with the COMMAND-3 and COMMAND-4 to define the period (i.e., the start date and the end date) of the TARGET IMAGES DURATION for the analysis. Each command includes three variables to assign the year, the month, and the date separately. The users are recommended to assign the same date for the START DATE of the TARGET IMAGES DURATION (COMMAND-3) and the END DATE of the FIRST REFERENCE IMAGE (COMMAND-2). Please kindly consider that the duration from the START DATE to the END DATE of the TARGET IMAGES DURATION is an ONE-MONTH duration counted from the date of the FIRST SUNDAY of a MONTH to the FIRST SUNDAY of the following

MONTH. Please type the preferred period as shown below:

```
// [COMMAND-3] TARGET IMAGES DURATION - Start Date
/*  Instruction:
(a) Define the Start Date of the TARGET IMAGES DURATION.
(b) The Start Date of the TARGET IMAGES DURATION is the FIRST SUNDAY of a MONTH.
(c) The Start Date of the TARGET IMAGES DURATION should be the same date as the
    End Date of the FIRST REFERENCE IMAGE.
(d) Insert the YEAR, MONTH, and DATE on separate variables.
*/
var targetStart_YEAR = 2018;
var targetStart_MONTH = 6;
var targetStart_DATE = 3;


// [COMMAND-4] TARGET IMAGES DURATION - End Date
/*  Instruction:
(a) Define the End Date of the TARGET IMAGES DURATION.
(b) The End Date of the TARGET IMAGES DURATION is the FIRST SUNDAY of the following MONTH from
    the Start Date of the TARGET IMAGES DURATION.
(c) For TARGET IMAGES DURATION, from Start Date to End Date is a ONE-MONTH duration from
    a FIRST SUNDAY of a month to the FIRST SUNDAY of the following month.
(d) Insert the YEAR, MONTH, and DATE on separate variables.
*/
var targetEnd_YEAR = 2018;
var targetEnd_MONTH = 7;
var targetEnd_DATE = 1;
```

5. Proceed with the COMMAND-5 to define the TOTAL WEEKS of the TARGET IMAGES DURATION to be used for analysis. An ONE-WEEK is counted from a given SUNDAY to the following SUNDAY. Please type the amount as shown below:

```
// [COMMAND-5] TOTAL WEEKS
/*  Instruction:
Define the TOTAL WEEKS of the TARGET IMAGES DURATION.
*/
var totalWeeks = 4;
```

6. Proceed with the COMMAND-6 to select the area of interest (AOI) to be used for forest loss detection. This script is supported weekly forest loss detection for two AOIs that are the Amanab Consolidated Concession ('AMANAB') and the Rottock Bay Consolidated Concession ('ROTTOCK'). Please type the preferred AOI as shown below:

```
// [COMMAND-6] AREA OF INTEREST
/*  Instruction:
Select the Area of interest (AOI) to be calculated:
(a) Type 'AMANAB' for Amanab Consolidated Concession.
(b) Type 'ROTTOCK' for Rottock Bay Consolidated Concession.
*/
var aoi_select = 'AMANAB';
```

7. Proceed with the COMMAND-7 to select the method to be used for cloud/haze elimination purposes. On this script, two cloud/haze elimination methods are available to be used, i.e., the QA band method and the FMASK-algorithm method. The recommended method to be used for cloud/haze elimination is listed for the user's convenience. Please type the preferred cloud/haze elimination method as shown below:

```
// [COMMAND-7] CLOUD/HAZE ELIMINATION METHOD
/*  Instruction:
Select the method to be used for cloud/haze elimination.
(a) Type 'QA_BAND' for using the QAband method.
(b) Type 'FMASK' for using the FMASK-algorithm method.
-----------------------------
RECOMMENDED METHOD: 'FMASK'
-----------------------------
*/
var getImageFunction = 'FMASK';
```


8. Proceed with the COMMAND-8 to select whether to display the cloud-free images to the GEE Map or not. Please type the preferred option as shown below:

```
// [COMMAND-8] CLOUD-FREE IMAGES
/*  Instruction:
Do you want to display cloud-free images to the GEE Map?
(a) Type 'YES' to display.
(b) Type 'NO' to not display.
*/
var showCloudFree = 'YES';
```

9. Proceed with the COMMAND-9 to select the method to be used for forest loss detection purposes. On this script, two forest loss detection methods are available to be selected, i.e., the combination of NDVI, NDWI, and NBR method and the integration of SMA and NDFI method. Please type the forest loss detection method as shown below:

```
// [COMMAND-9] FOREST LOSS DETECTION METHOD
/*  Instruction:
Select the method to be used for forest loss detection.
(a) Type 'NDVI_NDWI_NBR' for using the combination of NDVI, NDWI, and NBR.
(b) Type 'SMA_NDFI' for using the integration of SMA and NDFI.
*/
var methodOfAnalysis = 'NDVI_NDWI_NBR';
```

10. Proceed with the COMMAND-10 to assign the threshold value to define a unit of forest loss in the analysis (so-called the tIndex). The recommended tIndex to be applied to each AOI and on each forest loss detection method is listed for the user's convenience. Please type the preferred tIndex as shown below:

```
// [COMMAND-10] THRESHOLD VALUE
/*  Instruction:
Set a threshold value to define a unit of forest loss in the analysis.
------------------------------------------------
RECOMMENDED THRESHOLD VALUE:
(1) 'AMANAB'
    (a) For 'NDVI_NDWI_NBR' set tIndex to 0.190
    (b) For 'SMA_NDFI' set tIndex to 1.945
(2) 'ROTTOCK'
    (a) For 'NDVI_NDWI_NBR' set tIndex to 0.275
    (b) For 'SMA_NDFI' set tIndex to 1.975
------------------------------------------------
*/
var tIndex = 0.190;
```

11. Proceed with the COMMAND-11 to select whether to display the loss images to the GEE Map or not. Please type the preferred option as shown below:

```
// [COMMAND-11] LOSS IMAGES
/*  Instruction:
Do you want to display loss-images to the GEE Map?
(a) Type 'YES' to display.
(b) Type 'NO' to not display.
*/
var showLossImages = 'YES';
```

12. Proceed with the COMMAND-12 to select whether to calculate the loss areas in square kilometers and print it to the GEE Console or not. Please type the preferred option as shown below:

```
// [COMMAND-12] LOSS AREA CALCULATION
/*  Instruction:
Do you want to calculate loss area and print it to the GEE Console?
(a) Type 'YES' to proceed.
(b) Type 'NO' to not proceed.
*/
var calLossArea = 'YES';
```

13. Proceed with the COMMAND-13 and COMMAND-14 to select whether to export the loss images to user's Assets in GEE or not and to export the loss images to user's Google Drive account or not, respectively. Please type the preferred option as shown below:

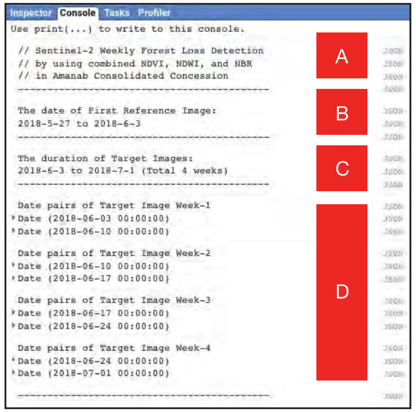
```
// [COMMAND-13] EXPORT LOSS IMAGES TO ASSET
/* Instruction:
Do you want to export loss-images to user's Asset?
(a) Type 'YES' to export.
(b) Type 'NO' to not export.
*/
var exportLossToAsset = 'YES';


// [COMMAND-14] EXPORT LOSS IMAGES TO GOOGLE DRIVE
/* Instruction:
Do you want to export loss-images to user's Google Drive?
(a) Type 'YES' to export.
(b) Type 'NO' to not export.
*/
var exportLossToDrive = 'YES';
```

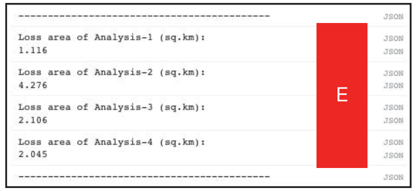
14. Finally, please kindly check that all input commands have been filled correctly by following each instruction and click 'Run' button on the top-side of the GEE Code Editor to start the forest loss analysis.

b. Description of the printed results and displayed outputs.

To understand the printed results in the GEE Console and the displayed outputs in the GEE Map, the users are kindly recommended to have a look at the following descriptions:

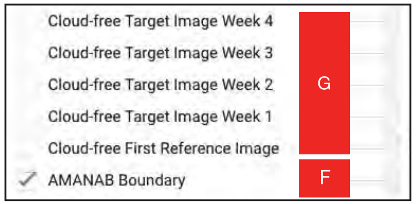
1. The printed results in the GEE Console are shown as follows:

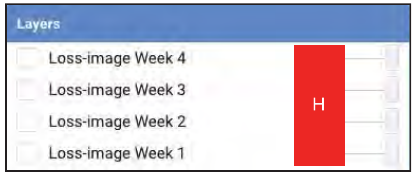




The A section displays the title of the script that includes the name of the sensor being used, the information about the selected forest loss detection method, and the name of the AOI being analyzed. Afterward, the B section shows the duration of the FIRST REFERENCE IMAGE for the analysis. Meanwhile, the C section is the duration of TARGET IMAGES for the analysis including the information of the TOTAL WEEKS. Next, the D section displays the weekly date pair within the TARGET IMAGES duration. On each weekly date pair, the upper date is the start date of a weekly TARGET IMAGE (on a given SUNDAY), and the lower date is its end date (the following SUNDAY). The number of the weekly date pair depends on the number of TOTAL WEEKS. Finally, the E section shows the calculated loss areas for all analysis in square kilometers (sq. km).

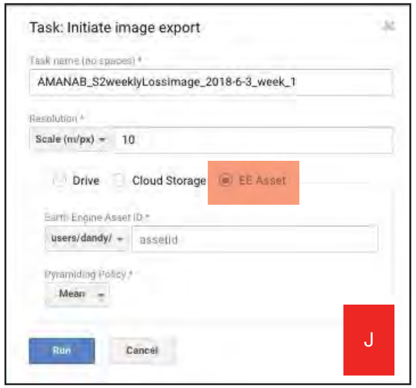
2. The displayed outputs in the GEE Map that are listed in the 'Layers' tab are shown as follows:

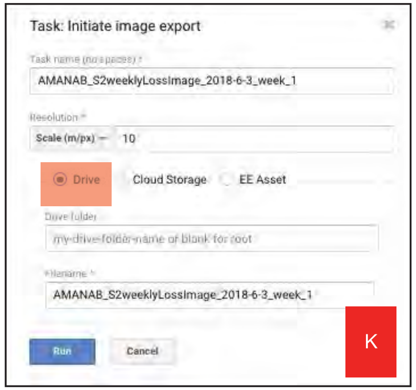




The F section is the layer of the boundary of the selected area of interest (AOI_name Boundary). Afterward, the G section is the cloud-free image collection for the FIRST REFERENCE IMAGE and each TARGET IMAGE; please check the box to display a cloud-free image to the GEE Map (R: SWIR1; G: NIR; B: RED). Lastly, the H section is associated with the loss-image collection for each forest loss analysis; please check the box to display a loss-image to the GEE Map. On a loss-image, the detected forest loss areas are shown in red color.

3. Finally, to proceed the export options to user's Assets in GEE and or to user's Google Drive account, please navigate to the GEE 'Tasks' tab for validating export as shown below:





The I section is the list of the loss-image collection waited to be exported to either user's Assets in GEE or user's Google Drive account; the users are kindly requested to click the 'Run' button to proceed the export. By clicking the 'Run' button, the J section would appear for exporting to user's Assets in GEE option, while the K section would appear for exporting to user's Google Drive account option. Please kindly check and confirm the details and click the 'Run' button on the pop-up window to start the export.

3. Conclusion and remarks

The Sentinel-2 Weekly Forest Loss Detection (v2018.12.11) script is developed to monitor the weekly logging activities inside of logging concessions in Papua New Guinea. This script is supported the weekly forest loss detection for two AOIs, which are the Amanab Consolidated Concession and the Rottock Bay Consolidated Concession. In this script, two forest loss detection methods are available to be selected, i.e., the combination of NDVI, NDWI, and NBR method and the integration of SMA and NDFI method.

The outputs of this script are: (a) The weekly forest loss areas calculated in square kilometers unit for each analysis and (b) The forest loss image for each analysis in TIFF format that could be displayed in the GEE Map and or exported to the user's Assets in GEE or Google Drive account. Furthermore, the primary advantage of using this script is the ability to obtain the weekly forest lost areas by using the Sentinel-2 images so that this script could provide a rapid and reliable forest monitoring technique, especially for monitoring the logging activities inside of logging concessions in Papua New Guinea. Moreover, the dynamic trend of the logging activities in both AOIs could be understood in greater detail (i.e., weekly) so that might help stakeholders to advance both the short-term and the long-term decision-making actions, especially from the viewpoint of geospatial analysis.

In this script, the users are allowed to select the preferred methods for cloud/haze elimination (The QA band method and the FMASK-algorithm method) and forest loss detection (The combination of NDVI, NDWI, and NBR method and the integration of SMA and NDFI method), as well as to define the preferred threshold value for describing a unit of forest loss in the analysis (the tIndex). Therefore, the result of the forest loss detection highly depends on the selected methods and threshold values. For the user's convenience, the recommended methods and threshold values are listed on the script. Moreover, the performance of these recommendations has been analyzed and validated with the Global Land Analysis & Discovery (GLAD) alerts data (https://www.globalforestwatch.org/map).

Finally, as quick-start guidance for using the script, the users are kindly requested to follow the default settings for filling the input commands as listed below:

Table 3.1 Sentinel-2 Weekly Forest loss Detection

Input Commands			
Command	Variable	Value	Remark
COMMAND-1	firstRefStart_YEAR firstRefStart_MONTH firstRefStart_DATE	Please refer to the Input Commands (COMMAND-1 to COMMAND-5) column of Weekly Analysis for each month.	Please define the year, month, and date separately as the following example: COMMAND-1 firstRefStart = yyyy-mm-*dd* firstRefStart_YEAR = yyyy firstRefStart_MONTH = mm firstRefStart_DATE = *dd*
COMMAND-2	firstRefEnd_YEAR firstRefEnd_MONTH firstRefEnd_DATE	Please refer to the Input Commands (COMMAND-1 to COMMAND-5) column of Weekly Analysis for each month.	Please define the year, month, and date separately as the following example: COMMAND-2 firstRefEnd = yyyy-mm-*dd* firstRefEnd_YEAR = yyyy firstRefEnd_MONTH = mm firstRefEnd_DATE = *dd*
COMMAND-3	targetStart_YEAR targetStart_MONTH targetStart_DATE	Please refer to the Input Commands (COMMAND-1 to COMMAND-5) column of Weekly Analysis for each month.	Please define the year, month, and date separately as the following example: COMMAND-3 targetStart = yyyy-mm-*dd* targetStart_YEAR = yyyy targetStart_MONTH = mm targetStart_DATE = *dd*
COMMAND-4	targetEnd_YEAR	Please refer to the Input Commands (COMMAND-1 to COMMAND-5)	Please define the year, month, and date separately as the following example:

	targetEnd_MONTH	column of Weekly Analysis for each month.	COMMAND-4 targetEnd = yyyy-**mm**-*dd* targetEnd_YEAR = yyyy targetEnd_MONTH = **mm** targetEnd_DATE = *dd*
	targetEnd_DATE		
COMMAND-5	totalWeeks	Please refer to the Input Commands (COMMAND-1 to COMMAND-5) column of Weekly Analysis for each month.	The TOTAL WEEKS is the number of week within the TARGET IMAGES DURATION to be used for analysis
COMMAND-6	aoi_select	'AMANAB'	For forest loss detection in Amanab Consolidated Concession
	aoi_select	'ROTTOCK'	For forest loss detection in Rottock Bay Consolidated Concession
COMMAND-7	getImageFunction	'FMASK'	
COMMAND-8	showCloudFree	'YES'	
COMMAND-9	methodOfAnalysis	'NDVI_NDWI_NBR'	Using the combination of NDVI. NDWI, and NBR method.
	methodOfAnalysis	'SMA_NDFI'	Using the integration of SMA and NDFI method.
COMMAND-10	tIndex	0.190	For COMMAND-6 = 'AMANAB' and COMMAND-7 = 'NDVI_NDWI_NBR'
	tIndex	1.945	For COMMAND-6 = 'AMANAB' and COMMAND-7 = 'SMA_NDFI'
	tIndex	0.275	For COMMAND-6 = 'ROTTOCK' and COMMAND-7 = 'NDVI_NDWI_NBR'
	tIndex	1.975	For COMMAND-6 = 'ROTTOCK' and COMMAND-7 = 'SMA_NDFI'
COMMAND-11	showLossImages	'YES'	
COMMAND-12	calLossArea	'YES'	
COMMAND-13	exportLossToAsset	'YES'	Exporting all loss images to user's Assets in GEE.
COMMAND-14	exportLossToDrive	'YES'	Exporting all loss images to user's Google Drive account.

Results for Amanab Consolidated Concession

Forest Loss Detection

Input Commands (COMMAND-1 to COMMAND-5)	Analysis	Weekly Forest Loss (sq. Km) for NDVI, NDWI, and NBR Method	Weekly Forest Loss (sq. Km) for SMA and NDFI Method
Weekly Analysis For January 2018 COMMAND-1 firstRefStart = 2017-12-31 COMMAND-2 firstRefEnd = 2018-1-7 COMMAND-3 targetStart = 2018-1-7 COMMAND-4 targetEnd = 2018-2-4 COMMAND-5 totalWeeks = 4	Forest Loss in Week-1	3.222	2.912
	Forest Loss in Week-2	0.620	0.558
	Forest Loss in Week-3	1.673	2.788
	Forest Loss in Week-4	0.124	0.000
Weekly Analysis For February 2018 COMMAND-1 firstRefStart = 2018-1-28 COMMAND-2 firstRefEnd = 2018-2-4 COMMAND-3 targetStart = 2018-2-4 COMMAND-4 targetEnd = 2018-3-4 COMMAND-5 totalWeeks = 4	Forest Loss in Week-1	5.142	12.763
	Forest Loss in Week-2	1.673	3.160
	Forest Loss in Week-3	0.744	1.115
	Forest Loss in Week-4	0.496	0.000
Weekly Analysis For March 2018 COMMAND-1 firstRefStart = 2018-2-25 COMMAND-2 firstRefEnd = 2018-3-4 COMMAND-3 targetStart = 2018-3-4 COMMAND-4 targetEnd = 2018-4-1 COMMAND-5 totalWeeks = 4	Forest Loss in Week-1	0.867	1.673
	Forest Loss in Week-2	1.735	4.522
	Forest Loss in Week-3	5.204	5.885
	Forest Loss in Week-4	1.053	0.991
Weekly Analysis For April 2018 COMMAND-1 firstRefStart = 2018-3-25 COMMAND-2 firstRefEnd = 2018-4-1 COMMAND-3 targetStart = 2018-4-1 COMMAND-4 targetEnd = 2018-5-6 COMMAND-5 totalWeeks = 5	Forest Loss in Week-1	0.062	0.062
	Forest Loss in Week-2	4.586	6.259
	Forest Loss in Week-3	1.673	1.859
	Forest Loss in Week-4	3.780	4.276
	Forest Loss in Week-5	2.788	4.028

Weekly Analysis For May 2018 COMMAND-1 firstRefStart = 2018-4-29 COMMAND-2 firstRefEnd = 2018-5-6 COMMAND-3 targetStart = 2018-5-6 COMMAND-4 targetEnd = 2018-6-3 COMMAND-5 totalWeeks = 4	Forest Loss in Week-1	2.231	1.053
	Forest Loss in Week-2	2.371	2.185
	Forest Loss in Week-3	2.107	2.292
	Forest Loss in Week-4	1.178	2.231
Weekly Analysis For June 2018 COMMAND-1 firstRefStart = 2018-5-27 COMMAND-2 firstRefEnd = 2018-6-3 COMMAND-3 targetStart = 2018-6-3 COMMAND-4 targetEnd = 2018-7-1 COMMAND-5 totalWeeks = 4	Forest Loss in Week-1	1.116	1.425
	Forest Loss in Week-2	4.276	4.338
	Forest Loss in Week-3	2.106	2.106
	Forest Loss in Week-4	2.045	1.983
Weekly Analysis For July 2018 COMMAND-1 firstRefStart = 2018-6-24 COMMAND-2 firstRefEnd = 2018-7-1 COMMAND-3 targetStart = 2018-7-1 COMMAND-4 targetEnd = 2018-8-5 COMMAND-5 totalWeeks = 5	Forest Loss in Week-1	7.622	7.499
	Forest Loss in Week-2	3.904	8.056
	Forest Loss in Week-3	6.196	7.560
	Forest Loss in Week-4	0.868	1.363
	Forest Loss in Week-5	3.036	2.727
Weekly Analysis For August 2018 COMMAND-1 firstRefStart = 2018-7-29 COMMAND-2 firstRefEnd = 2018-8-5 COMMAND-3 targetStart = 2018-8-5 COMMAND-4 targetEnd = 2018-9-2 COMMAND-5 totalWeeks = 4	Forest Loss in Week-1	1.259	1.259
	Forest Loss in Week-2	0.496	0.558
	Forest Loss in Week-3	1.588	1.135
	Forest Loss in Week-4	3.036	2.664
Weekly Analysis For September 2018 COMMAND-1 firstRefStart = 2018-8-26 COMMAND-2 firstRefEnd = 2018-9-2 COMMAND-3 targetStart = 2018-9-2 COMMAND-4 targetEnd = 2018-10-7 COMMAND-5 totalWeeks = 5	Forest Loss in Week-1	4.275	4.709
	Forest Loss in Week-2	0.372	1.115
	Forest Loss in Week-3	0.000	0.000
	Forest Loss in Week-4	0.372	0.929
	Forest Loss in Week-5	3.470	7.002
Weekly Analysis For October 2018 COMMAND-1 firstRefStart = 2018-9-30 COMMAND-2 firstRefEnd = 2018-10-7 COMMAND-3 targetStart = 2018-10-7 COMMAND-4 targetEnd = 2018-11-4 COMMAND-5 totalWeeks = 4	Forest Loss in Week-1	5.081	1.921
	Forest Loss in Week-2	0.248	0.124
	Forest Loss in Week-3	0.000	0.000
	Forest Loss in Week-4	0.000	0.000
Weekly Analysis For November 2018 COMMAND-1 firstRefStart = 2018-10-28 COMMAND-2 firstRefEnd = 2018-11-4 COMMAND-3 targetStart = 2018-11-4 COMMAND-4 targetEnd = 2018-12-2 COMMAND-5 totalWeeks = 4	Forest Loss in Week-1	0.620	0.558
	Forest Loss in Week-2	6.506	6.630
	Forest Loss in Week-3	18.342	10.782
	Forest Loss in Week-4	0.124	0.682

Results for Rottock Bay Consolidated Concession

Forest Loss Detection

Input Commands (COMMAND-1 to COMMAND-5)	Analysis	Weekly Forest Loss (sq. Km) for NDVI, NDWI, and NBR Method	Weekly Forest Loss (sq. Km) for SMA and NDFI Method
Weekly Analysis For January 2018 COMMAND-1 firstRefStart = 2017-12-31 COMMAND-2 firstRefEnd = 2018-1-7 COMMAND-3 targetStart = 2018-1-7 COMMAND-4 targetEnd = 2018-2-4 COMMAND-5 totalWeeks = 4	Forest Loss in Week-1	0.000	0.000
	Forest Loss in Week-2	0.000	0.000
	Forest Loss in Week-3	0.000	0.124
	Forest Loss in Week-4	0.000	0.000
Weekly Analysis For February 2018 COMMAND-1 firstRefStart = 2018-1-28 COMMAND-2 firstRefEnd = 2018-2-4 COMMAND-3 targetStart = 2018-2-4 COMMAND-4 targetEnd = 2018-3-4 COMMAND-5 totalWeeks = 4	Forest Loss in Week-1	0.000	0.000
	Forest Loss in Week-2	0.000	0.000
	Forest Loss in Week-3	0.000	0.000
	Forest Loss in Week-4	0.000	0.000
Weekly Analysis For March 2018 COMMAND-1 firstRefStart = 2018-2-25 COMMAND-2 firstRefEnd = 2018-3-4 COMMAND-3 targetStart = 2018-3-4 COMMAND-4 targetEnd = 2018-4-1 COMMAND-5 totalWeeks = 4	Forest Loss in Week-1	0.000	0.000
	Forest Loss in Week-2	0.000	0.000
	Forest Loss in Week-3	0.000	0.000
	Forest Loss in Week-4	0.062	0.247

Weekly Analysis For April 2018 COMMAND-1 firstRefStart = 2018-3-25 COMMAND-2 firstRefEnd = 2018-4-1 COMMAND-3 targetStart = 2018-4-1 COMMAND-4 targetEnd = 2018-5-6 COMMAND-5 totalWeeks = 5	Forest Loss in Week-1	0.247	0.309
	Forest Loss in Week-2	0.000	0.000
	Forest Loss in Week-3	0.000	0.000
	Forest Loss in Week-4	0.124	0.741
	Forest Loss in Week-5	0.000	0.185
Weekly Analysis For May 2018 COMMAND-1 firstRefStart = 2018-4-29 COMMAND-2 firstRefEnd = 2018-5-6 COMMAND-3 targetStart = 2018-5-6 COMMAND-4 targetEnd = 2018-6-3 COMMAND-5 totalWeeks = 4	Forest Loss in Week-1	0.865	0.371
	Forest Loss in Week-2	0.062	0.000
	Forest Loss in Week-3	0.989	0.309
	Forest Loss in Week-4	0.000	0.000
Weekly Analysis For June 2018 COMMAND-1 firstRefStart = 2018-5-27 COMMAND-2 firstRefEnd = 2018-6-3 COMMAND-3 targetStart = 2018-6-3 COMMAND-4 targetEnd = 2018-7-1 COMMAND-5 totalWeeks = 4	Forest Loss in Week-1	0.000	0.000
	Forest Loss in Week-2	0.000	0.000
	Forest Loss in Week-3	0.000	0.000
	Forest Loss in Week-4	0.000	0.000
Weekly Analysis For July 2018 COMMAND-1 firstRefStart = 2018-6-24 COMMAND-2 firstRefEnd = 2018-7-1 COMMAND-3 targetStart = 2018-7-1 COMMAND-4 targetEnd = 2018-8-5 COMMAND-5 totalWeeks = 5	Forest Loss in Week-1	0.185	0.062
	Forest Loss in Week-2	0.000	0.000
	Forest Loss in Week-3	0.000	0.000
	Forest Loss in Week-4	0.000	0.000
	Forest Loss in Week-5	0.000	0.000
Weekly Analysis For August 2018 COMMAND-1 firstRefStart = 2018-7-29 COMMAND-2 firstRefEnd = 2018-8-5 COMMAND-3 targetStart = 2018-8-5 COMMAND-4 targetEnd = 2018-9-2 COMMAND-5 totalWeeks = 4	Forest Loss in Week-1	0.000	0.000
	Forest Loss in Week-2	0.185	0.062
	Forest Loss in Week-3	0.185	0.185
	Forest Loss in Week-4	0.309	0.185
Weekly Analysis For September 2018 COMMAND-1 firstRefStart = 2018-8-26 COMMAND-2 firstRefEnd = 2018-9-2 COMMAND-3 targetStart = 2018-9-2 COMMAND-4 targetEnd = 2018-10-7 COMMAND-5 totalWeeks = 5	Forest Loss in Week-1	0.309	0.247
	Forest Loss in Week-2	0.000	0.000
	Forest Loss in Week-3	0.000	0.000
	Forest Loss in Week-4	0.000	0.000
	Forest Loss in Week-5	0.247	0.556
Weekly Analysis For October 2018 COMMAND-1 firstRefStart = 2018-9-30 COMMAND-2 firstRefEnd = 2018-10-7 COMMAND-3 targetStart = 2018-10-7 COMMAND-4 targetEnd = 2018-11-4 COMMAND-5 totalWeeks = 4	Forest Loss in Week-1	0.000	0.000
	Forest Loss in Week-2	0.000	0.000
	Forest Loss in Week-3	0.000	0.000
	Forest Loss in Week-4	0.000	0.000
Weekly Analysis For November 2018 COMMAND-1 firstRefStart = 2018-10-28 COMMAND-2 firstRefEnd = 2018-11-4 COMMAND-3 targetStart = 2018-11-4 COMMAND-4 targetEnd = 2018-12-2 COMMAND-5 totalWeeks = 4	Forest Loss in Week-1	0.000	0.000
	Forest Loss in Week-2	0.062	0.124
	Forest Loss in Week-3	0.000	0.000
	Forest Loss in Week-4	0.000	0.000

Reference

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Souza, C.M., Jr., Firestone, L., Silva, L.M., and Roberts, D. Mapping forest degradation in the Eastern Amazon from SPOT 4 through spectral mixture models. *Remote Sens. Environ*. 2003, 87, 494–506.

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Souza, C.M., Jr., Siqueira, J.V., Sales, M.H., Fonseca, A.V., Ribeiro, J.G., Numata, I., Cochrane, M.A., Barber, C.P., Roberts, D.A., and Barlow, J. *Remote Sens*. 2013, 5, 5493-5513.

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添付資料 10

Land Change Modeler による解析マニュアル

Manual for Land Change Modeler Analysis (Draft)

March 2017

PNGFA-JICA Technical Cooperation Project "Capacity Development Project for Operationalization of PNG Forest Resource Information Management System for Addressing Climate Change"

Contents

Introduction

Land Change Modeler (LCM) is a land planning and decision support system developed by Clark University, USA. LCM can analyse land cover change, empirically model relationships to explanatory variables, and simulate future land change scenarios. Therefore, LCM can be utilized for evaluating forest operation plans comparing simulated future forest statuses caused by multiple policies. In PNGFA HQ, LCM for ArcGIS Software Extension (2.0) is installed in a Workstation in the Inventory and Mapping Branch named as POM-MAP-GIS04.

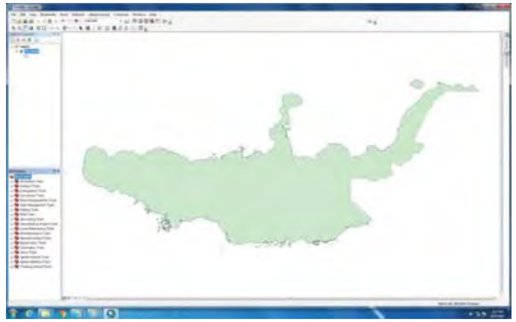
In this document, a procedure for standard LCM analyses is described with points to be noted. Also, a few case studies regarding forest cover change using LCM is shown as references.

Procedure for Standard Land Change Modeler Analyses

1. Preparation of Environment in ArcMap

For analysis using Land Change Modeler, it is necessary to prepare raster layers with identical properties such as the coordinate system, cell size, number of Columns and Rows, etc. For this purpose it is highly recommended to set the environment of ArcMap before preparation of raster layers for analysis.

1.1 In ArcMap, open a feature file of the targeted area. The coordinate system of the feature file should be projected coordinate system. Check whether the coordinate system of the data frame is same as the feature file from “View” > “Data Frame Properties” > “Coordinate System”.

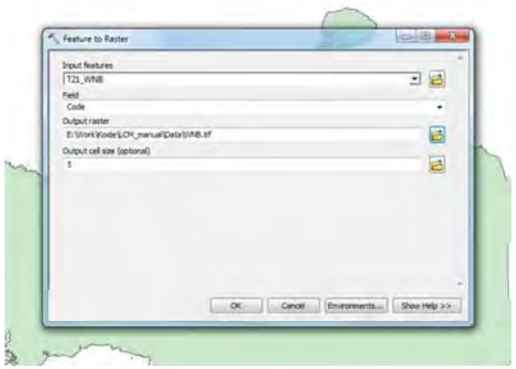


A lot of GIS data in PNG-FRIMS is based on WGS 1984 series of projected coordinate system. Employed zones of each province are on the following table.

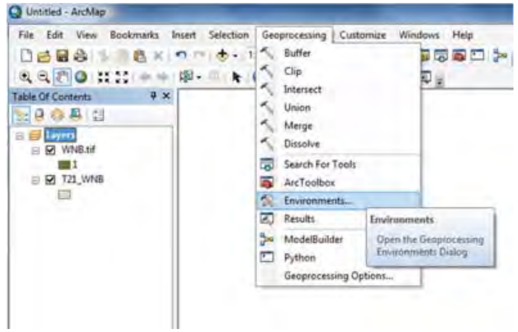
No.	Province	Abbreviation	Zone
01	Western	WES	S54
02	Gulf	GUL	S54
03	Central	CEN	S55
04	National Capital District	NCD	S55
05	Milne Bay	MIL	S55
06	Oro	ORO	S55
07	Southern Highlands	SHP	S54
08	Hela	HLA	S54
09	Enga	ENG	S54
10	Western Highlands	WHP	S54
11	Jiwaka	JIW	S54
12	Chimbu	SIM	S55

13	Eastern Highlands	EHP	S55
14	Morobe	MOR	S55
15	Madang	MAD	S55
16	East Sepik	ESP	S55
17	West Sepik	WSP	S54
18	Manus	MAN	S55
19	New Ireland	NIP	S56
20	East New Britain	ENB	S56
21	West New Britain	WNB	S56
22	Autonomous Region of Bougainville	ARB	S57

1.2 Convert the shape file to a raster file using "ArcToolbox" > "Conversion tool" > "To Raster" > "Feature to Raster". Output cell size should be unified through whole analysis. Note that smaller cell size, the bigger file size to take longer time for analyses. Hereinafter, this raster layer is called "the Target Raster".



1.3 Set environments in ArcGIS from "Geoprocessing" > "Environments".



1.4 "Output Coordinates" > "Output Coordinate System" is set as "Same as Layer "…."" referring the Target Raster. "Processing Extent" > "Extent", "Processing Extent" > "Snap Raster", "Geodatabase Advanced" > "Output XY Domain", "Geodatabase Advanced" > "Output M Domain", "Geodatabase Advanced" > "Output Z Domain and "Cartography" > "Cartographic Coordinate System" should be referring the Target Raster as well. "XY Resolution and Tolerance" > "XY Resolution" must be set.

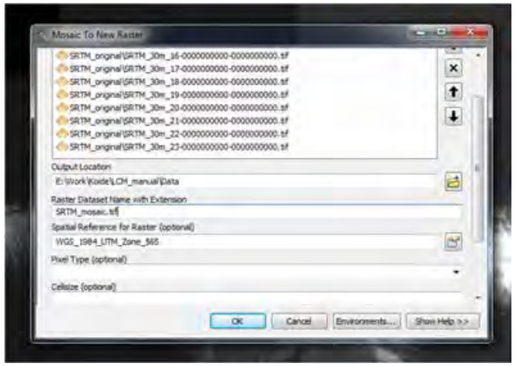
2. Preparation of Raster Layers

The Land Change Modeler accept only 8-bit unsigned integer or 32-bit float raster layers for analyses. Before starting analysis with LCM, necessary data for the analysis must be converted to the required form.

2.A. Raster to Raster

2.A.1 Open raster file(s) to cover full extent of the target area.

2.A.2 When more than 1 rasters cover the target area, mosaic the raster files using “Data Management Tools” > “Raster” > “Mosaic Dataset” > “Mosaic to New Raster”. When only 1 raster can cover the target area, skip this.



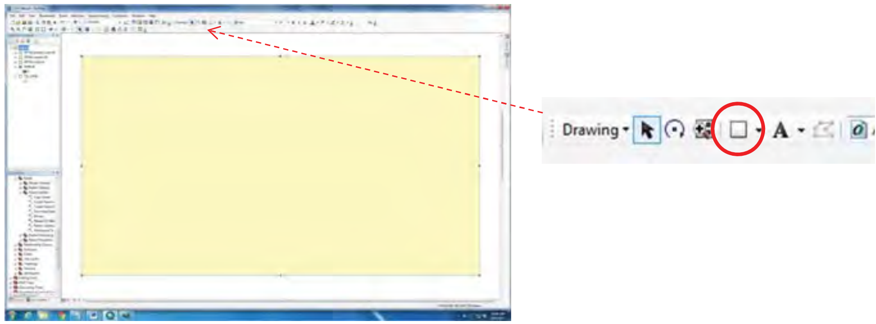
2.A.3 Copy raster using “Data Management Tools” > “Raster” > “Mosaic Dataset” > “Copy Raster”. Pixel type must be set as “8_BIT_UNSIGNED” or “32_BIT_FLOAT” for applying LCM analysis later. If necessary, rescale pixel values in the raster to fit to extent of unsigned 8-bit (0-255) checking “Scale Pixel Value”. Set no data value if necessary.

2.A.4 Finally, a raster layer with same coordinate system and extent as the Target Raster is generated.

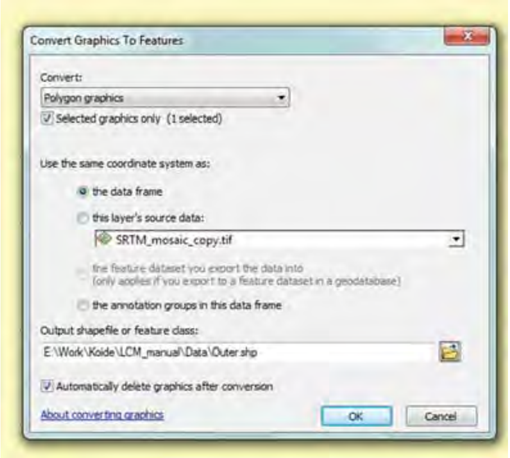
2.B. Polygon to Raster

2.B.1 Open “Draw” tool bar from “Customize” > “Tool bars” > “Draw”.

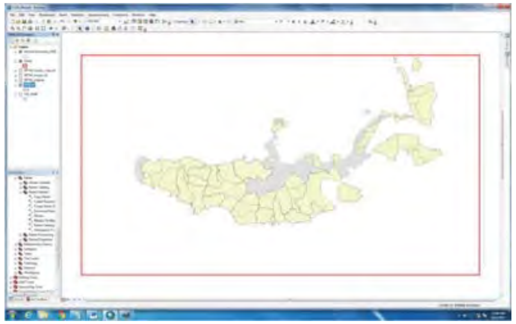
2.B.2 Use “Rectangle” tool in the “Draw” tool bar to draw rectangle enough large to cover the whole extent of the Target Raster.



2.B.3 Select the drawn rectangle and convert it to a feature using “Drawing” in the “Draw” tool bar > “Convert Graphics to Features”. Check “the data frame” to use the same coordinate systems and “Automatically delete graphics after conversion”. Hereinafter, this feature layer is called “the Outer Feature”.

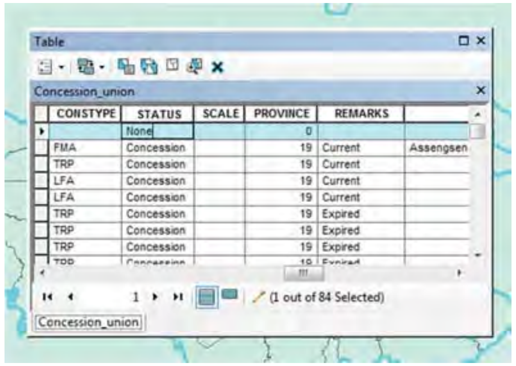


2.B.4 Open feature file(s) to be converted to a raster.

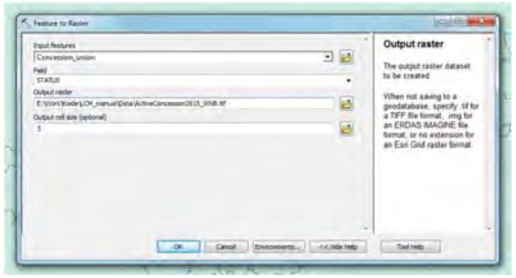


2.B.5 Union the features including the Outer Feature using "Geoprocessing" > "Union".

2.B.6 Edit the attribute table of the unioned feature to fill values for every polygon.



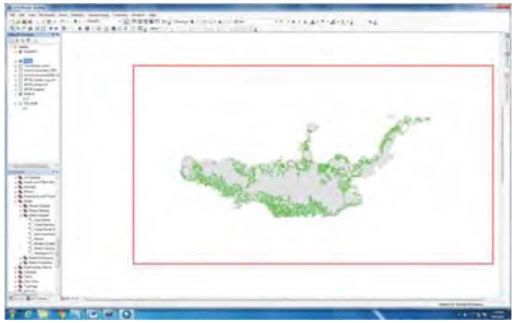
2.B.7 Convert the feature to a raster using "Conversion Tools" > "To Raster" > "Feature to Raster". Set necessary attribute in "Field" and cell size as same as that of the Target Raster.



2.B.8 After the conversion, check the pixel value and pixel depth of the converted raster float from the properties whether the pixels are 8-bit unsigned integer or 32-bit. Otherwise, copy the raster using "Copy Raster" tool to set appropriate pixel type to the raster (refer 2.A.3). Check whether the coordinate system is same as the data frame.

2.C. Polyline to Raster

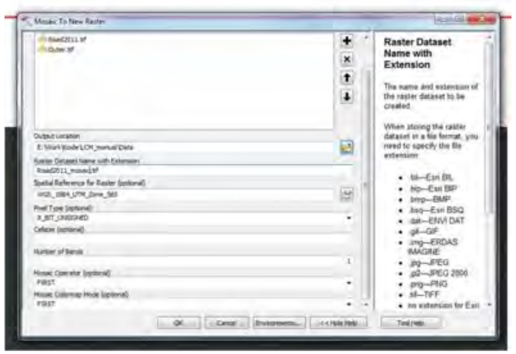
2.C.1 Open a polyline file to be converted to a raster.



2.C.2 Convert the polyline to a raster using “Conversion Tools” > “To Raster” > “Feature to Raster”. Set the cell size as same as that of the Target Raster.

2.C.3 Convert the Outer Feature to a raster.

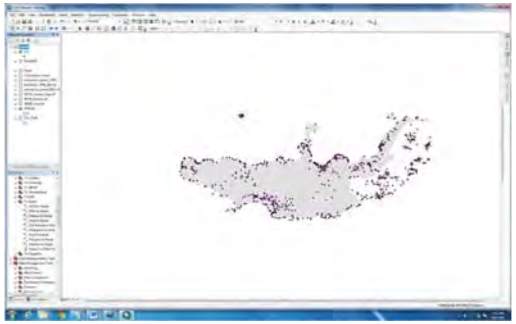
2.C.4 Mosaic the converted polyline and Outer Feature using “Data Management Tools” > “Raster” > “Mosaic Dataset” > “Mosaic to New Raster”. The first input raster should be the converted polyline and the second should be the converted Outer Feature. The pixel type must be set as “8_BIT_UNSIGNED”. “Mosaic Operator” must be set as “FIRST”.



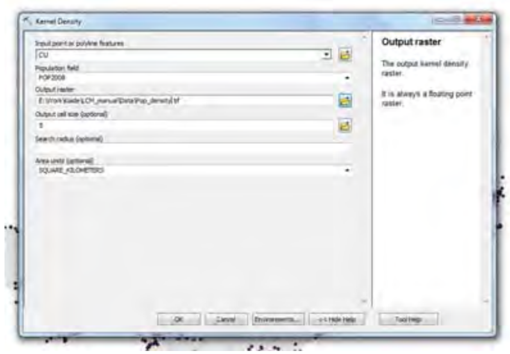
2.C.5 Check whether the pixel type and coordinate system are correct.

2.D. Density calculation utilizing point data

2.D.1 Open point data containing numbers such as population.



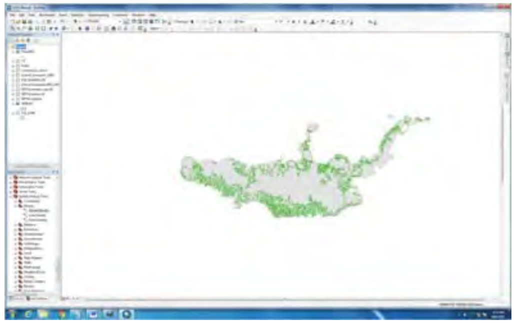
2.D.2 Calculate density distribution using “Spatial Analyst Tools” > “Density” > “Kernel Density”. Attribute containing numbers for calculating density is set into “Population filed”.



2.D.3 Check whether the pixel type and coordinate system are correct.

2.E. Distance from features

2.E.1 Open a feature layer for calculating distance from the feature.



2.E.2 Calculate distance using “Spatial Analyst Tools” > “Distance” > “Euclidean Distance”.

2.E.3 Check whether the pixel type and coordinate system are correct.

3. Land Change Analysis

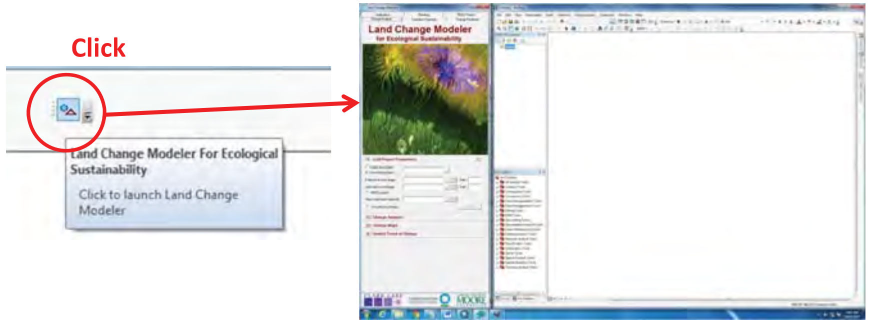
Land Change Modeler offers environment to implement various simulation regarding future land change. Here a basic procedure of a land change analysis will be introduced. To see further examples of analyses, see the Tutorial document[1].

3.A. Transition Potential Modelling

3.A.1 Open “Land Change Modeler” tool bar from “Customize” > “Tool bars” > “Land Change Modeler”.

3.A.2 Launch Land Change Modeler.

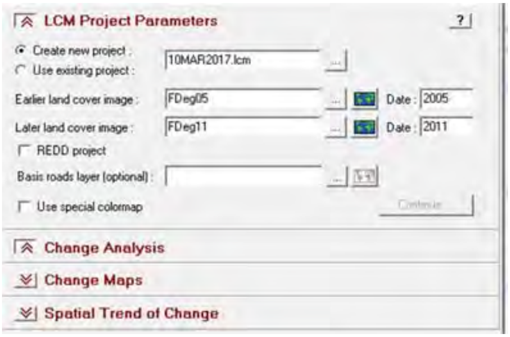
[1] Stored in \\Pngfa-hq-srv3\nfrdms\75_Manuals\Land_Change_Modeler



3.A.3 Check “Create new project” and set a location to be saved and set a project name.

3.A.4 Set two time series of land cover map into “Earlier land cover image” and “Later land cover image”[2]. Set the dates (years) as well.

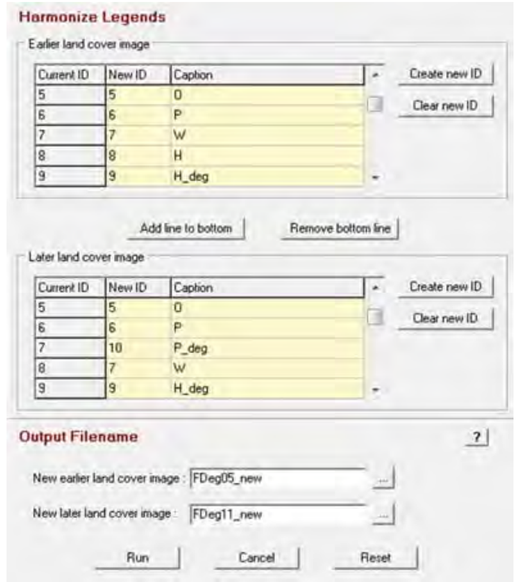
[2] All raster data to be utilized for the analysis must be gathered in just one folder. The project file will be created in the folder as well.



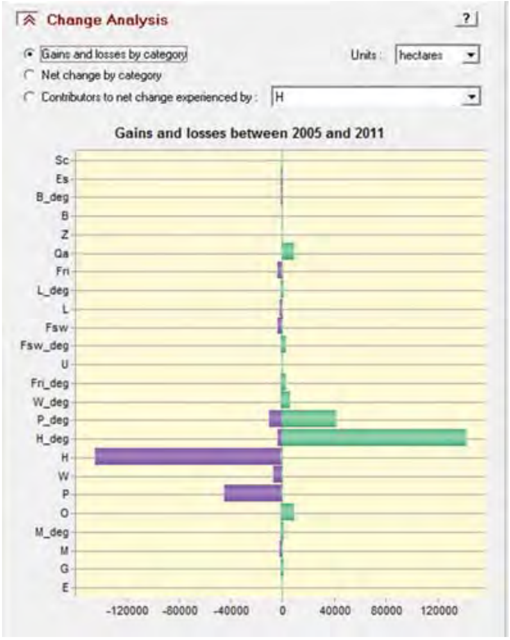
3.A.5 Open the "Change Analysis" panel located under the "LCM Project Parameters" panel.

3.A.6 In some cases, an indication shown below will appear. Then click "Yes".

3.A.7 Set new IDs to each caption (land cover type) to harmonize legends in both "Earlier land cover image" and "Later land cover image". Set Output File name for each image and click "Run".

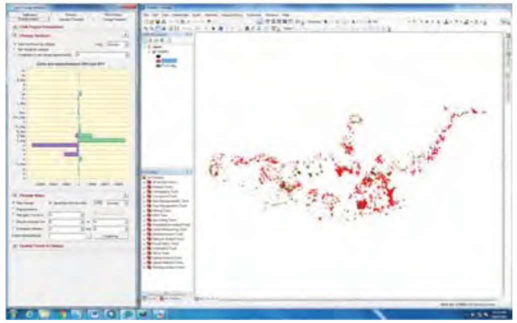


3.A.8 In the "Change Analysis" panel, a graph of gains and losses of each land cover type between the two time points. Major types of land change are clarified now. Simulation of future trends of these changes is implemented hereinafter.

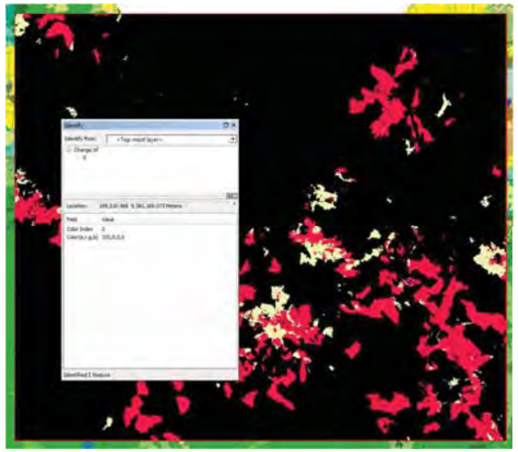


3.A.9 In the "Change Maps" panel, check "Map changes" and "Ignore transitions less than" and set number to ignore minor land change from the simulation. Then click "Create Map".

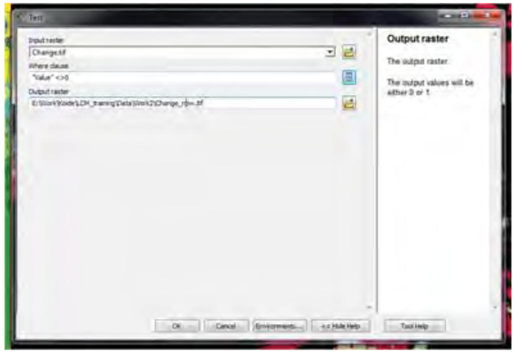
3.A.10 Locations with land cover change in period of the analysis are indicated. In the example below, only two kinds of land cover change larger than 10000 hectares are indicated and the other changes are ignored.



3.A.11 For later use, the created land cover change map is mosaicked to the Target Raster. Firstly, copy the created map to a new raster file using "Data Management Tools" > "Raster" > "Mosaic Dataset" > "Copy Raster", if the map doesn't be projected. The copied file is mosaicked to the Target Raster using "Data Management Tools" > "Raster" > "Mosaic Dataset" > "Mosaic to New Raster". The first input raster should be the created land cover change map and the second should be the Target Raster. "Mosaic Operator" must be set as "FIRST" (refer **2.C.4** as well). Here, check the background value.

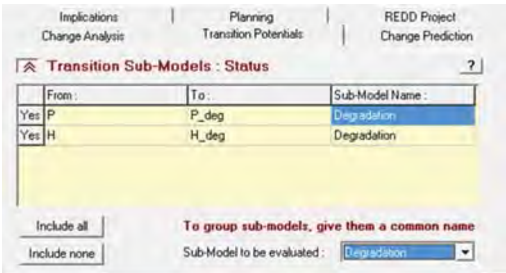


Assign 0 as the background value and 1 as the other value using “Spatial Analyst” > “Math” > “Logical” > ”Test”. Set the mosaicked raster as “Input raster” and “”Value” <> 0”, when the background value equals to 0, is typed into “Where clause” window[3]. Set the name of “Output raster” and press OK.



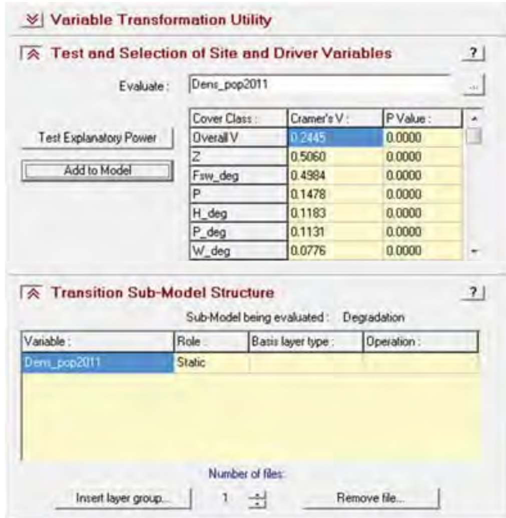
The generated raster file here is 2-bit file, so that transform it to an unsigned 8-bit file using “Data Management Tools” > “Raster” > “Mosaic Dataset” > “Copy Raster”. Hereinafter, this raster layer is called “the Land Cover Change Raster”.

3.A.12 Open “Transition Potentials” tab and open the “Transition Sub-Models: Status” panel. Set Sub-Model Name for each type of land cover change. To group sub-models, give them a common name. Set Sub-Model to be evaluated.



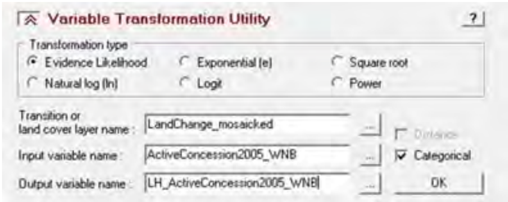
[3] This is depend on the background value. If the back ground value was 1, type as “”Value” <> 1”.

3.A.13 Open the “Test and Selection of Site and Driver Variables” panel and select a raster (variable) utilized for the simulation. Evaluate the raster clicking “Test Explanatory Power”[4]. “P value” of “Overall V” should be less than 0.05. Then click “Add to Model” to add the raster for the simulation. The added raster is shown in the “Transition Sub-Model Structure” panel.

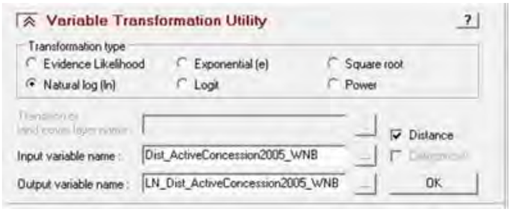


3.A.14 Categorical raster such as concession boundary must be transformed using the “Variable Transformation Utility” panel. Check “Evidence Likelihood” as “Transformation type”. The Land Cover Change Raster (Refer 3.**A.11**) is set to “Transition or land cover layer name”. The categorical raster to be transformed is set to “Input variable name”. Set output variable name. Be sure to check on “Categorical” in the left side of the panel. Press “OK” to implement the transformation.

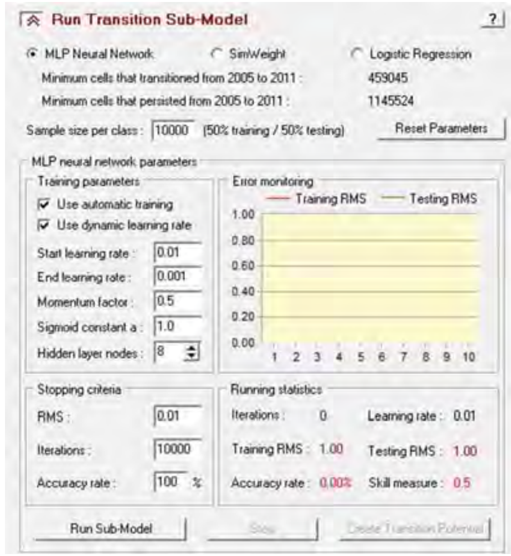
[4] When error is occurring at this point, check whether the numbers of “Columns and Rows” and “Cell Size (X, Y)” are same as the land cover maps. If not, “Copy Raster” tool may help adjust the numbers.



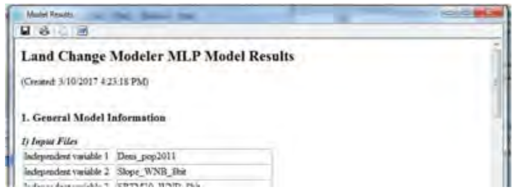
3.A.15 In many cases, effects of a driver causing land cover change decrease exponentially with the distance from the driver. In these cases, raster layers indicating distance from some feature should be log-transformed using the "Variable Transformation Utility" panel. Check "Natural log (ln)" as "Transformation type". The distance raster to be transformed is set to "Input variable name". Set output variable name. Be sure to check on "Distance" in the left side of the panel. Press "OK" to implement the transformation.



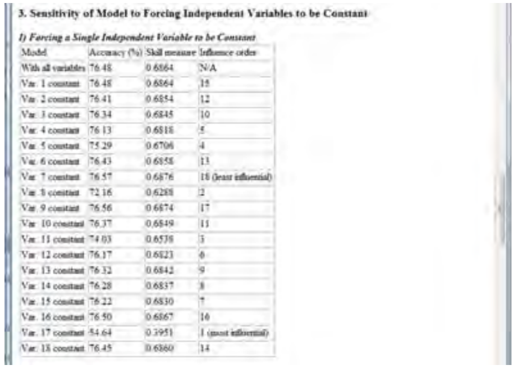
3.A.16 Open the "Run Transition Sub-Model" and check "MLP Neural Network". Usually, it is not necessary to change any parameters on this panel. Click "Run Sub-Model" to start the analysis. The final "Accuracy rate" should be more than 75.00%. When the rate is less than this value, reconsider the employing variables.



3.A.17 Finishing the analysis, "Model Results" page is generated automatically. Click "Create Transition Potential" button on the "Run Transition Sub-Model" panel for further analysis.



3.A.18 Most influential variables to the model can be seen in this file. These are the key drivers of the land cover change.



3. Sensitivity of Model to Forcing Independent Variables to be Constant

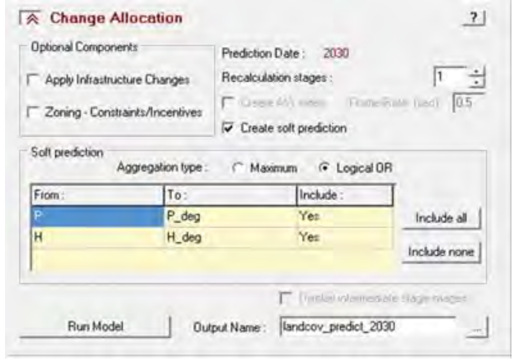
I) Forcing a Single Independent Variable to be Constant

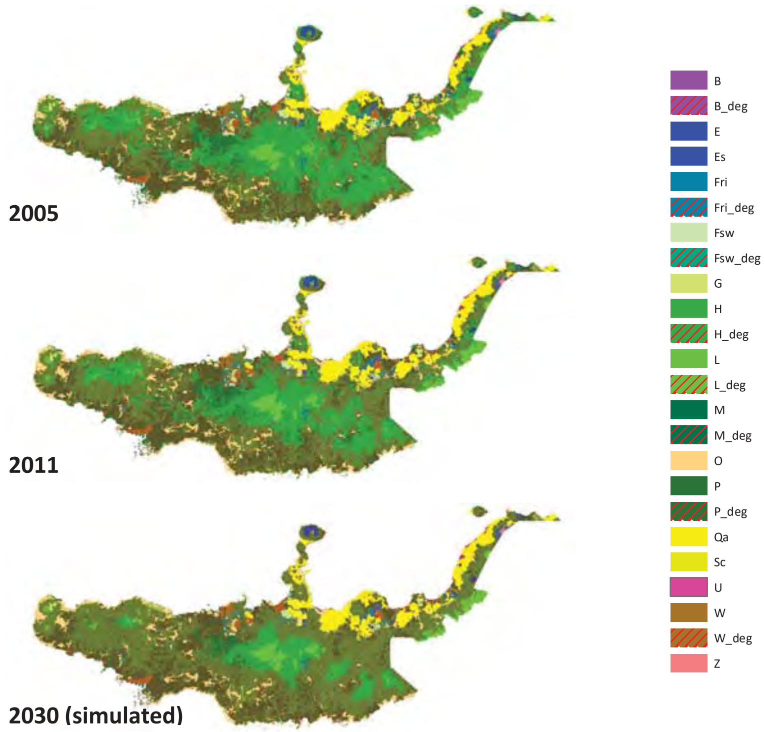
Model	Accuracy (%)	Skill measure	Influence order
With all variables	76.48	0.6864	N/A
Var. 1 constant	76.48	0.6864	15
Var. 2 constant	76.41	0.6854	12
Var. 3 constant	76.34	0.6845	10
Var. 4 constant	76.13	0.6818	5
Var. 5 constant	75.29	0.6706	4
Var. 6 constant	76.43	0.6858	13
Var. 7 constant	76.57	0.6876	18 (least influential)
Var. 8 constant	72.16	0.6288	2
Var. 9 constant	76.56	0.6874	17
Var. 10 constant	76.37	0.6849	11
Var. 11 constant	74.03	0.6538	3
Var. 12 constant	76.17	0.6823	6
Var. 13 constant	76.32	0.6842	9
Var. 14 constant	76.28	0.6837	8
Var. 15 constant	76.22	0.6830	7
Var. 16 constant	76.50	0.6867	16
Var. 17 constant	54.64	0.3951	1 (most influential)
Var. 18 constant	76.45	0.6860	14

3.B. Change Prediction

3.B.1 Open "Change Prediction" tab and open the "Change Demand Modelling" panel. Check "Markov Chain" and specify the end year of the prediction.

3.B.2 Open the "Change Allocation" panel. Check "Create soft prediction" and confirm whether each modelled land changes are included for Soft Prediction. Click "Run Model".





Case Studies Regarding Forest Cover Change

1. Simulation on effects of enlargement of plantation and agricultural field around Kimbe, West New Britain Province

Land Change Modeler enables estimation of the drivers for deforestation through comparison of land use at two points in time and enables simulation of a case in which deforestation would continue at the current pace (business-as-usual (BAU) case). In this section, the flow of the simulation on effects of enlargement of plantation and agricultural field around Kimbe, West New Britain Province, is described.

An area (of approx. 4,870 km^2) in the pilot province of West New Britain Province, where the developments of plantations along with population growth have been causing rapid deforestation, was used in the simulation. A 2011 forest base map and a 2014 forest cover map, which was created by comparing the forest base map with a LANDSAT Greenest Pixel and a corrected base map of the changes detected in the comparison, were used as the land use maps of two points in time (Figure 1).

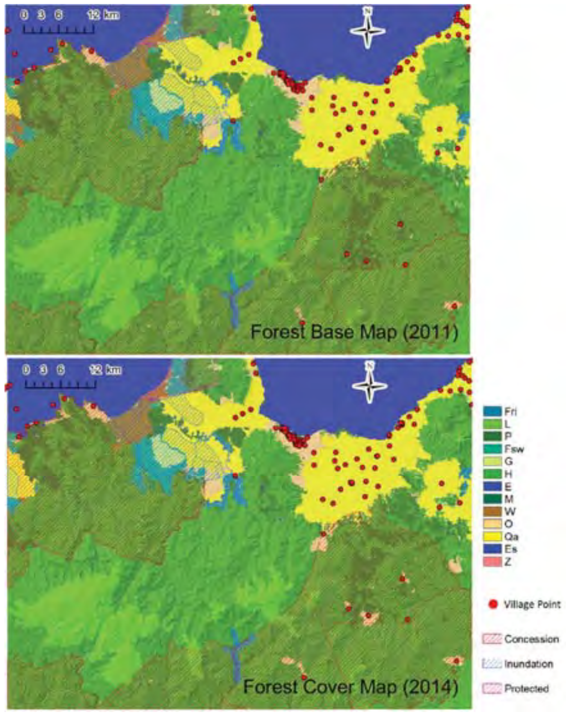


Figure 1 Forest maps of two points in time used in the simulation with Land Change Modeler

In the beginning, the maps of 2011 and 2014 were compared to elucidate what types of land use increased and what types of land use decreased between 2011 and 2014 (Figure 2). The comparison revealed that the areas of agricultural plantations (Qa) and subsistence farmland (O) had increased and the areas of lowland forest (P), hill forest (H), wetland forest (Fsw), open woodland (W) and grassland (G) had decreased between 2011 and 2014. Therefore, the development of agricultural plantations and subsistence farmland was selected as the driver of deforestation and their distribution in the future (in the year 2030) was estimated. The elevation (SRTM, resolution of 30 m), slope, distance from the sea, population density (Kernel analysis), boundaries of reserves, wetland and active concession areas and the land use boundaries in 2011 were used as the model parameters.

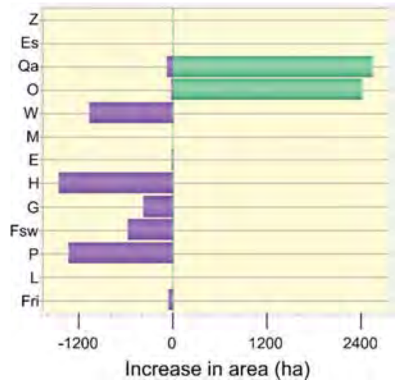


Figure 2 Changes in the land use between the two points in time

The accuracy of the model of agricultural plantations was estimated at 80.83%. Because this figure is larger than the threshold for the sufficient accuracy of 80%, this model is considered a valid model (Table 1). The boundaries of inundation area are the parameters that have the largest influence on the accuracy of the model, followed by, in descending order, the following: the land use boundaries of 2011 (base map), protected area boundaries, active concession boundaries, elevation (SRTM, resolution of 30 m), distance from the sea, population density and slope.

Table 1 Influence that each parameter has on the accuracy of the model of agricultural plantations

Model	Accuracy (%)	Skill measure	Influence order
With all variables	**80.83**	**0.787**	N/A
Without SRTM_30 m	69.44	0.6605	5
Without slope	78.38	0.7598	8 (Least influential)
Without distance from sea	69.69	0.6632	6
Without population density	75.02	0.7224	7
Without protected area	46.72	0.408	3
Without inundation area	40.69	0.341	1 (Most influential)
Without concession area	65.03	0.6115	4
Without base map	43.97	0.3775	2

The accuracy of the model of subsistence farmland was estimated at 81.73%. Because this figure is larger than the threshold for sufficient accuracy of 80%, this model is considered a valid model (Table 2). The boundaries of inundation area are the parameters that have the largest influence on the accuracy of the model, followed by, in descending order, the following: active concession boundaries, protected area boundaries, the land use boundaries of 2011 (base map), distance from the sea, elevation (SRTM, resolution of 30 m), population density and slope.

Table 2 Influence that each parameter has on the accuracy of the model of subsistence farmland

Model	Accuracy (%)	Skill measure	Influence order
With all variables	**81.73**	**0.7564**	**N/A**
Without SRTM_30m	73.75	0.6499	6
Without Slope	80.91	0.7454	8 (Least influential)
Without Distance from sea	66.4	0.5521	5
Without Population density	77.8	0.704	7
Without Protected area	60.86	0.4781	3
Without Inundation area	60.68	0.4758	1 (Most influential)
Without Concession area	60.7	0.4761	2
Without Base map	63.94	0.5193	4

A forest cover map of 2030 was created in the simulation using these models (Figure 3). The map predicts increases in the areas of agricultural plantations and subsistence farmland by 17.7% and 124.9%, respectively, and decreases in the areas of lowland forest, hill forest, wetland forest, open woodland and grassland by 16.7%, 2.8%, 31.8%, 64.6% and 26.6%, respectively (Table 3). This map is considered representative of the land use pattern in 2030 if the current trend in deforestation and forest degradation (BAU) continues till 2030.

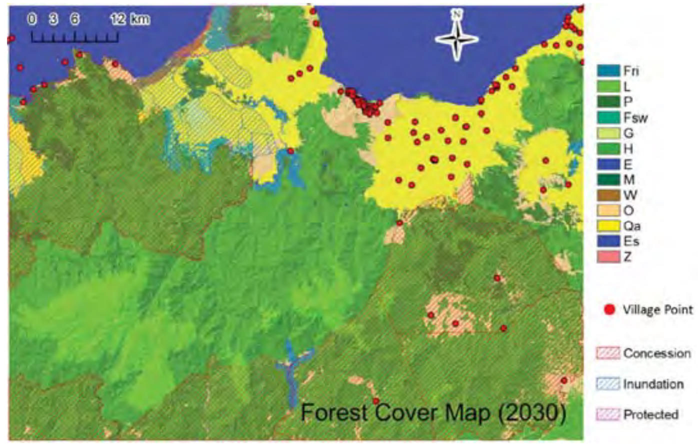


Figure 3 Forest cover map of 2030 simulated with Land Change Modeler

Table 3 Influence that each parameter has on the accuracy of the model of subsistence farmland

Land use	Area 2011 (ha)	Area 2014 (ha)	Area 2030 (ha)	Change in area comparing 2014 and 2030 (%)
P	39,564	38,232	31,848	-16.7
H	271,024	269,568	261,913	-2.8
Fri	4,131	4,070	4,070	0
Fsw	8,373	7,791	5,314	-31.8
W	6,010	4,942	1,749	-64.6
L	32,018	32,018	32,018	0
M	108	108	108	0
G	5,879	5,503	4,039	-26.6
Z	51	51	51	0
E	1,505	1,497	1,497	0
Es	60,864	60,864	60,864	0
Qa	51,572	54,054	63,606	17.7
O	6,907	9,307	20,930	124.9

The biomass of the vegetation in the area concerned was estimated by multiplying the area of each land cover type on the map by the default factors of IPCC (Table 2.3 4). All the agricultural plantations in this area were assumed to be oil palm plantations. The biomass of the vegetation in this area was estimated to decrease by 4.1 Mt in the period between 2014 and 2030. This figure corresponds to 7.5 Mt CO_2-eq and, thus, a loss of approx. US$ 37 million, on the assumption that 1t CO_2-eq is worth US$ 5.

Table 4 Comparison between the biomass in 2014 and the estimated biomass in 2030

Land use	Biomass 2014 (Mt)	Biomass 2030 (Mt)	Change in biomass comparing 2014 and 2030 (Mt)
P	11.5	9.6	-1.9
H	80.9	78.6	-2.3
Fri	1.2	1.2	0
Fsw	2.3	1.6	-0.7
W	0.6	0.2	-0.4
L	4.5	4.5	0
M	0	0	0
G	0	0	0
Z	0	0	0
E	0	0	0
Es	0	0	0
Qa	7.4	8.7	1.3
O	0	0	0
Total	108.4	104.3	-4.1

The area of agricultural plantation is expected to increase by 9,552 ha between 2014 and 2030. If this area is assumed to increase at a constant rate in this period, the cumulative area increase will be 81,192 ha × year. If the yield of palm oil per unit area is assumed at 3.74 t ha^{-1} $year^{-1}$ [(5)] and its price is assumed at US$ 562 t^{-1} [(6)], the revenue from the sales of palm oil is expected to increase by US$ 170 million in this period. The total area of lowland and hill forests is expected to decrease by 14,040 ha in the same period. If this area is assumed to decrease at a constant rate, the cumulative area loss will be 119,348 ha × year. If the harvesting period and price per unit volume of timber are assumed for 35 years at US$ $142m^{-3}$ [(7)], respectively, a loss of approx. US$ 17 million is expected from the area loss. In conclusion, an increase in the revenue of US$ 116 million is expected from the deforestation and forest degradation on the BAU basis in the period between 2014 and 2030 (Table 5).

[5] http://www.soyatech.com/Palm_Oil_Facts.htm
[6] http://www.indexmundi.com/commodities/?commodity=palm-oil&months =300
[7] https://www.wageningenur.nl/upload_mm/5/c/1/b0b121e8-469b-4e65-9689-c4e6fd7c8d1e_WOt-technical%20report%2010%20webversie.pdf

An estimation similar to the one mentioned in the preceding paragraph was conducted in the cases in which 1) only open woodland and grassland could be converted to agricultural plantations and 2) only grassland could be converted to agricultural plantations. Increases in the revenue of US$ 85.2 million and US$ 28 million in the period between 2014 and 2030 were expected in cases 1) and 2), respectively. As restriction on the changes in land use increases, the increase in the revenue from the changes decreases. The policy of the government on forest management will depend on whether it can find value in conserving the forests themselves without deforestation and forest degradation.

Table 5 Comparison of the revenue increases between 2014 and 2030 with different scenarios

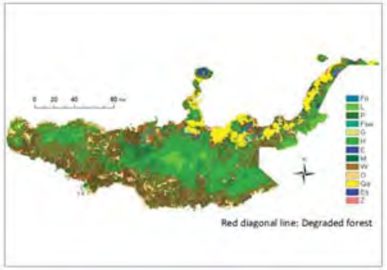
	Scenario 1	Scenario 2	Scenario 3
Net forest loss	19,711 ha	14,816 ha	11,623 ha
Net P&H loss	14,040 ha	11,623 ha	11,623 ha
Net plantation gain	9,552 ha	4,657 ha	1,464 ha
Price of increased carbon due to plantation development	-37.3 mil USD	2.00 mil USD	1.82 mil USD
Price of palm oil from newly developed plantation	171 mil USD	83.2 mil USD	26.2 mil USD
Price of increased timber due to developing oil palm plantations	-16.9 mil USD	0 mil USD	0 mil USD
Net increase in profit	116 mil USD	85.2 mil USD	28.0 mil USD

Note) Scenario 1: BAU; Scenario 2: Newly developing plantation is only allowed in W and G after 2014, increasing in subsistence agriculture is BAU; Scenario 3: Newly developing plantation is only allowed in G after 2014, increasing in subsistence agriculture is BAU

2. Simulation on distribution of deforestation and forest degradation in West New Britain Province

In this section, the flow of the simulation on distribution of deforestation and forest degradation in West New Britain Province is described.

The whole area of the pilot province of West New Britain Province (approx. 20,340 km^2) was used in the simulation. A 2011 forest base map and a 2005 forest cover map were used as the land use maps of two points in time. Information of drivers of forest degradation and deforestation were attached with each polygon in each map in advance. In this analysis, (1) forest land cover with drivers such as facility construction, road construction, forest plantation, perennial plantation, subsistence agriculture, "gardening" and selective logging was assumed as "degraded forest" and (2) forest land cover with drivers such as disasters and wood collection or without any drivers was assumed as "non-degraded forest" (Figure 4).



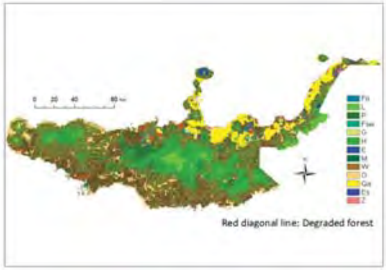


Figure 4 Forest Cover Map in 2005 (left) and Forest Base Map in 2011 (right)

In the beginning, the maps of 2005 and 2011 were compared to elucidate what types of land cover increased and what types of land cover decreased between 2005 and 2011. The comparison revealed that main changes in land cover were degradation of hill forest (H), plain forest (P) and woodland (W) and conversion of P into perennial plantation (Qa) and subsistence agriculture field (O) (Table 6). These land cover changes were put in a model to estimate land cover in 2026. The following were as the model parameters: elevation (SRTM, resolution of 30 m), slope, distance from the sea, distance from rivers, distance from forest edge, distance from forest/perennial plantation, distance from subsistence agriculture field, distance from degraded forest (as of 2005), population density (Kernel analysis), boundaries of reserves, wetland, active concession areas (as of 2005) and forest types.

Table 6 Five major land cover changes between 2005 and 2011 in West New Britain Province

Rank	Land cover in year 2005	Land cover in year 2011	Area (ha)
1	H	H (Degraded)	142,000
2	P	P (Degraded)	41,000
3	W	W (Degraded)	4,900
4	P (Degraded)	Qa	7,000
5	P (Degraded)	O	4,800

The accuracy of the model was estimated at 82.31%. Because this figure is larger than the threshold for sufficient accuracy of 80%, this model is considered a valid model (Table 7). The forest types are the parameters that have the largest influence on the accuracy of the model, followed by, in descending order, the following: distance from forest/perennial plantation, distance from subsistence agriculture field, distance from forest edge, active concession areas and distance from road.

Table 7 Influence that each parameter has on the accuracy of the model

Model	Accuracy (%)	Skill measure	Influence order
With all variables	82.31	0.801	N/A
Population density	82.29	0.8007	15
Active concession area as of 2005	80.04	0.7755	6
Distance from Non-forest land use	74.88	0.7174	5
Distance from rivers	81.82	0.7955	12
Distance from roads as of 2011	80.37	0.7792	7
Distance from sea	82.26	0.8005	13
Inundation area	81.71	0.7943	11
Slope	82.31	0.801	16 (least influential)
Altitude	82.29	0.8007	14
Distance from CU points	81.27	0.7893	10
Distance from protected area	80.51	0.7807	8
Distance from "plantation"	70.29	0.6657	3
Distance from "Agricultural land use"	72.02	0.6852	4
Distance from Degraded forest	49.87	0.436	2
Distance from logged-over area	80.81	0.7841	9
Forest type	48.37	0.4192	1 (most influential)

A forest cover map of 2026 was created in the simulation using this model (Figure 5). The map predicts increases in the areas of degraded H, degraded P and degraded W by 33.8%, 7.3% and 47.7%, respectively, and decreases in the areas of non-degraded H, non-degraded P and non-degraded W by 51.7%, 54.0% and 55.4%, respectively (Table 8). This map is considered representative of the land use pattern in 2026 if the current trend in deforestation and forest degradation (BAU) continues till 2026.

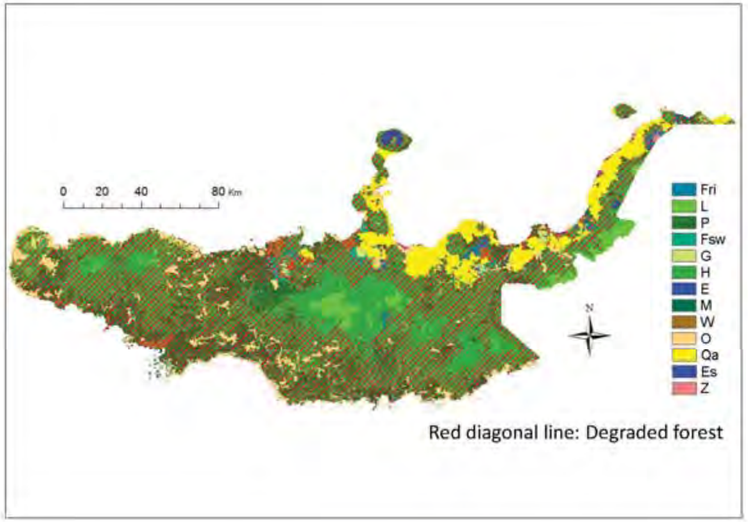


Figure 5 Simulated Forest cover map of 2026

Table 8 Changes in areas of each land cover

Change in area of Land cover other than degraded forest			
Land cover	Area in year 2011 (ha)	Aria in year 2026 (ha)	Change ratio
B	250	249	-0.40%
Fri	5000	5004	0.10%
Fsw	5587	5584	-0.10%
H	414485	200291	-51.70%
L	62089	62109	0.00%
M	4910	4905	-0.10%
P	103129	47430	-54.00%
Sc	112	113	0.50%
W	16732	7458	-55.40%
E+Es	14431	14433	0.00%
G	30721	30723	0.00%
O	122038	135033	10.60%
Qa	147766	160785	8.80%
U	651	652	0.20%
Z	1137	1135	-0.10%

Change in area of degraded forest			
Land cover	Area in year 2011 (ha)	Aria in year 2026 (ha)	Change ratio
B_deg	861	863	0.20%
Fri_deg	15366	15361	0.00%
Fsw_deg	18622	18606	-0.10%
H_deg	633555	847772	33.80%
L_deg	4224	4224	0.00%
M_deg	4643	4642	0.00%
P_deg	408523	438148	7.30%
Sc_deg	0	0	0.00%
W_deg	19471	28760	47.70%

This indicates that areas of non-degraded forest would decrease from about 612,000 ha in 2011 to 333,000 ha in 2026 and areas of degraded forest would increase from about 1,105,000 ha in 2011 to 1,358,000 ha in 2026. Pearson *et al.* (2014) suggests that carbon emission from a unit area caused by forest degradation reaches 12% of that of deforestation. About 165,000 ha of areas are simulated as experiencing forest degradation by logging between 2011 and 2026. Assuming average forest carbon stock of 200 Mg C ha^{-1}, carbon emission from the forest degradation by logging during this period is estimated as the following:

$165,000 \times 200 \times 0.12 = 3,960,000$ (Mg C)

Further, assuming 1 t CO_2-eq = 5 USD, the estimated value of carbon emitted due to forest degradation by logging activity between 2011 and 2026 in West New Britain Province is estimated as the following:

$396,000 \times (44/12) \times 5 = 72,600,000$ (USD)

添付資料 11

PNG-FRIMS の利用に係る資料

TRAINING MNUAL FOR GPS_GIS_LAN-MAP for Efficient Forest Monitoring

UTILIZATION OF UAV IN THE FOREST AREA

TRAINING MANUAL FOR GPS_GIS_LAN-MAP
for Efficient Forest Monitoring

May, 2019

Papua New Guinea Forest Authority (PNGFA)
Japan International Cooperation Agency (JICA)

Table of Contents

Why?

Topographic maps represent the Earth's features accurately and to scale on a two-dimensional surface. Topographic maps are an excellent planning tool and guide and, at the same time, help make outdoor adventures enjoyable and safe.

What is a topographic map?

A topographic map is a detailed and accurate illustration of man-made and natural features on the ground such as roads, contours, elevations, rivers, lakes and geographical names. The topographic map is a two-dimensional representation of the Earth's three-dimensional landscape. The most frequently used Papua New Guinea topographic map is at the scale of 1:100 000.

What information is on a topographic map?

Topographic maps identify numerous ground features, which can be grouped into the following categories **(LEGENDS/ KEYS)**:

- ***Relief***: mountains, valleys, slopes, depressions as defined by contours
- ***Hydrography***: lakes, rivers, streams, swamps, rapids, fall
- ***Vegetation:*** wooded areas
- ***Transportation:*** roads, trails, railways, bridges, airports/airfield, seaplane anchorages
- ***Culture:*** buildings, urban development, power transmission line, pipelines, towers
- ***Boundaries:*** international, provincial/territorial, administrative, recreational, geographical
- ***Toponymy:*** place names, water feature names, landform names, boundary names

What do the colours mean?

A variety of colours can be found on a map, each relating to different types of features.

- **Black** shows cultural features such as buildings, railways and power transmission lines. It is also used to show geographical names (toponymy), certain symbols, geographic coordinates and precise elevations.

- **Blue** represents water features, such as lakes, rivers, falls, rapids, swamps and marshes. The names of water bodies and water courses are also shown in blue, as are magnetic declination and UTM grid information.

- **Green** indicates vegetation such as wooded areas, grassland.

What are contour lines?

Contour lines connect a series of points of equal elevation and are used to illustrate relief on a map. They show the height of ground above mean sea level (MSL) either in meters or feet, and can be drawn at any desired interval. For example, numerous contour lines that are close to one another indicate hilly or mountainous terrain; when further apart they indicate a gentler slope; and when far apart they indicate flat terrain.

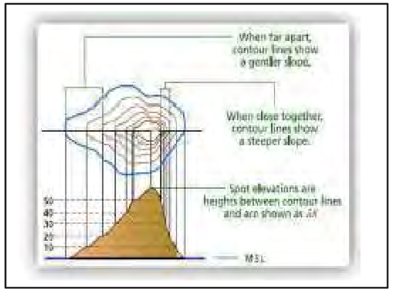


Figure 1: shows the contour lines for a gentle slope

What is the map scale?

- This is important because scale tells you about the comparative size of features and distances displayed on the map.
- A map represents a given area on the ground.
- A map scale refers to the relationship (or ratio) between distance on a map and the corresponding distance on the ground. Map scales can be shown using a scale bar.

  A standard Papua New Guinea topographic map is produced at 1:100 000, where 1 cm on the map represents 1 km on the ground.

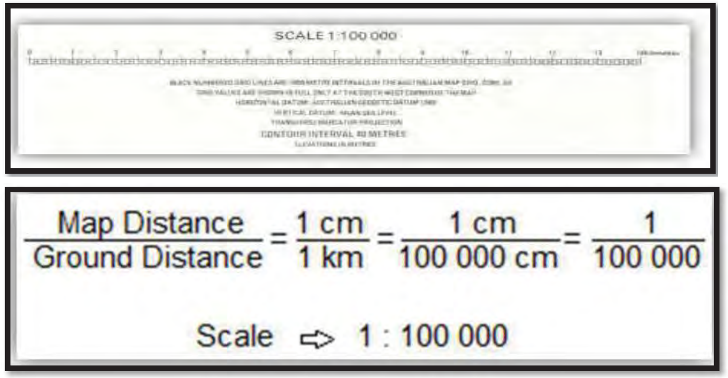


Figure 3: illustrating the map scales & Datum (AGD88) and scale map conversion.

What is a grid?

A grid is a regular pattern of parallel lines intersecting at right angles and forming squares; it is used to identify precise positions. To help you locate your position accurately on the surface of the Earth (or map sheet), topographic maps have two kinds of referencing systems:

- Universal Transverse Mercator (UTM) projection (easting/northing)
- Geographic: degrees and minutes (longitude/latitude)

The projection used for topographic maps is UTM.The UTM grid is a square grid system of lines depicted on maps and based on the transverse Mercator projection. It can be used to accurately locate the position of features on the map by distance or direction. To express your location in grid coordinates or geographic coordinates, read the following section.

How can I find or express a location on a map?

You can find or express a location on a map by using geographic coordinates (longitude, latitude) or by using UTM grid coordinates (easting, northing). Geographic coordinates are expressed in degrees, minutes and seconds and can be determined on the map by using the longitude and latitude graticules placed along the edges of the map. Latitude graticules are placed along the east and west edges of the map and longitude graticules are placed along the north and south edges of the map. The longitude and latitude of your location can be determined by projecting your location to the map edges and then by reading the corresponding latitude and longitude values' grid coordinates are expressed in meters and can be determined on the map by using the UTM grid lines. These grid lines are equally spaced horizontal and vertical lines superimposed over the entire map. The coordinate value for each grid line can be found along the edge of the map. Northing values can be read along the east or west edges of the map and easting values can be read along the north or south edges of the map. The easting and northing of your location can be determined by projecting your location to the nearest horizontal and vertical grid lines and then reading the corresponding easting and northing values.

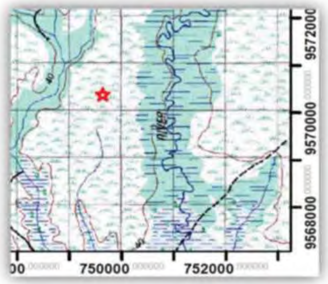
How do I find a grid reference?

Example:

To find the map reference of a feature located at 9568000 on a 1:100 000 scale topographic map,

- Determine the easting:
  - Read the grid line value left of the feature: 75.
  - Estimate tenths of a square to the right (eastward) to feature: 7.
  - Your easting is 757.
- Determine the northing:
  - Read the grid line value below the feature: 95.
  - Estimate tenths of a square up (northward) to the feature: 575.
  - Your northing is 9575.

The map reference for this feature is 9575000N, 757000E.



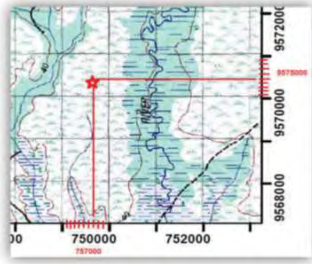


Figure 4: Using grids to locate your point of interest on a Topo Map.

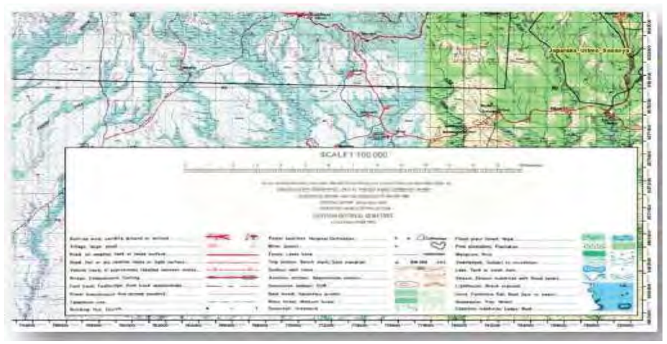
How can I determine where I am on a map using a GPS receiver?

- Go to Settings in your GPS device by touching the Setup  icon;

Touch Setup > Position Format

- Position Format >UTM
- Map Datum > WGS 84
- Map Spheroid > WGS 8

Note: Since the plot coordinates are in decimal degrees changes position format as above in order to get your Northing's and Easting's coordinates to locate the plot on the TOPO map.



Global Positioning System (GPS)

The Global Positioning System (GPS) is a location system based on a collection of about 24 satellites that orbits the earth at approximately 17, 703 km above sea level. The GPS unit helps you to describe a feature in the real world onto a flat sheet (map) by uploading the captured data to a GIS (Geographic Information System) system. There are different types of GPS receivers:

1. Not-self-contained receivers;

- A GPS without a screen which is aided by a computer- camera with GPS

2. Self-contained receivers;

- A computer is integrated in the GPS receivers- e.g. Handheld GPS, car GPS etc.…

The Garmin Oregon 650 has a High-sensitivity receiver which receives not only GPS signals but also GLONASS signals. GLONASS (Global Navigation Satellite System) is a satellite navigation system using Russian satellites. GPS and GLONASS satellite tracking enable to get more accurate positioning information even in closed forest.

The Oregon 650 like any other GPS units used worldwide is a touch screen navigator with an 8-megapixel digital camera. It comes preloaded with a worldwide built-in base map with shaded relief and has a physical Unit dimension of 6.1(W)*11.4(H)*3.3(D) cm with display resolution of 240(W)*400(H) pixels. Weighing about 209.8 grams with batteries, it has a lifespan of 16 hours of battery usage with high-speed USB interface and a high receiving sensitivity.

Basic Features:

Getting started with OREGON GPS

Battery Information

The Oregon (Garmin) device uses two AA batteries. Either Nickel metal hydride battery or Lithium battery can be used in place of rechargeable batteries.

Note: Alkaline batteries lose a significant amount of their capacity as the temperature decreases. Therefore, use lithium batteries when operating the device in below freezing conditions.
Standard alkaline batteries are not recommended for the Oregon 650 models when using camera feature.

Installing the batteries:

1. Turn the D-ring counter-clockwise, and pull up to remove the cover.

2. Insert the battery pack, observing polarity i.e. ***N***egative (-) and ***P***ositive (+) signs.

3. Replace the battery cover, and turn the D-ring clockwise.

Turning the GPS On and Off

Switching On and Off the Garmin GPS

1. To turn on the GPS, press and hold the Power Key located on the top right-hand side of the device till the Garmin logo appears.
2. To switch off, press and hold the Power Key till the device shuts down.

Setting up the Oregon

Basis steps:

1. Switch on the GPS

Note: After the Unit is switched on you view the Main Menu window which is divided into a number of separate pages having different Applications (functions) e.g. Setup, Maps, Compass, etc. As shown in the Figure below:

Figure 5: main menu window showing applications.

*You can view the other pages by swiping your finger across the screen to pan or scroll the screen

2. In the Main Window touch the Setup icon 

3. System Setup

Touch Setup > System
- Satellite System> GPS
- WAAS/EGNOS>On (Wide Area Argumentative System)
- Text Language > English
- Interface > Garmin Serial
- Battery Type > Alkaline or Rechargeable
- Tones > On

4. Changing Time Settings

Touch Setup > Time
- Time Format > 24 Hours
- Time Zone > Automatic

5. Tracks Setup

On the Main Menu, touch Setup > Tracks
- Record Method > Time
- Interval > 00:00:30
- Auto Pause > Off
- Auto Start > On

- Output Format > Tracks (GPX)
- Advance Setup
  - Auto Archive > When Full
  - Trip Recording > When Tracking
  - Recorded Data Reset > Track and Trip

6. Changing Measurement Units

Touch Setup > Units
- Distance/ Speed > Metric
- Elevation > Meters
- Depth > Meters
- Temperature > Celsius
- Pressure > Millibars
- Vertical Speed > Meters (m/sec)

7. Altimeter Setup

Touch Setup > Altimeter
- Auto Calibration > At Power On
- Barometer Mode > Variable Elevation
- Pressure Trending > Save When Power On
- Plot Type > Elevation/Time
- Altimeter Calibration: GPS can automatically calibrate the Altimeter

8. Position Format

Touch Setup > Position Format
- Position Format >hddd° mm' ss.s"
- Map Datum > WGS 84
- Map Spheroid > WGS 84

9. Changing the Camera Settings

Touch Setup > Camera
- Photo Resolution > Select either options (8MP, 5MP, 2MP)
- Save Photos To > Select the storage location (Internal Storage/Data Card, if present)

10. Modifying the Compass

Touch Setup > Heading
- Display > Direction Letters (N, S, E, W)
- North Reference > True (sets true north as the Heading reference)
- Go to Line/ Pointer > Bearing (Large)- *to show the Bearing Pointer, which indicates the direction to your destination*
- Compass > Auto
- Compass Calibration > Start and follow the on-screen directions

(Note: it is recommended that the calibration of the electronic compass must be done outdoors).

Data Capturing Methods

Note: *All GPS units are different, hence use different terms for the same FUNCTION. For instance, the Mobile Mapper GPS uses Point Feature to capture Point Data and Line Feature to capture Line Data. Whereas for the Garmin GPS, it uses* ***Waypoint*** *which refers to* ***Point Data*** *and* ***Track*** *as* ***Line Data****.*

Capturing Waypoints/ Point Features

- In the **Main Menu** Window select the **Mark Waypoint** icon to capture a Point feature
- Once you touch the Mark Waypoint Function the screen will read "Waypoint Marked as waypoint 001??" and below it you have two options.

A) **Cancel** > to cancel without saving and;
B) **Save** > to save instantly without editing. With this option selected you are shown the different attributes:
1. Change Symbol
2. Change Name
3. Change Comment
4. Change Location
5. Change Elevation
6. Change Depth
7. Reposition Here
8. Change Photo
9. Move Waypoint
10. Delete Waypoint
11. View Map
12. Project Waypoint
13. After all edition, select the Save icon to store the Point feature

14. Select the Cancel key to get back to the Main Menu

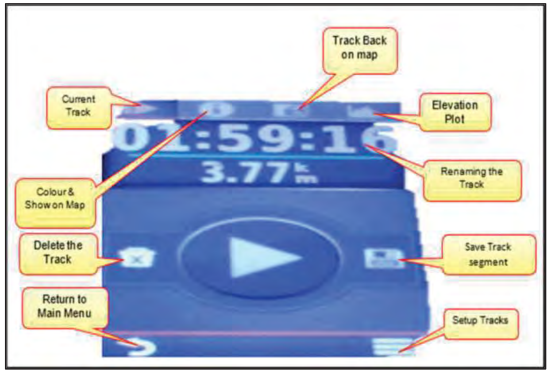
- Editing the **Waypoint** saved using the (A) **Save** option

– In the **Main Menu**>**Waypoint Manager**
– Select the saved **Waypoint** (e.g. 001) for editing
– **Waypoint** attributes for editing are shown and you may edit the attributes if necessary.
– The device automatically saves changes once you edit the Point features
– Select the arrow key to return to the Main Menu

Capturing a Line Feature/ Area Feature

Note: Because the Initial **Setup** for the Record Method for Tracks was Auto hence the track is automatically recorded once the GPS is switched on.

- In the **Main Menu** window select **Track**
- **From Manager Track Manager** select **Current Track**, In **Current Track** you have the options of:



- Save Track – renaming the Track
- Save Portion – saving a track segment
- View Map – Viewing the Track on the Map
- Elevation Plot –Viewing the Altitude of the captured Track over time
- Set Colour – Colouring the Track (Line Feature)
- Clear Current Track – Deleting the Track
- Once the editing is done select the save icon to store the line feature
- Select the arrow key to return to the Main Menu

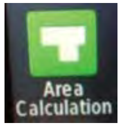
Using the Camera

- From the Main Menu window select the **Camera** icon
- Turn the device horizontally or vertically to change the orientation of the picture.
- If necessary, select symbol to turn on the flash or you can select Auto to use flash only when the camera detects a low light scene.
- To zoom in, spread two fingers & to zoom out, pinch two fingers together.

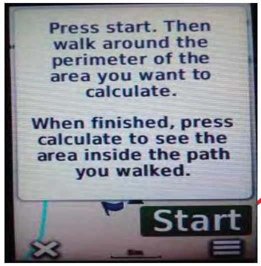
Area Calculation of Polygons

*Area of Interest = AOI

- From the Main Menu, select the "Area Calculation'' icon.

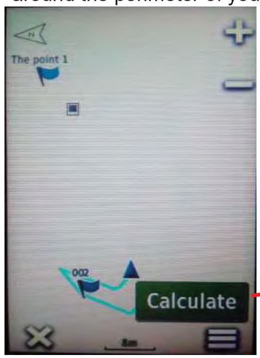


- A pop-up window appears.
- Follow the instruction on the pop-up window.

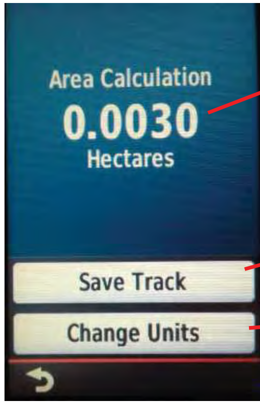


- Press the "Start" button on the screen before walking around the perimeter of your AOI.

- After pressing the "Start" button, the display will immediately show the map view of where the GPS is located. Use the map to keep track of your movements when walking around the perimeter of your AOI.

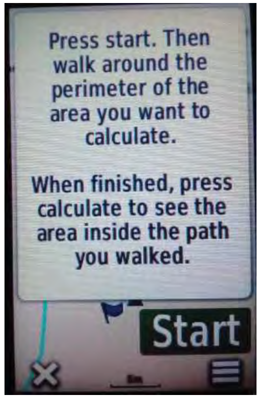


- When you have completed walking around the perimeter of Your AOI, (Be sure to end where you have started), press the "Calculate" button to calculate your area.



- The display will show the calculated area of your AOI. **Make sure to record your area separately as the area is not stored on the GPS when you EXIT the ''Area Calculation '' function.**
- The perimeter of your AOI can be saved as Track data by pressing the ''Save Track'' button.
- Measurement units for area calculation can also be saved by pressing the 'Change Units'' button and selecting your preferred unit of area measurement.

- Press the back button to go back to map display.



- Pop-up window appears again. Press the exit button to exit the''Area Calculation'' function.

Navigation Method

- Select "Where To?" icon
- Select Coordinates
- Enter coordinates and press ✓ to save
- Select Waypoint Manager>Coordinates
- Edit name (ex. Coordinates to Iboki Log pond) and press ✓ to save
- Press "View Mao" and Select Go, the map opens with your route marked with a magenta line
- Navigate to this location with map or compass

- When you arrive at the location GPS will give a beep sound and a message will pop up saying you are arriving at the location

Awareness/Precautions

1. Caring for the Oregon GPS

- *Cleaning the case*
  Use a dampened cloth with a mild detergent solution and wipe the unit's case dry. Avoid cleaners that may damage the plastic components.

- *Cleaning the screen*
  Use a soft, clean, lint-free cloth. Use water or eyeglass cleaner. Apply the liquid to the cloth, and gently wipe the screen with the cloth.

- *Cleaning the camera lens*
  Clean the lens only when necessary. Use a soft lens cloth. Apply lens cleaning fluid to the cloth and gently wipe the lens with the cloth.

2. Plan your field trips. Avoid GPS fieldwork during cloudy or wet conditions/ weather.

3. When capturing data under crowded tree or canopy forest cover make sure the GPS has enough signal strength to collect a point/line feature.

4. Battery

The unit takes 2 AA batteries-- alkaline, NiMH or lithium are options. Alkaline batteries are not recommended for Oregon 650
Battery Life: Up to 16 hours> Full charge for 6 hours

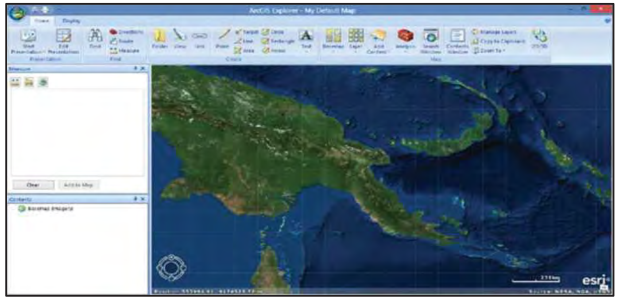
ArcGIS Explorer Desktop

About ArcGIS Explorer

ArcGIS Explorer lets you explore and present maps. Maps show you where things are, tell you what they are and help you understand why they are that way. ArcGIS Explorer lets you open a map, add other content to it, navigate around it, ask questions the map can answer, and present and share the map with others.

Start ArcGIS Explorer

Typically, you'll *start ArcGIS Explorer* by clicking its shortcut icon on your Desktop. This shortcut may have been added to your machine by your system administrator or by the act of installing the software. You can also access the application by clicking the *Windows Start* button and locating *ArcGIS Explorer* in the ArcGIS folder.

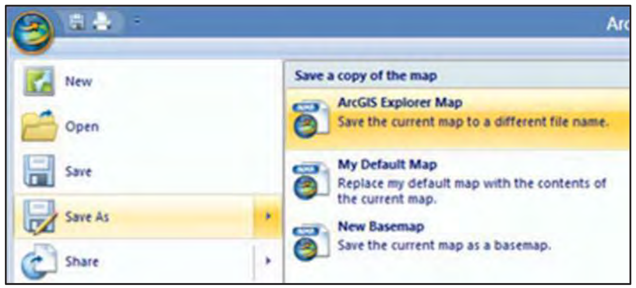


Save a Map

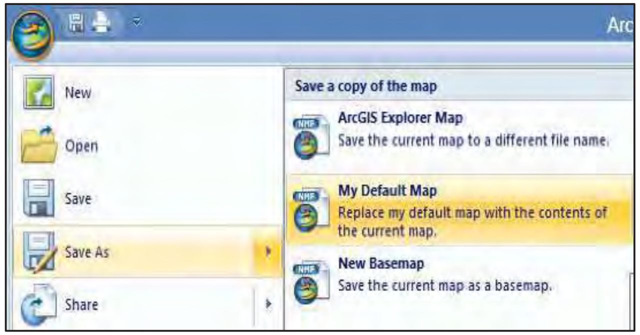
When you click *New* to create a new map, ArcGIS Explorer gives the map a generic title.
Once you've finished working with the map you can save it for later or share with others.

To save a map

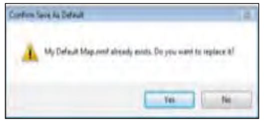
1. To save a map to a different file name
   Click the ArcGIS Button,point to the arrow to **Save As** and then click **ArcGIS Explorer Map:**



2. To replace My Default Map with the contents of the current map. Click the *ArcGIS Explorer Button*, point to the arrow next to **Save As** and then click **My Default Map**



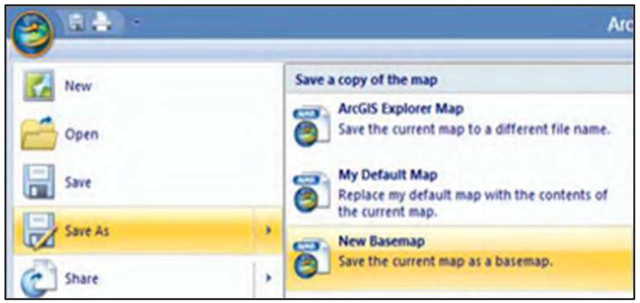
If you've already saved *My Default Map*, you'll be prompted to make certain you want to overwrite it:



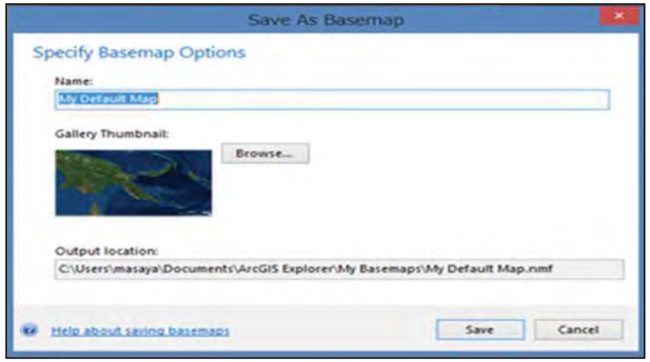
The next time you start ArcGIS Explorer, the new version of My Default Map will display on startup.

3. To save the current map as a baseman

Click the *ArcGIS Explorer* Button, point to the arrow next to *Save As* and then click ***New Baseman***:



Clicking *New Base map* displays the Save As *Basemap dialog* in which you can specify a name for the base map without the nmf extension and an image to associate with it.



The name will appear in the Gallery with an image, when you add the base map to an application configuration. Note that by default, Explorer generates a thumbnail image of the current map display as the basemap's Gallery image. If you've created an image for the Gallery yourself, click the Browse... button to locate it on your machine or local network. Note also that the Output location listed at the bottom of the dialog can't be changed.

Use the Navigation Control

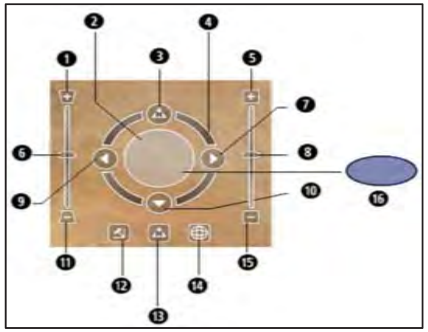
- **Move the map:** Click the left mouse button and drag the map in the direction you want to move it.
- **Zoom in on/out from the map:** Roll the mouse wheel

Set Display Mode to 2D or 3D

You can switch the map display from 2D to 3D Display mode and vice versa by clicking the **2D/3D button** in the Map group on the Home tab and then choosing the mode you prefer or that is most conducive to the map's content.

At the bottom left of the display by default, the Navigation Control provides various ways to move around the map and control your viewing position; in addition, it indicates the orientation of the map and the degree to which it has been tilted.

1. Click to tilt down
2. Shows degree of tilt
3. Click to move North*
4. Drag to rotate
5. Click to zoom in
6. Drag to tilt up or down
7. Click to move East*
8. Drag to zoom in or out
9. Click to move West*
10. Click to move South*
11. Click to tilt
12. Reset tilt to initial setting
13. Set North at the top of the map
14. Display the full extent of the map
15. Click to zoom out
16. Tilt disc changes color when the observer position is beneath the surface



* Note that if you click and hold the mouse down on any one of the cardinal direction buttons, you can move the mouse continuously in the direction indicated

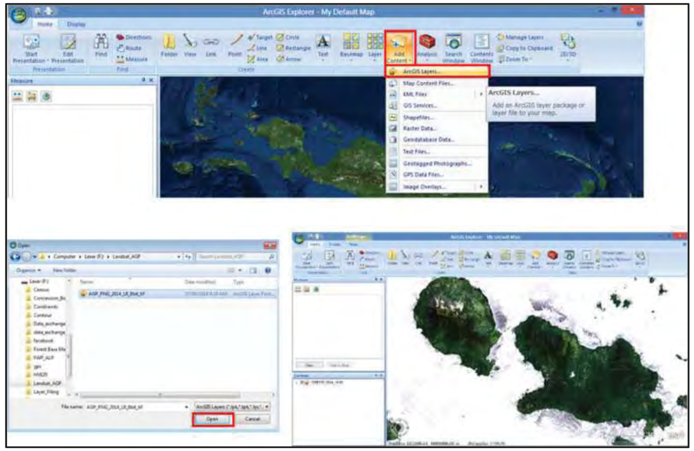
Add Content to a map

Work with ArcGIS Layers and Layer Packages

A layer package (.lpk file) is a single, convenient, ready-to-use file containing an ArcGIS Desktop map layer or group layer and the data it uses. Once you've added a layer package to ArcGIS Explorer you can work with its contents like any other layer. For example, if available you can click layer features to identify them, view a layer package's legend, hide and show its layers, etc.

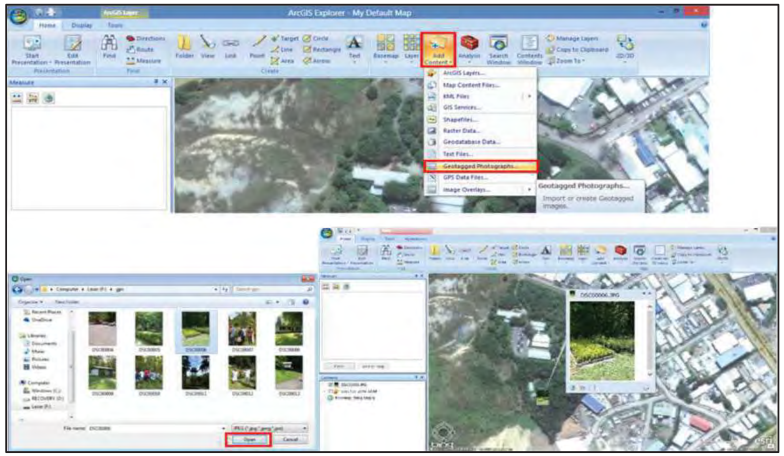
To add a layer or layer package to ArcGIS Explorer

On the Home tab, in the Map group, click Add Content and then click **ArcGIS Layers....** You'll see a dialog you can use to browse for ArcGIS Layers (*.lpk, *.lyr). Click Open to add the layer or layer package to the map.



Add Geotagged photographs to a map

On the Home tab, in the Map group, click Add Content and then click **Geotagged photographs....** You'll see a dialog you can use to browse for Geotagged photographs. Click Open to add the Geotagged photographs to the map.

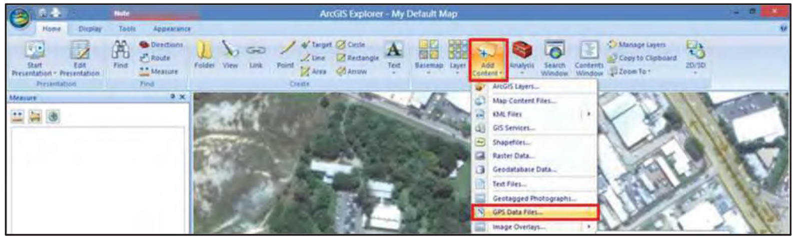


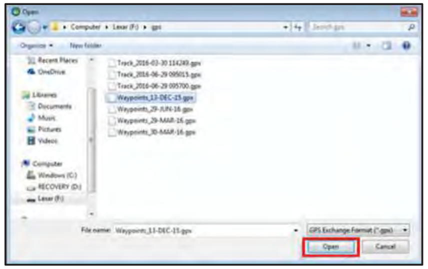
Add GPS Data Files

You can add data captured with a GPS device by converting the data to a file in GPS Exchange Format

To add GPS data files to the map

On the Home tab, in the Map group, click Add Content and then click **GPS Data Files....** You'll see a dialog you can use to browse for GPS Exchange Format Files (*.gpx):





Once you've selected the file to display, you'll see the Add GPS Data File dialog which will let you specify which data type(s) to add:

Waypoints:

These are points, that the GPS user recorded manually, often specifying a name, to mark added locations on the map

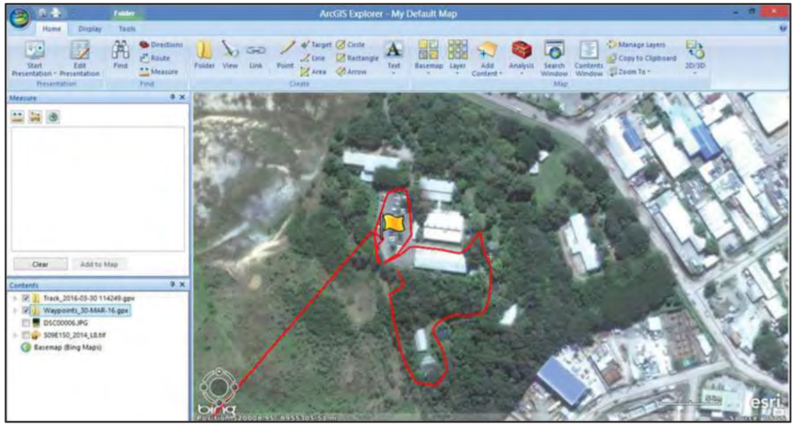
Tracks:

These are points, the GPS device recorded automatically at a periodic interval. Tracks are rendered as linear features.

Routes:

These are points, the GPS device used to navigate to a specified location. Routes are rendered as linear features.

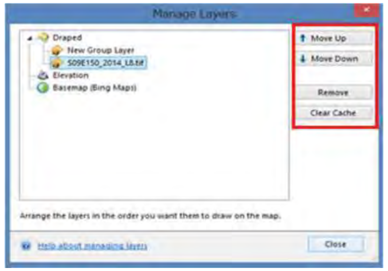
Clicking add adds the data types you've selected to the map



You can change the symbols assigned to the various data types you've chosen to display by right-clicking a waypoint, track, or route in the Contents window and in the context menu that appears, choose Properties. In the dialog presented, choose Symbol.

Manage Layers

You can control the drawing order and presence of layers in the map by using the Manage Layers dialog box.



To move the display position of a layer

Select the layer in the tree view and click either the **Move Up** or **Move Down buttons** to move the layer in the corresponding direction or you can also drag and drop the layer to the position you want.

To remove a layer from the current map

Select the layer and click the Remove button at the right of the dialog box.

To remove a layer's cache

Select the layer and click the Clear Cache button at the right of the dialog box. This has the effect of fetching the most recent data of the service related to the layer.

Control Layer Appearance

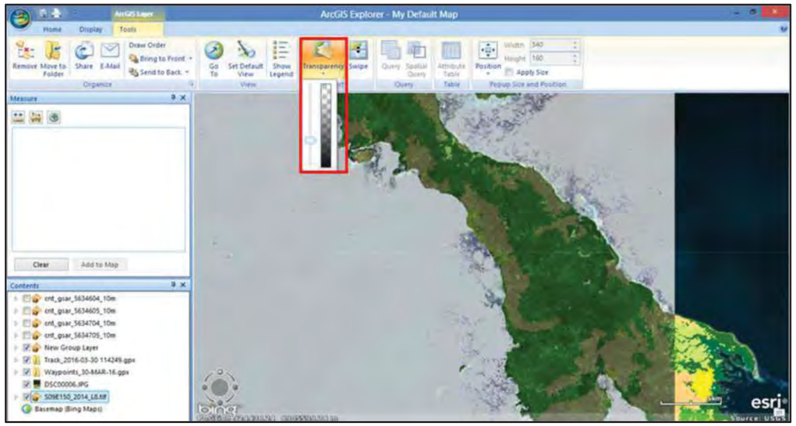
You can apply effects to the map to control the appearance of layers. Select the layer in the Contents window and you'll see that the Tools tab has the following functionality available in its Effects group to change the appearance of layers:

Transparency

Transparency can be used for any symbolization type, but it is especially useful for drawing raster layers with other layers on your map. This allows you to see the raster layer while still viewing underlying layers.

To adjust the transparency of a layer;

1. In the Contents window, select the layer whose transparency you want to adjust.
2. Click the Transparency button on the Tools tab.
   A slider bar appears which you can move to adjust the transparency of the layer and, depending on how you've set the Layers options, layers above it.
3. Move the slider bar to adjust the transparency; as you move the slider handle upward, the layer becomes more transparent.

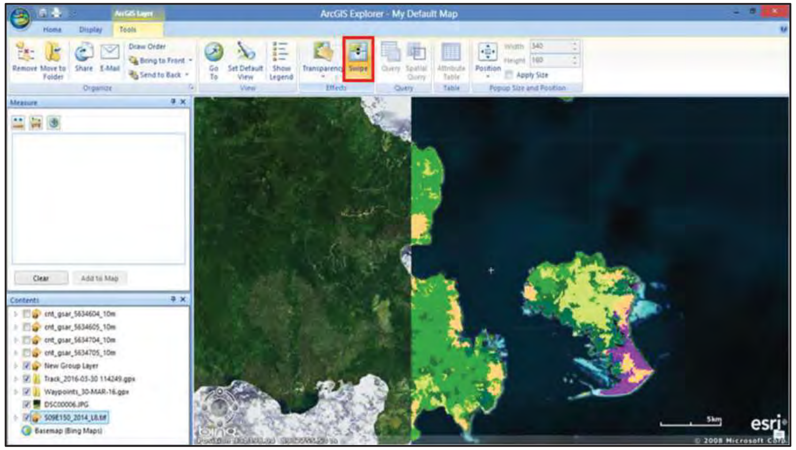


Swipe

Use *Swipe* to reveal layers beneath the layer you chose to swipe and, depending on how you've set the Layers options, the layers above it. This button makes it easy to quickly see what is underneath a particular layer without having to turn it off in the Contents window or reorder layers.

To reveal layers beneath the layer you've selected

Choose the layer or group layer you want to swipe from the Contents window, then move the cursor over the map. You'll notice that the cursor changes based on whether you are resting the mouse pointer on the top, bottom, left, or right of the map. This lets you choose the direction in which you want to swipe the layer. Hold down the left mouse button and drag in the direction indicated by the mouse pointer.



Tips

- With Swipe selected, holding down the Shift key and clicking the mouse will flicker the selected layer on and off manually. The selected layer is off as long as you hold down the mouse. Flicker is particularly useful for temporal change detection (especially of satellite images or air photographs taken at different times of the same location), data quality comparison, and other analysis where you want to see the difference between layers. Fast rates of flicker can be used to make differences between layers appear to jump out due to the optical effect of the eye being attracted to changes between rapidly alternating displays (an effect also exploited by the early experiments in cinematography).
- If you hold down the Ctrl key while swiping, you'll remain in Swipe mode. This is useful if you want to continue swiping, but in a different direction, for example up/down after swiping left/right.
- Holding down both Ctrl and Shift at the same time will allow you to flicker the display continuously.

Select symbols

When you add content to the map (i.e. create a note, add a shapefile, etc.), the application assigns a default symbol for you to display the data. You can change the symbol used by clicking the item's Appearance tab.

The Appearance tab includes a Symbol group that contains various controls for selecting symbols to draw the GIS data with and controls for modifying properties of the symbol. Notice the different galleries for points, line, and areas (polygons):

The Symbol Gallery

The Symbol Gallery displays the list of symbols available for the type of GIS feature that you are symbolizing (i.e. point, line or polygon). You can scroll through the symbols or drop the gallery down to see more symbols. When you click a symbol, that symbol is assigned and the map updates to display it.

Changing the symbol properties

Once you choose a symbol, you use the other controls in the symbol to change some characteristics of how it's displayed. Note that the controls are specific to the geometry of the symbol; in other words, some controls only display when you've selected points or lines or polygons.

Transparency: clicking the transparency control displays a slider control that allows you to change how transparent the symbol displaying the data is. The more transparent, the more you can see the map content that is drawn under the symbolized data. The transparency control is available for all geometry types in feature layers: point, lines, and polygons:

Size: when you add points to a map, a symbol size is assigned for you based on the scale ranges the data is displayed in, what the data represents (that is, a map note versus a GIS feature), etc. In ArcGIS Explorer this point size is represented in terms of pixels or a point to map units' conversion. In most cases, you just want to adjust the symbol to be a little larger or smaller. Two controls, one to increase, the other to decrease the point size, are available in the Appearance tab's Symbol group:

A similar pair of controls is available for changing the width of lines or the outlines of fill symbols:

Line Color: you can change the color of a line symbol or the outline of a polygon symbol by clicking the Line Color control to display a selection of standard palette of colors and variations on those colors that you can pick from.

Measure area and distance and determine elevation

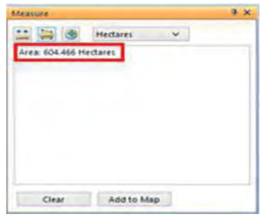
Measure provides tools that allow you to determine the area of a surface, the length of a vector, the aggregate length of multi segment lines, and the location and elevation of a point. Before or after performing each measurement, you can set or change length units or area units, implicitly converting existing measurements. The task also provides a way to add the measurement as a note on the map.

To make a measurement

1. Choose the tool you want to use.

2. Move the mouse pointer over the map and click as appropriate; for example, a single click with the Point location tool will provide the location and elevation of that point; click once for every vertex of a multi segment line or polygon, and double-click to signal the end of all line types or a polygon.

The measurement will appear in the area below the tools.

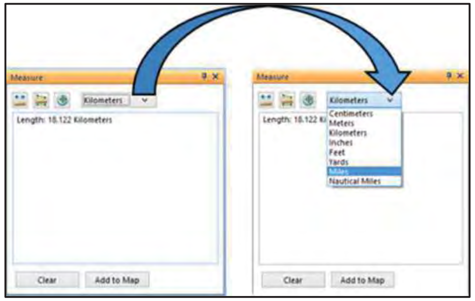


To move the map while measuring

- You may find that what you want to measure is not completely contained within the current extent of the map; for example, a street or parcel may extend beyond what is visible. In order to move the map as you're measuring, while still maintaining the cumulative total distance or area, you can simply hold down the left mouse button and pan the map in the direction you want. Once you're at the location you want to be, resume measuring by clicking the map with the left mouse button.

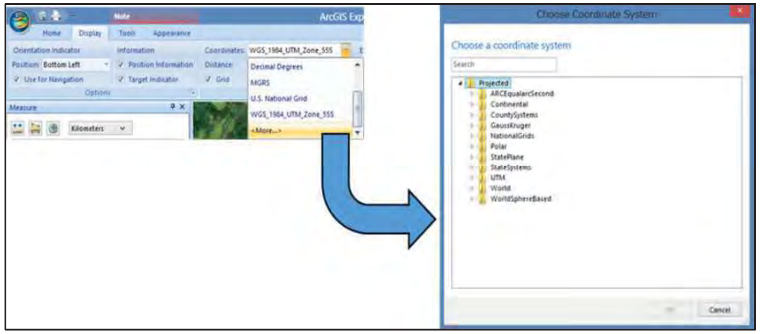
To change units

- Either before or after making the measurement, set the appropriate units. If you change units after making the measurement, the current units will convert in the report area to the newly selected units.



To change coordinate units

• When you use Measure to find information about a point location, such as its coordinates and elevation, the units that it reports in are the current coordinate units of the map. You can set these units in the Units group on the Display tab.



To store a measurement as a note

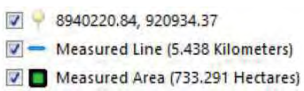
1.Choose a tool and perform a measurement.

2.Press the Add to Map button. The measurement will be added and selected, as the first item at the top of the Contents window with one of the following forms of default names, as appropriate to the measurement type:

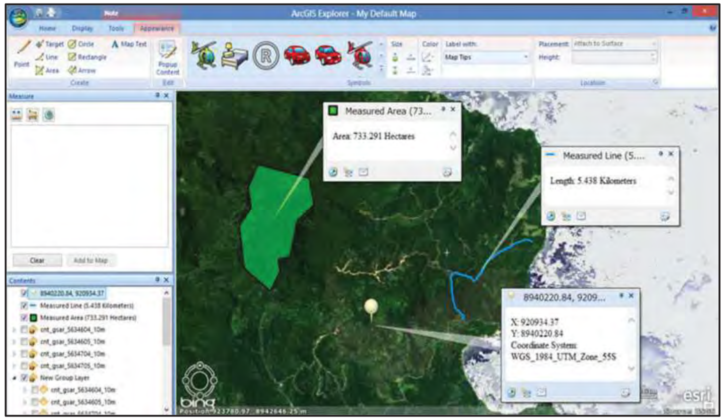
The coordinates of the measured point.

Measured Line (line and units).

Measured Area (area and units).



To change the title of a note, select Rename in the note's context menu or click the note twice in succession.



Copy to Clipboard

You may want to incorporate the current view that's displayed to use in other applications by capturing an image of the map. To do this, establish the view that you want, then on the Home tab in the Map group, click Copy to Clipboard:

As an alternative, you can use the keyboard shortcut Ctrl+Shift+C to copy the current view to the Clipboard.

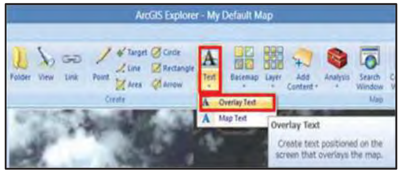
The underlying data for each layer may require a copyright notification, depending on the distribution agreement for the data. You may want to include this information in a screen capture. While this copyright information for each layer appears cyclically in the Status Bar during the session, Copy View to Clipboard gathers all layer copyrights and displays them all on the image captured:

Add Text

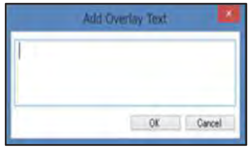
Add Overlay Text

Overlay text is designed for use in presentations. Similar to an image overlay it allows you to put textual information on the screen.

Click the overlay text button

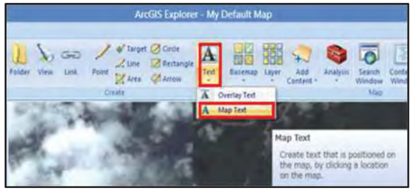


Type in the text that you want to display on the screen.

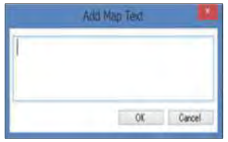


Add Map Text

Map text is designed for use in presentations. Similar to a note it allows you to put textual information on the map.



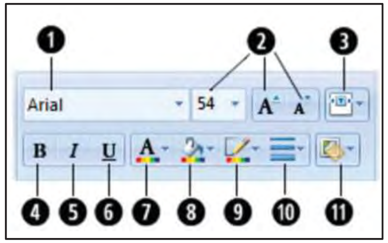
And click a geographic location on the map to position the text, then type in the text you want to display.



Change the text format

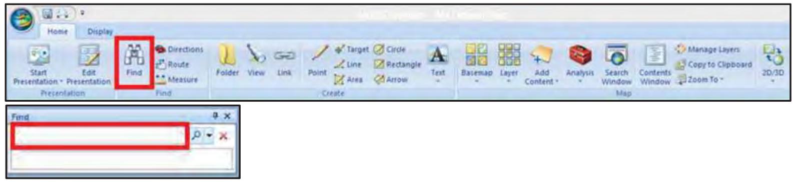
You can control the appearance of the text by setting an initial style from the Quick Styles gallery. You can change these properties for text.

1. Set the font face
2. Set the font size
3. Set its position on the slide
4. Make its text bold
5. Italicize its text
6. Underline its text
7. Set its font color
8. Set its background color
9. Set its outline color
10. Set the width of its outline
11. Set the transparency of its background



To find a location by specifying coordinates

Press “Find” button. If you enter a latitude and longitude in the text box and press Enter or click the Find button, ArcGIS Explorer creates a temporary item and moves the map so that the location you specified is marked with a temporary place marker at the centre of the display.



Latitude and longitude

- When you enter coordinates on the dialog box that you enter them in this order. The latitude must be entered first.
- Whether you use Decimal Degrees (DD), Degrees Minutes Seconds (DMS), or Degrees Decimal Minutes (DDM), coordinates can be entered by using a minus sign before the numeric value to signify the Western or Southern quadrants.
- Values in DMS coordinates can be separated with the ° ' " special characters (such as when you paste coordinates that you have copied from other dialog boxes or applications that use those characters) or spaces. A space will between the DMS coordinates will be interpreted as a change to a new unit type, e.g. Degrees <followed by a space> Minutes <followed by a space> Seconds.

- Whether you use DD, DMS, or DDM on the dialog box, coordinates can be entered in any of the latitude/longitude formats, and they will be automatically converted to match your chosen format.
- When you are using DMS, coordinates you input are always converted to use E, W, N, S to signify quadrants and are given the ° ' " special characters.

The following are validly formatted latitude/longitude coordinates:

Latitude	Longitude
45	-45
45°30'30"N	45°30'30"W
45 30 30 N	45 30 30 W
45.50833	-45.50833

Make monitoring reports

The following instruction is used for making monitoring reports which will accompany Tick sheets for each stage of logging operational plan, log book, and field assessment sheet.

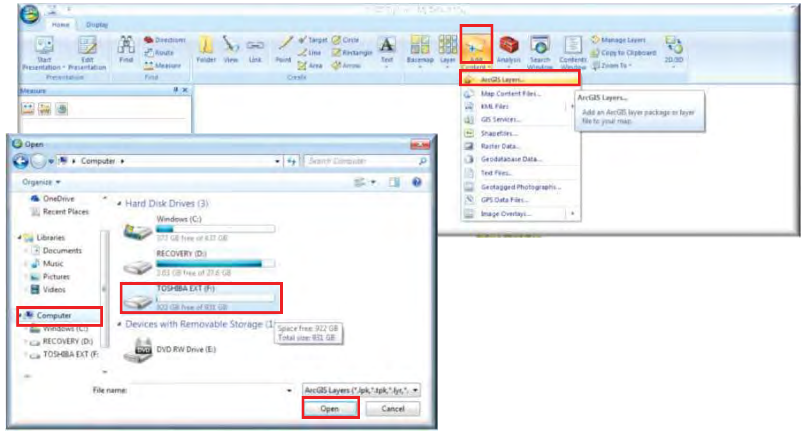
Officers can also use this document as guide to prepare other types of reports like quarterly reports, compliance report, annual report, project completion report and project activity reports. This is a first draft which we will be using for the training and is subject to further review in future.

Add Content to a map

Initially once you launch ArcGIS Explorer it will open without map contents unless you have saved a map document in your previous session, this map will display on start-up. In this section you will be tutored the steps of adding content to a map including Concession Areas, Landsat-8 Image, FWP_ALP_Coupes, Forest_Basemap and etc. Page 5 of the User Manual provides the basics on how you can add layers to your map.

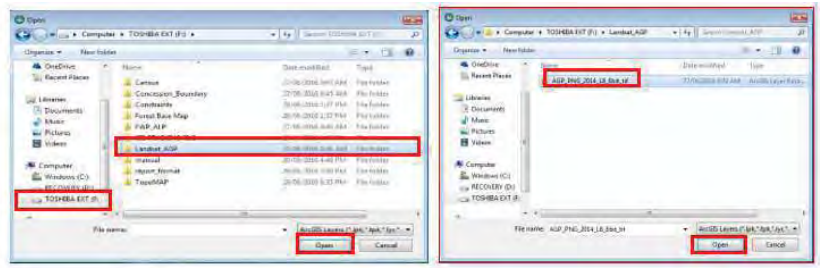
Steps for Adding ArcGIS layers or layer packages to ArcGIS Explorer

1. Click Add Content button on the Home Tab and browse to ArcGIS layers.
2. Click ArcGIS layers



3. Click Computer and select external drive. You will see that F:\ is highlighted.
4. Click Open

**All data for West New Britain is stored in the external drive.

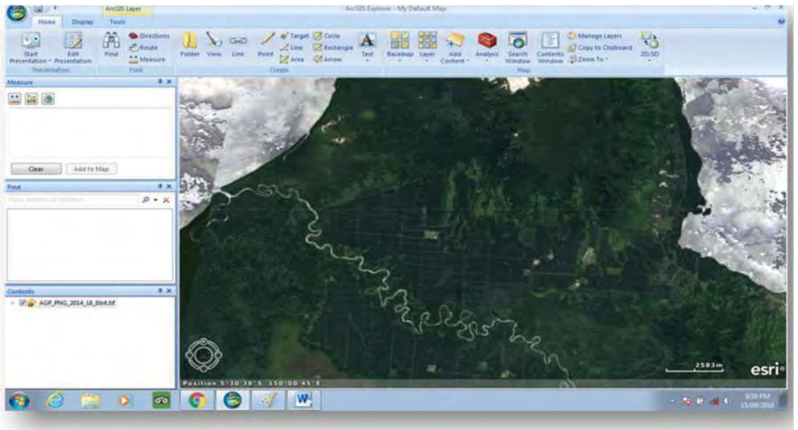


In the Open dialog box top left, a list of folders containing the data is displayed.

5. Browse to Landsat_AGP folder and click Open. A second dialog box appears as shown above on the right.

6. Select AGP_PNG_2014_LB_8bit_tif and click Open.

A Landsat image of 2014 is displayed on the map window.



7. Repeat Step 1-6 above to open other relevant data you wish to include in your map.

Add GPS Data Files

ArcGIS Explorer makes it easier for you to add data captured with a GPS device by converting the data to files in GPS Exchange Format. You can use data recorded while you are monitoring for your report. The following are examples of the type of data you may have checked or recorded in your monitoring

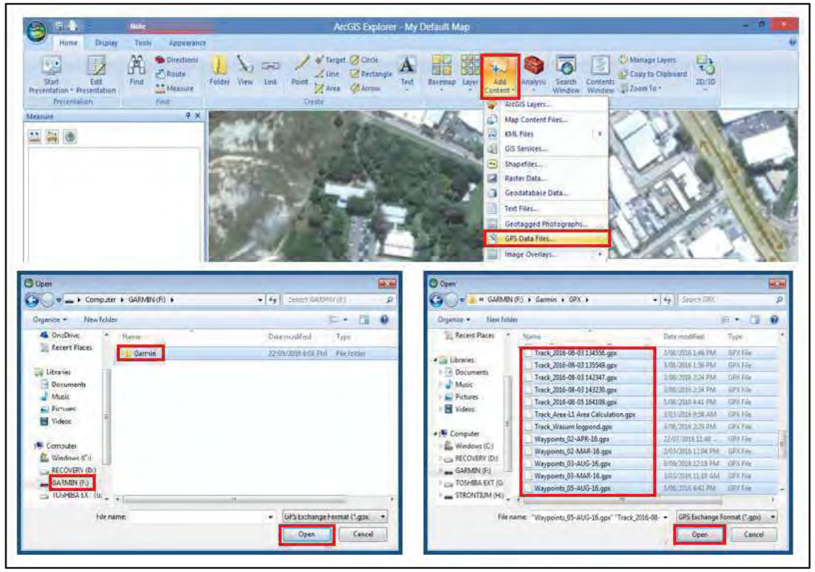
Type of Plan	Check Items during monitoring
Log Pond	*Located as per plan*
Basecamp	*Located as per plan*
ALP	*Inventory Strip lines (1 %/10 %)(established)*
	Permanent roads to be constructed are in a logical and practical
	Check that buffer zones are marked out in the field during set-up
Set-up	*Roads are constructed to approve standards*
	Roads are properly compacted
	Roads follow approved surveyed road lines
	Road corridors are less than 40 m wide
	Streams are free of soil
	Roads are properly drained
	Bridges are properly constructed
	Culverts are properly constructed
	Roads are properly drained at water course crossings
	Stumps heights less than 30 cm above fluting
	Water crossings located as per plan
	Log landings located and marked in the field
	Log landing size
	Log clusters are not permitted
	Forest roads are decommissioned after logging
	Remove logging debris from streams
	Construct water bars on skid tracks and decommissioned roads
	Log landings are ripped at right angle to the drainage direction
	Rubbish are removed from log landings and roads
	Clan boundaries
	Set-up/Coupe boundaries
	Concession boundary
	Wastes are managed properly at log ponds
	Reforestation area
	Agriculture blocks
	Damaged cultural site/ garden site
	Community Infrastructure

Table 1: shows different data files use in monitoring.

To add the data files to your map, the steps below will help you to add your files where ArcGIS Explorer will automatically convert the files to a format where it will be displayed on the map window.

Step of Adding GPS Data Files to a Map

1. Connect your GPS device to the computer
2. On the Home tab, click Add Content button > then click GPS Data Files.



3. Select Garmin (G:) > Garmin folder > GPX folder. A dialog box appears showing a list of GPS Data files (Waypoints, Tracks etc.) with file extension (.gpx).
4. Select the data files you want to add and then click Open.

Waypoints:

These are points that the GPS user recorded manually, often specifying a name, to mark added locations on the map

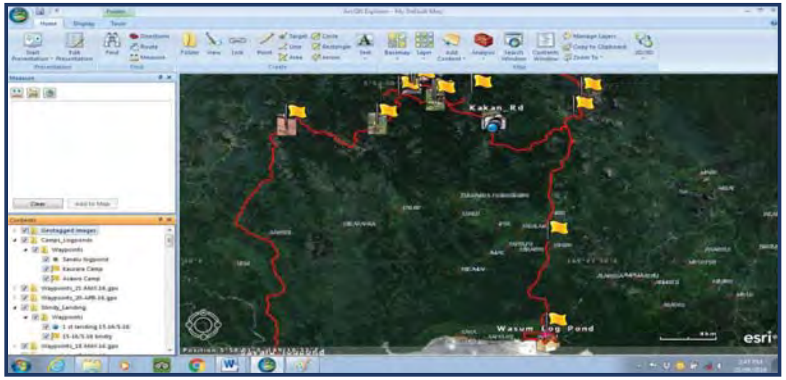
Tracks:

These are points the GPS device recorded automatically at a periodic interval. Tracks are rendered as linear features.

Routes:

These are points the GPS device used to navigate to a specified location. Routes are rendered as linear features.

You will see that all the data you have added are displayed with different default symbols as shown in the image below.



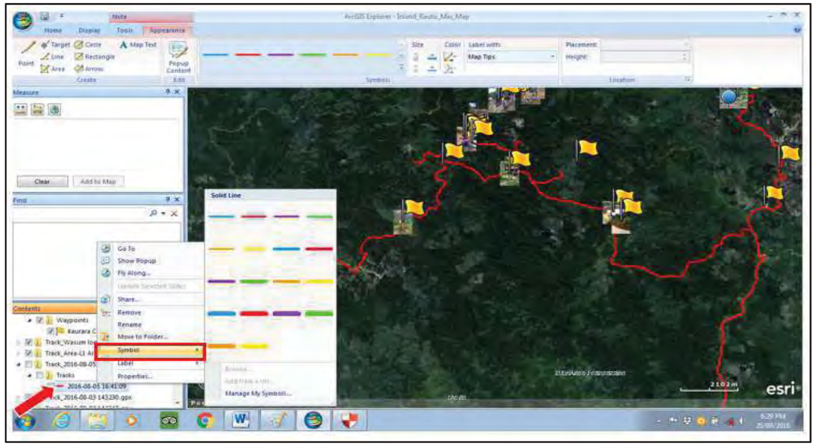
The data portrayed above is an example of a physical field layout of the current road network and locations of base camp, set-up boundaries, clan boundaries, and log pond in Inland Rauto Miu Project, Rottock Bay FMA.

Changing the Symbol of features

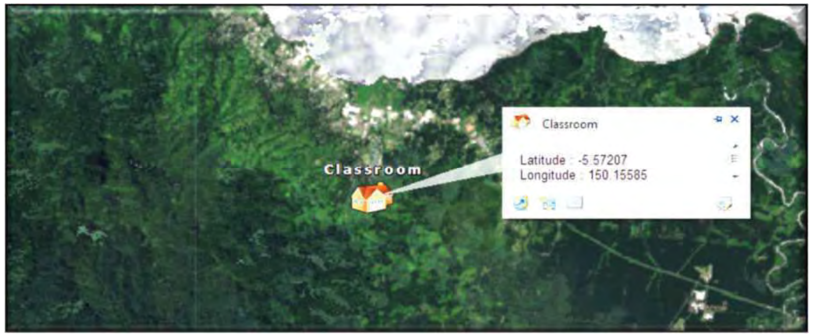
When you add content to the map (i.e. create a note, add a shapefile and etc.), the application assigns a default symbol for you to display the data. You can change the symbol used by clicking the item's Appearance tab and select a symbol you want to use from the different galleries for points, line, and areas (polygons).

Or you can also change the symbols assigned to the various data types you have chosen to display. For instance, if you want to change a symbol for a logging road;

1. Right-click Tracks (ex. Logging road) in the Contents window > Select Symbol
2. Select a symbol for road in the symbol gallery presented. An ideal symbol to represent a constructed road would be a red solid line as shown in the captured image below.
3. Repeat Step 1 if you want to change the symbol for other data types you have added.



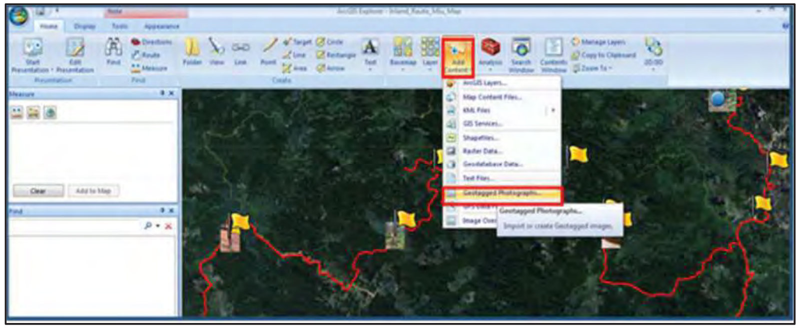
The image below shows the location of a classroom project being built during an ALP year to comply with permit obligation. The symbol used is a house selected from the symbol gallery to represent the building and location in which the building is located.



Steps of Adding Geotagged photographs to a map

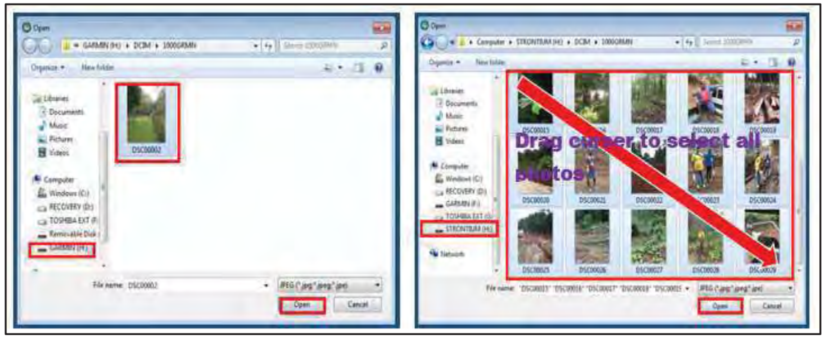
Geotagged photographs are mostly photos you have collected in the field using your GPS device during routine monitoring. To display or add photos to your map, the steps below will help you perform the task.

1. On the Home Tab; Click Add Content > Select Geotagged Photographs on the drop-down list.



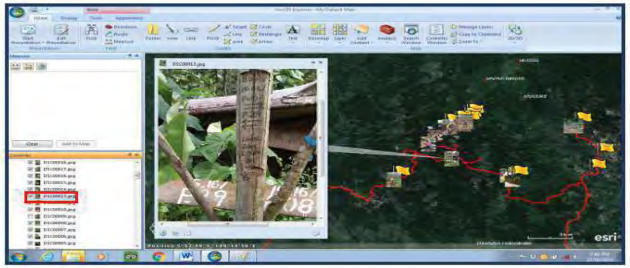
An Open dialog box appears giving you the option to browse to the location where the photographs are stored. Depending on where you chose to store your photos on the GPS device, browse to the storage location to open the photos.

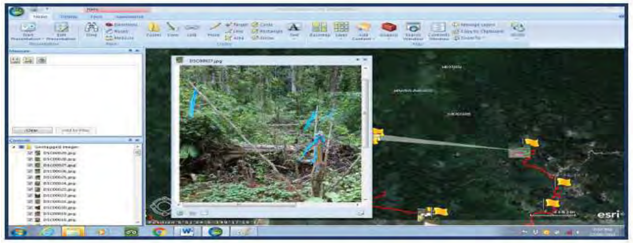
2. Select a folder where photos are saved in the GPS internal storage. On default setting, photos are stored in GARMIN (H:) > DCIM folder > 1000 GRMN folder. A list of Geotagged photographs is displayed which you can browse to select the photo of interest to add to your map.
3. If you set to save photos in a Data Card inserted to your device then, select STRONTIUM (H:) > DCIM folder > 1000 GRMN folder. Browse to select the Geotagged photographs you wish to add to your map.



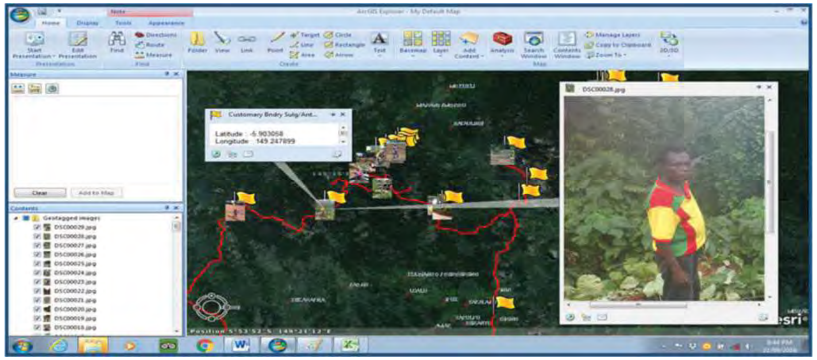
4. To select all photos, click the cursor on the top left corner of the first photo and drag the cursor across the first row of photos and then drag downward and release to select all photos.
5. Once you have selected all photos, click Open to add the photos.

The photographs are added to your map instantly and referenced to the locations where they were taken.

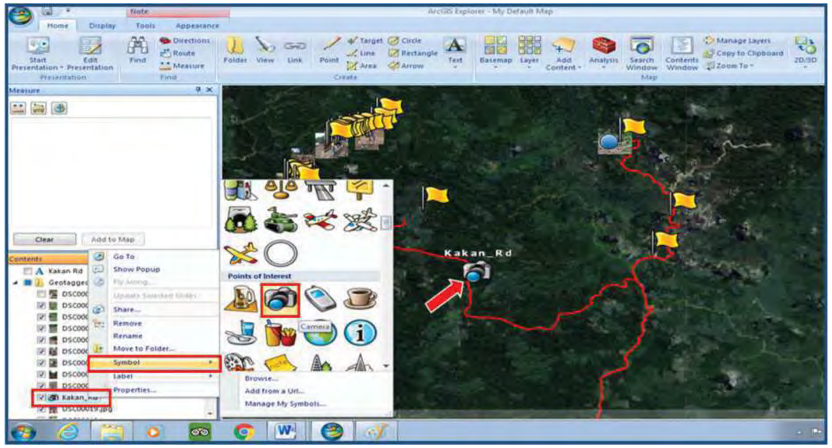




The image above shows the location and photo of a set-up boundary being established in the field and marked or tagged with blue ribbons in Inland Rauto Miu Project, Rottock Bay FMA.



The image above shows a landowner standing and pointing to where his customary land boundary is located in the field. Such information is vital for land mediation or dispute resolution over landownership.



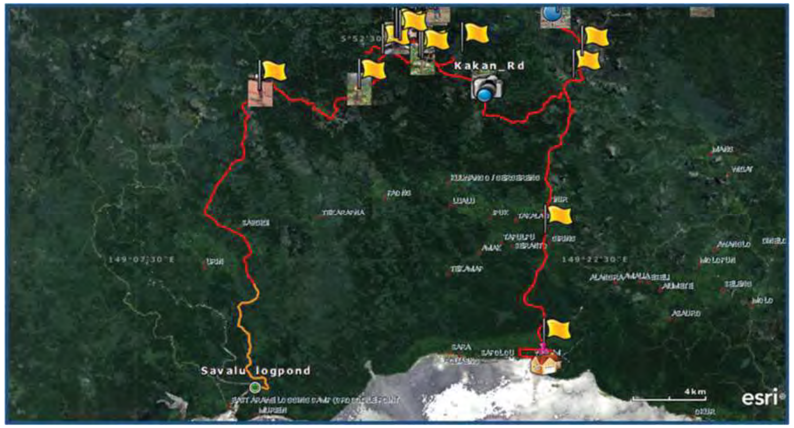
You can change the photo image to a symbol to use it showing the location where the feature was captured with the GPS.

1. Right-click a photo (ex. Kakan road) in the Contents window > Select Symbol
2. Select a symbol in the symbol gallery presented. An ideal symbol to use would be a camera icon as shown in the captured image above.

Copy Map View to Clipboard

You may want to incorporate the current view that is displayed to use in your report by capturing an image of the map. To do this, the steps below will help you perform the task.

1. Establish the view that you want. The image below is an example of a view showing the locations of features or activities captured with your GPS device during monitoring.

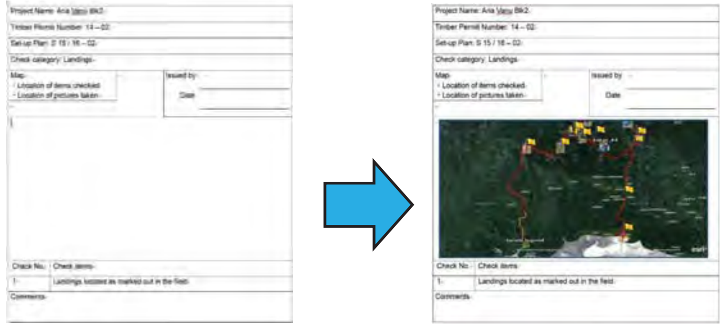


2. On the Home tab in the Map group, click Copy to Clipboard

3. As an alternative, use the keyboard shortcut Ctrl + Shift + C to copy the current view to the Clipboard.

You will use the Copy to Clipboard button to copy a map view and incorporate in your report. If you want to present the current view in your report, activate the word document of Report _Format.

4. Paste the photo to your report

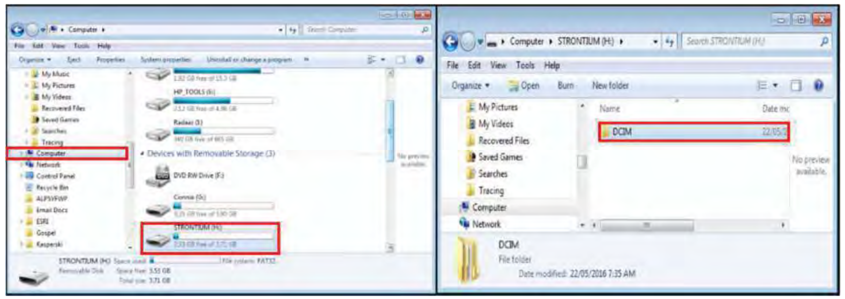


Copying GPS Photographs to Monitoring Reports

Photographs of features or activities captured in the field ascertains that those activities are actually being implemented or constructed. To retrieve this photo from your GPS device and paste them on your report is straight forward.

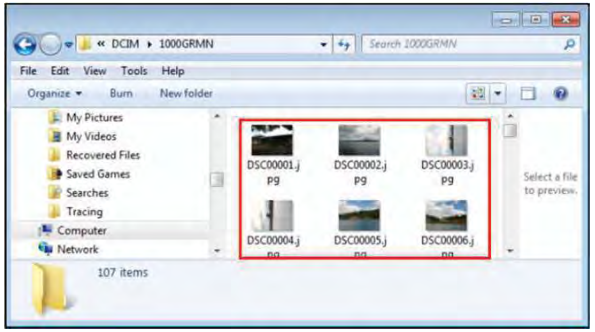
1. On the Desktop, double-click Computer and then double-click on STRONTIUM (H:) (STRONTUIM-brand name of Data Card inserted to your GPS)

2. Double-click on DCIM folder > 1000 GRMN folder.



Once you click the 1000 GRMN folder, a list of photographs is displayed as shown on screen capture below.

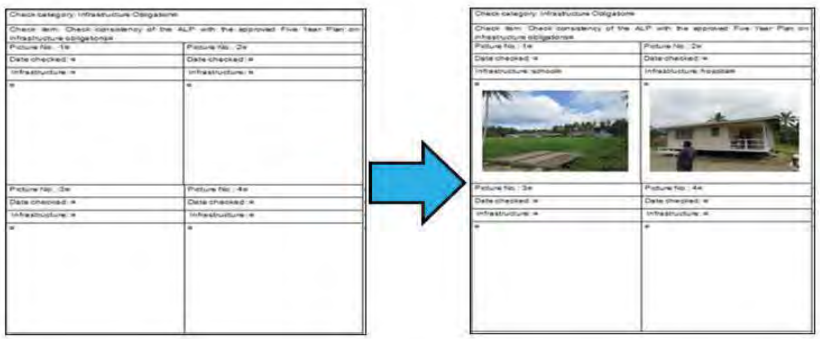
3. Browse to the photo of interest you want to add and highlight.



4. Right-click a photo of interest and then select copy or alternatively select the photo then press CTRL+C

5. Paste the photo to your report

You should know where to paste the photo in your report. If you captured a photo of an infrastructure obligation (ex. classroom), then you will paste it in the Infrastructure Obligations Category on the Report Form. You can do the same for other photos you want to include in your report.

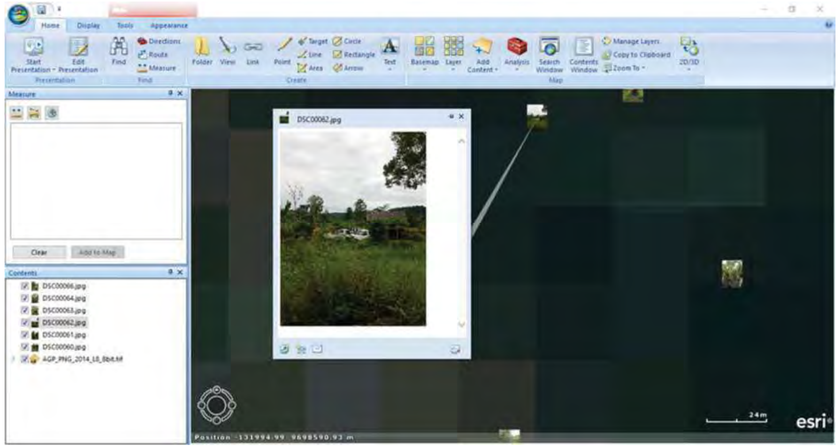


Alternative method for putting photos on a report

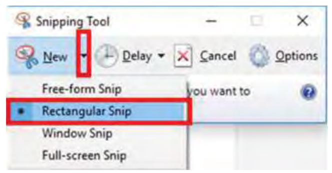
If you did not name the file properly, it is very difficult to find the photo which you want to put. Following is the easier method to put photos on a report.

Snipping tool

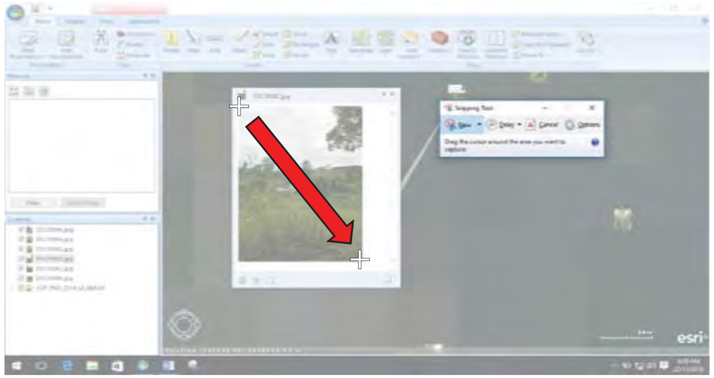
1. If you click the photos which you added on a map, the pop up of photos will display on a map. Then you start "Snipping tool" and snip the photos, you can easily put photos on a report.



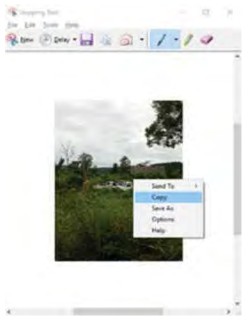
2. Start snipping tool and click "New button" and select "Rectangular Snip".



3. Click the top left corner of the photo and drag your cursor to bottom right corner.



4. The photo you snipped will be automatically displayed in "Snipping Tool Window", then right-click the photo and copy it



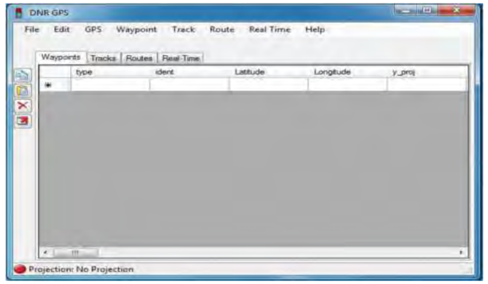
5. Paste the photo to your report

GIS Training in ArcGIS

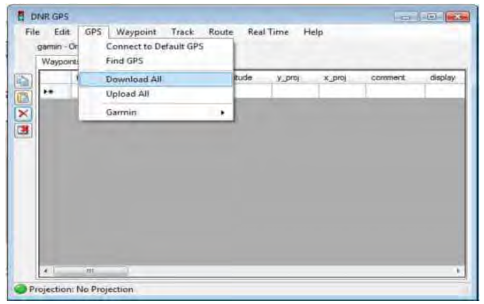
Steps in Uploading your GPS footprints and photographs as a layer on ArcGIS

Part 1: Uploading of GPS footprints in ArcGIS

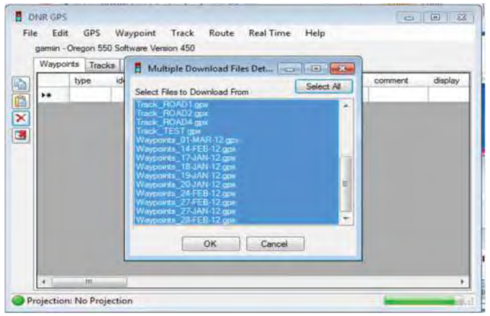
1. Connect your GPS device and **'Double click'** on the **DNRGPS** icon  to open DNRGPS.



2. In DNRGPS menu click on the **GPS**, then scroll down to the option '**Find GPS'** to detect the device. Once the GPS is connected you then go back to the **GPS** menu and select the '**Download All'** option to transfer all your field data from the GPS into the computer as shown below.

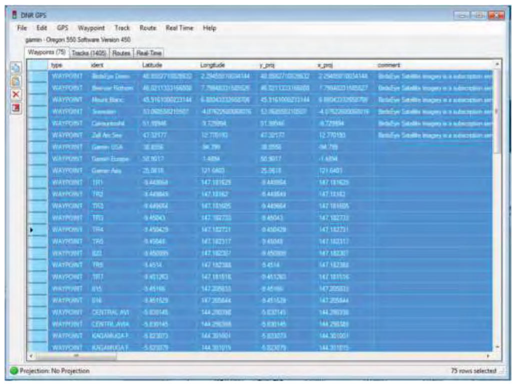


3. **Select All** and click **Ok**



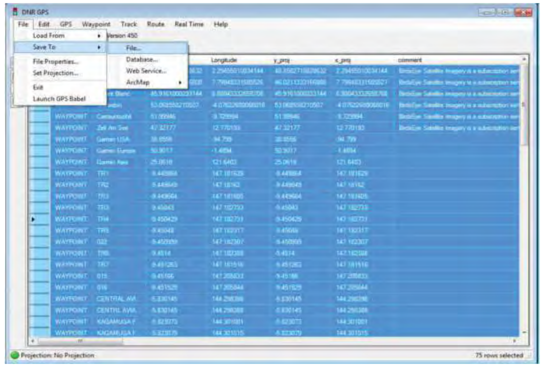
4. A Dialog box appears showing that the download is complete. Click **Ok**.

5.After the download is complete you then select all to save to your folder of interest.

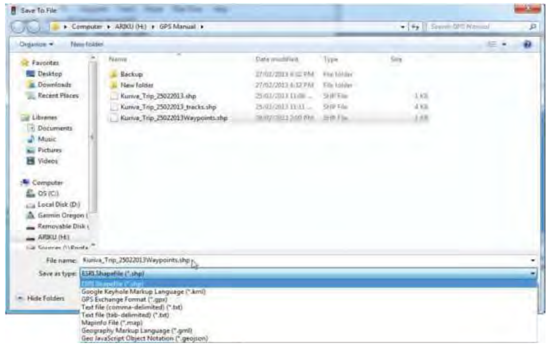


6.**Saving to your designated Folder**.

- To save go to File > Save To > and select File



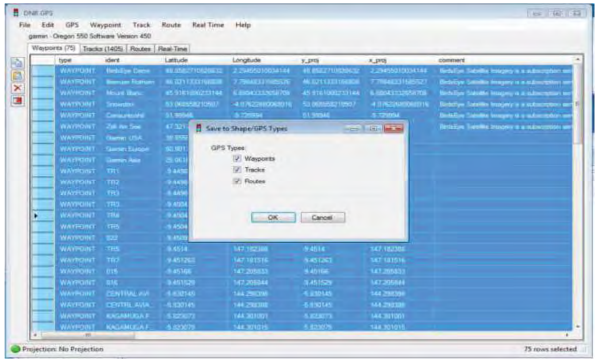
6. In the **File name**: give a name to data you're trying to save and in the **Save as type drop down bar**: select the extension file for *ArcGIS* which is- **ESRI Shapefile (*.shp)**



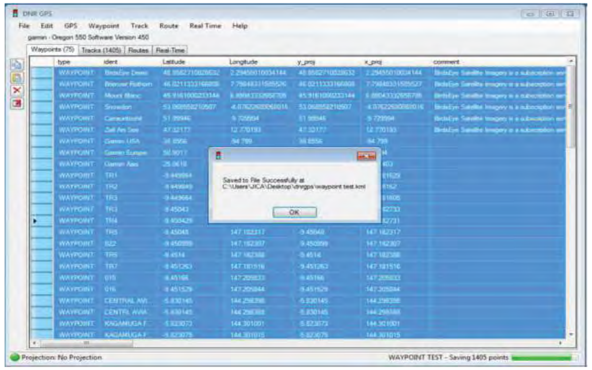
8. And select **Save.**
9. Note: once you have selected ***Save*** a prompted window appears showing **Save to Shape/GPS Types** with GPS Types:

1. Waypoints
2. Tracks
3. Routes

Select all and click **Ok**. *This option appears due to selecting the **Download All Function** at the initial stage.



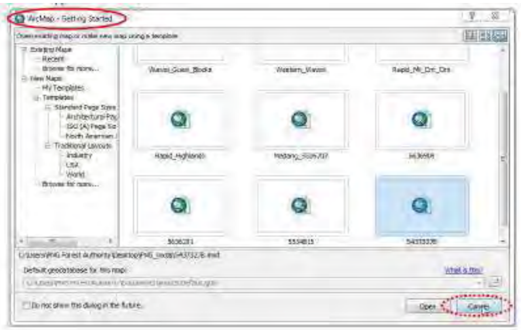
10. Select ***'Ok'*** to the ***'Saved to file Successfully at'*** dialog box: D:/PNGFA_WS_GIS_Training/GPS_Training



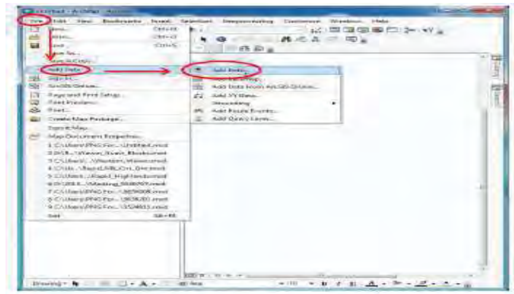
11. After saving your waypoints and tracks, open ArcMap 10.  **Like any other programs there are two means in which you can open an Application:

1. One way is through '***Start Menu'*** and search for the program; or
2. By the process of ***'Double Click'*** on the application's shortcut icon on the desktop, if there's one.

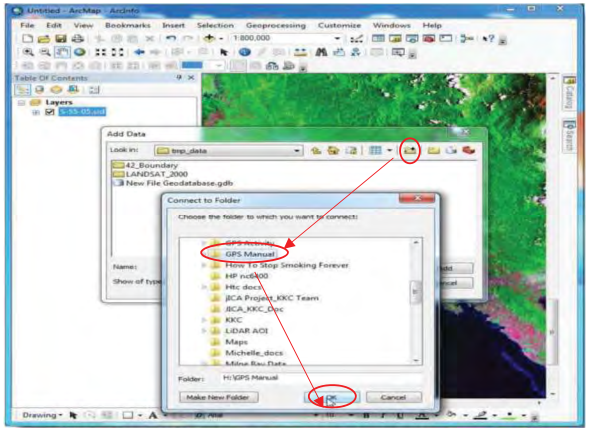
12. Just before the ArcMap application starts up, a prompt window ***'ArcMap – Getting Started'*** appears. **Cancel** the window.



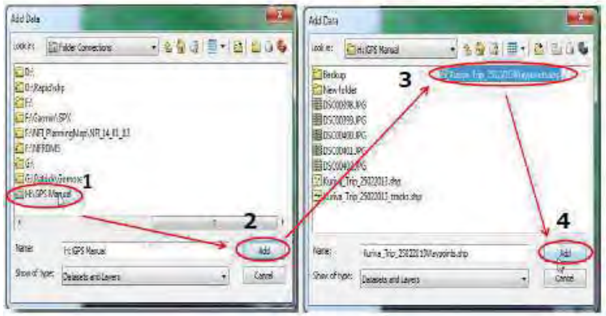
13. In ArcMap select ***'File'*** > ***'Cancel'*** the ***'Proxy Server Credentials'*** window > scroll down to ***'Add Data'*** menu > ***'Add Data'*** in the submenu as shown below:



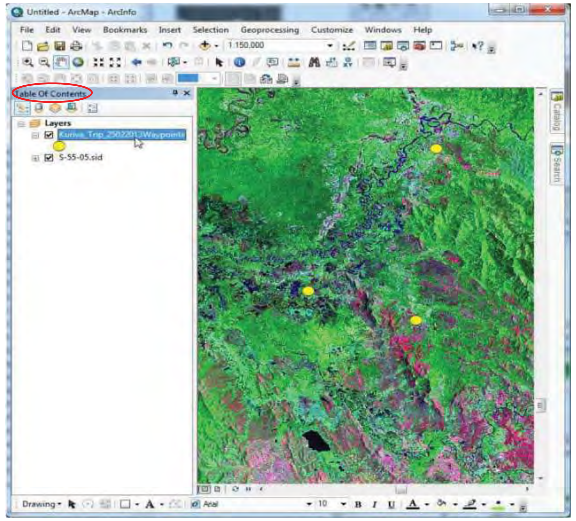
14. In the ***'Add Data'*** dialog box selects > ***'Connect to Folder'*** tab  > select the folder where you saved your data set and click ***'OK'***.



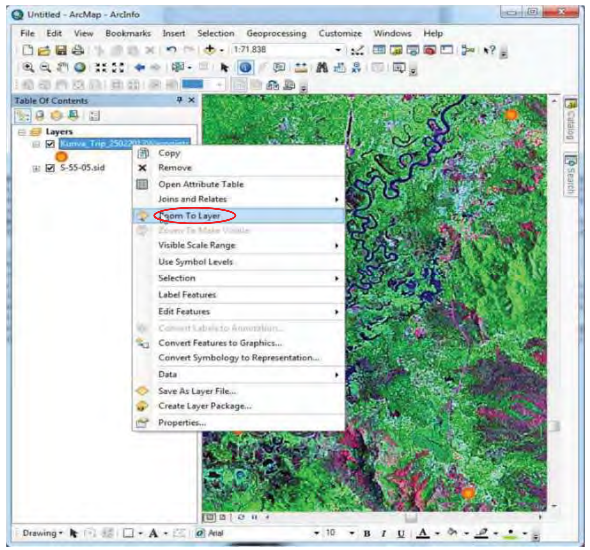
15. In the ***'Add Data'*** dialog box ***Double click*** the folder which you have selected in the ***'Connect to Folder'*** tab > select the ***'dataset'*** you want to upload and click ***'Add'***



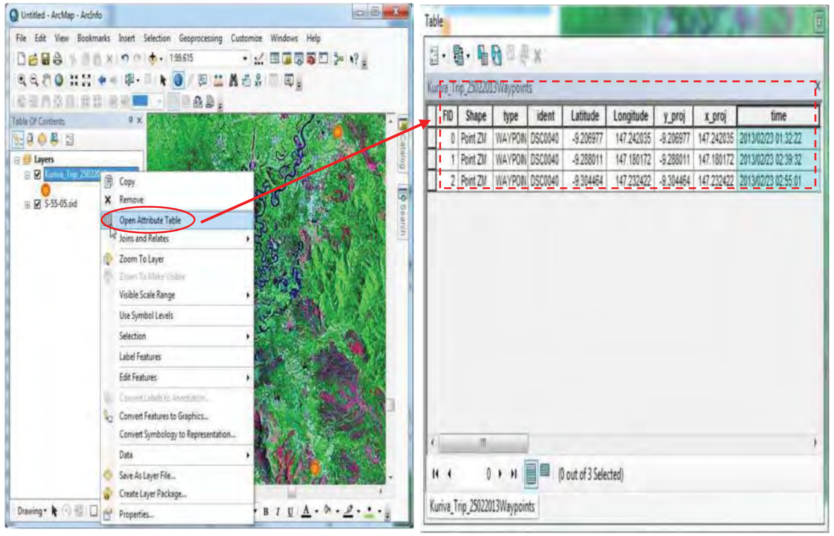
16. After you've selected the ***'Add'*** option you will find your GPS data added to ArcMap in the ***'Table of Content' (TOC)*** window.



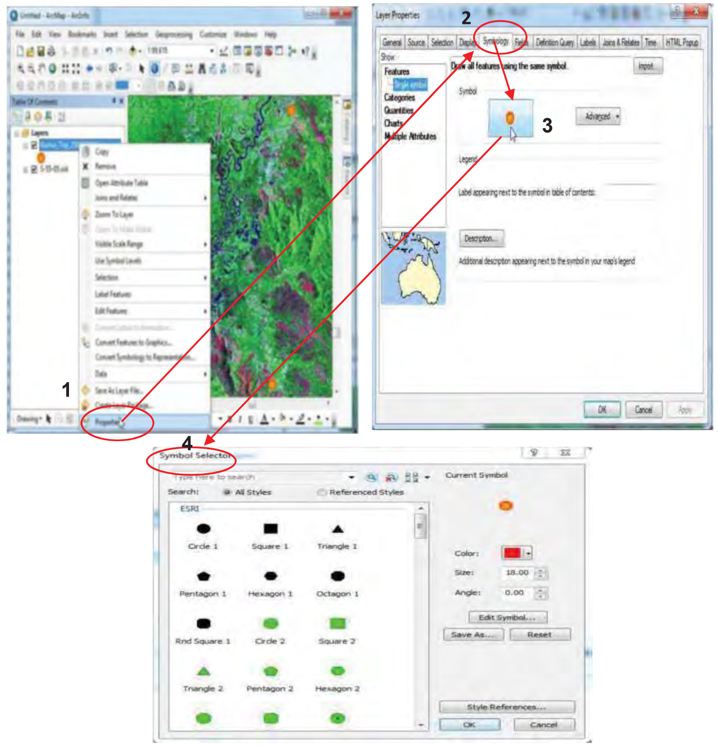
17. Right click on the GPS data you've added and select ***'Zoom to Layer'***, an option where you can zoom to the layer if it is not in the current view extent.



18. Again right click on the GPS data and select ***'Open Attribute Table'***, this option enables you to view the records of your capture data. E.g. time of capture, coordinates, etc…
**Note every layer has an Attribute Table with one record per feature.



19. Now, changing the layer's symbol. Right click > select ***'Properties'*** in ***'Layer Properties'*** Dialog box select ***'Symbology'*** > ***'Symbol Selector'***. This option enables you to customize the symbol of a feature.



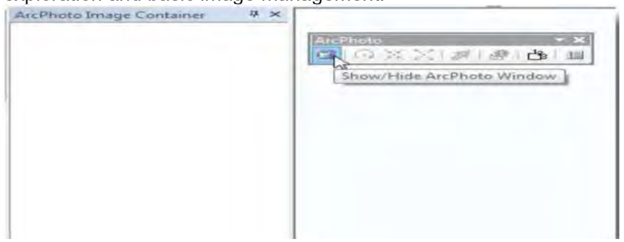
20. Finally, saving your map document. Go to ArcMap menu select ***'File'*** > ***'Save as'*** > navigate to the folder in which you uploaded your data from > give a name and ***'Save'***.

Part 2: Uploading your GPS Photographs in ArcGIS

1. Plug in your GPS device and open ArcMap 10. Click ‘Customize’ Menu > ‘Toolbars’ > ArcPhoto to open ArcPhoto toolbar which you can use to view your photos with exif information in ArcMap.

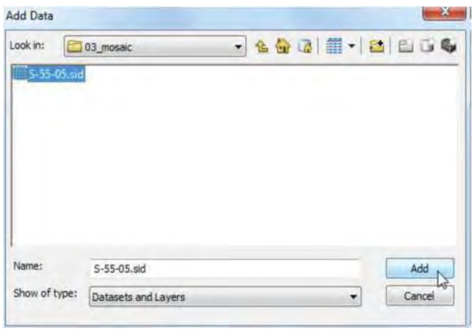
ArcPhoto toolbar:

2. Click ArcPhoto Window button ( ) to open the ArcPhoto window that is used for photo exploration and basic image management.



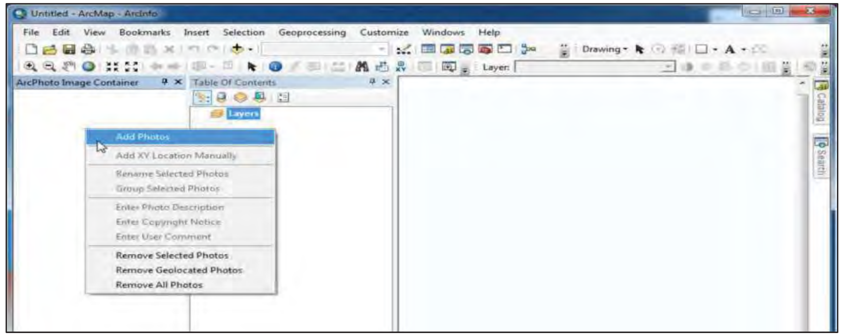
3. You will have to add a base map as a background data. Therefore, in this exercise will using the Landsat images.

Click the Add button’ ’, browse to Network/PNGFA-HQ-SRV3/nfrdms/01_Satellite/ LANDSAT_2000/ 03_mosaic, select S-55-05.sid, and then click ADD.

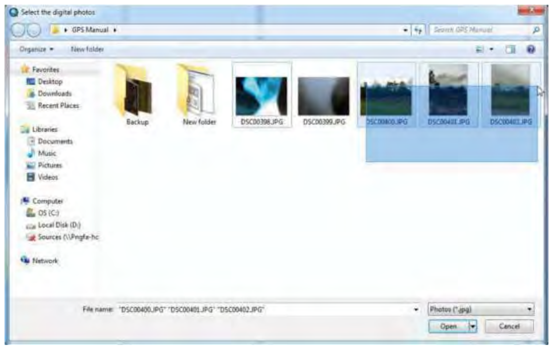


Now you will import your photos into ArcMap

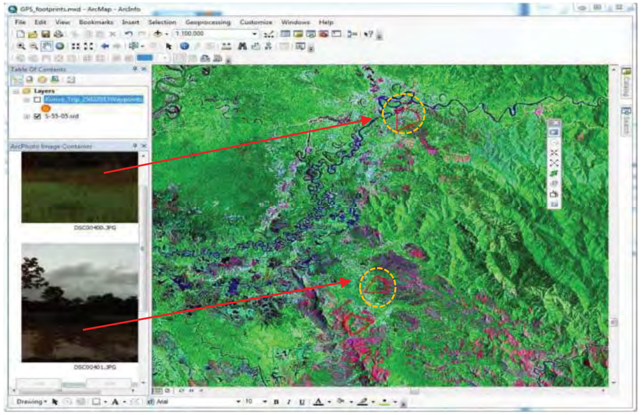
4. Right-click in the ArcPhoto Image Container window and from the context menu select the first menu entry **Add Photo**.



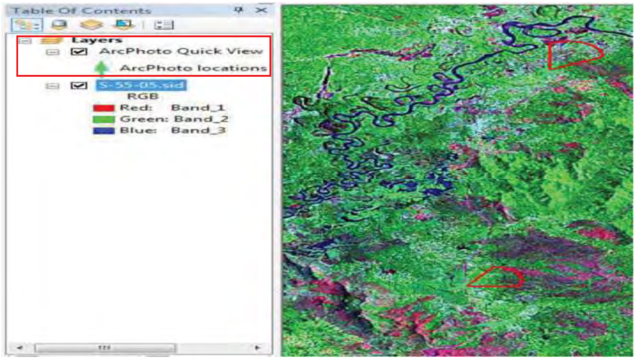
5.In the Select the photos ’dialog box navigates to D:/PNGFA_WS_GIS Training/picture where your image is stored and select images within this folder.



6. Click **Open** to accept the selection and to insert the images into the ArcPhoto window. After the images have been loaded, the window will show the images as a thumbnail and the corresponding position in the map view. The location is symbolized by representation of a position cone indicating the location of the recorded GPS signal and the direction in which the image was taken.

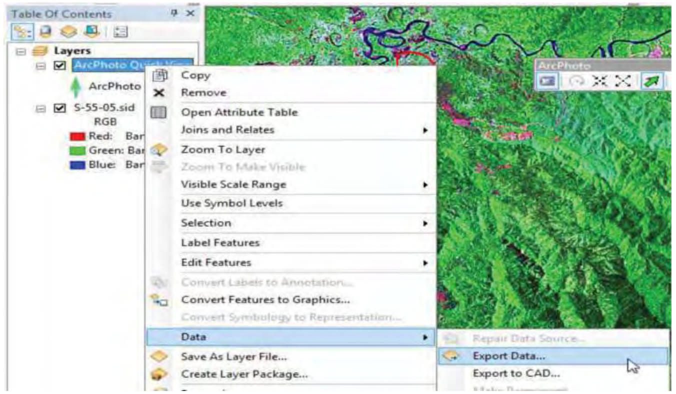


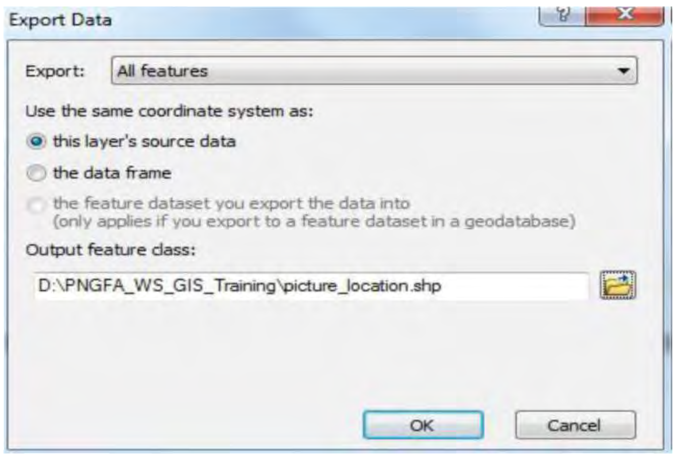
7. The next step is to quickly visualize the location and direction of all available images. Click the Quick View Location Tool, to generate an in-memory feature class providing a preview about the image location and direction.



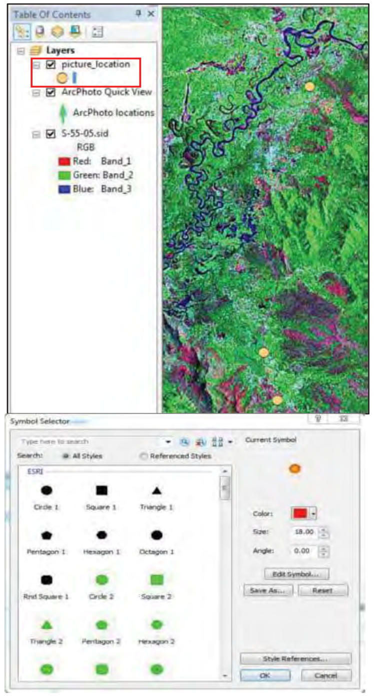
The green arrows show the location of the photo and the rotation of the arrow indicates the direction of the image. The tool acts as a toggle mechanism either it shows or hides the layer. There can only be one quick view layer in each data frame.

8. Now save the location points as shapefile to enable you to use them in the future. In the ***'Table of Contents'*** (TOC), right click ***ArcPhoto Quick View*** layer > ***Data*** > ***Export Data***…, Set output feature class in the Export Data window, and click ***'OK'***.

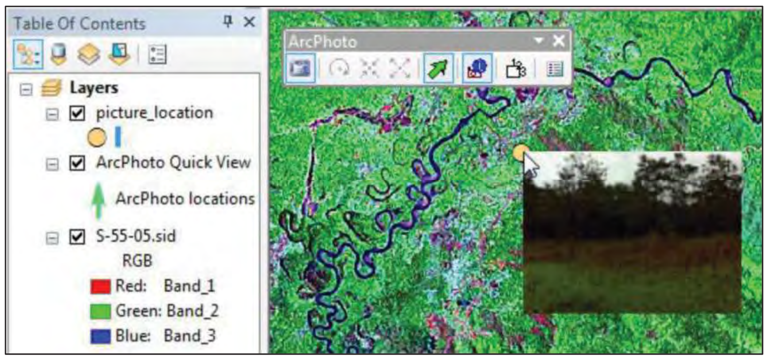




7. Add picture location .shp in map document. Change the symbol of the layer to make it viewable. To change symbol: double click on the symbol in the 'Table of Content' window



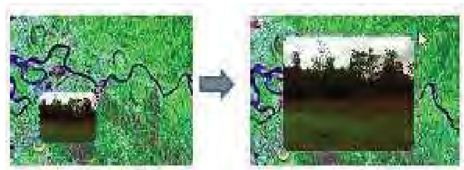
8. The next step is to quickly display the image itself in the context of the location. Click the Photo Maptip tool, and hover over one of the green arrows. *The tool itself works like the core hyperlink tool but is specialized for raster data.*



9. *You can create an ArcPhoto element (photo element) on the map.*
Right-click on a photo tooltip, then click Create Photo Element.

You can see a photo element on your map which includes a callout pointer from the photo, so you can move it anywhere without missing photo location, also change its size.

Click Select Elements button on Tools toolbar, hover over one of the corners of the photo, click and drag and drop to change the size.



Click on picture element, drag and drop to move it.

The photo elements can be repositioned and resized in the data frame and their leader lines are regenerated automatically.

When you want to delete photo elements, select photo elements and press Delete key.

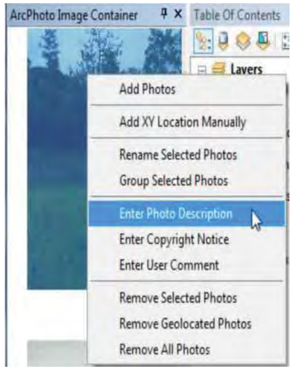
When you multiple images to place into view, click Select Features button on Tools toolbar, select green arrows which you want to create a photo element, click the Batch

Create Photo Elements tool  , and then click on view

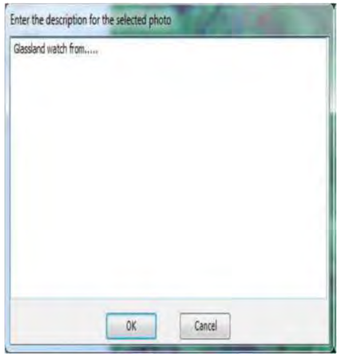
Click Clear Selected Features button  on Tools toolbar to clear your selection.

10. The next step is to add descriptive information to the photo.

You can also annotate the images with additional descriptive information or you can embed the copyright notice about the image.
Right-click on the image in ArcPhoto Image Container and select Enter Photo Description

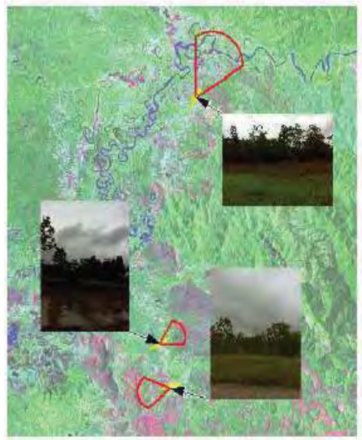


A dialog box opens where you enter descriptive information about the image.



Click OK after you type the image description

Save your map document after creating a display image if you want.

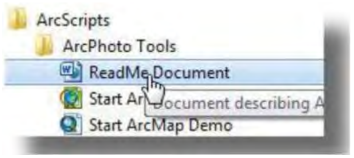


Awareness:

- Remember the ***'Directory/Path'*** in where you've stored/downloaded your GPS data to;
- Know the ***File Type/file extensions*** and its corresponding application;
- Practice repeating the whole procedures to be familiar with it;

- For additional information on:

    - ArcPhoto = Click 'Start Menu' > All Programs > ArcScripts > ArcPhoto Tools >ReadMe Document.

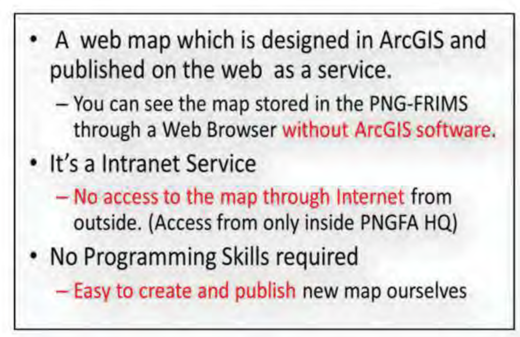


DNRGPS = <C:\Program Files (x86) \DNRGPS> dnrgps.pdf.

Forest Area Map on PNGFA's Intranet (LAN-Map)

LAN Map means Local Area Network is web map designed in ArcGIS and published on the web as a service.PNG-FRIMS LAN Map Browser is a user friendly that is published on Intranet Basis (Secured). Minimum programming skills required needed for utilisation. The main purpose is to share Forest information within PNGFA Head Quarter. Currently, the LAN Map is disseminated to only the Managing Director, Directors and JICA Project member can access to the map. This map shows Concession Area, Forest Base Map (Vegetation), Project Area and Topography.

Hence below show the overview of Forest Area Map on PNGFA's Intranet (LAN Map).

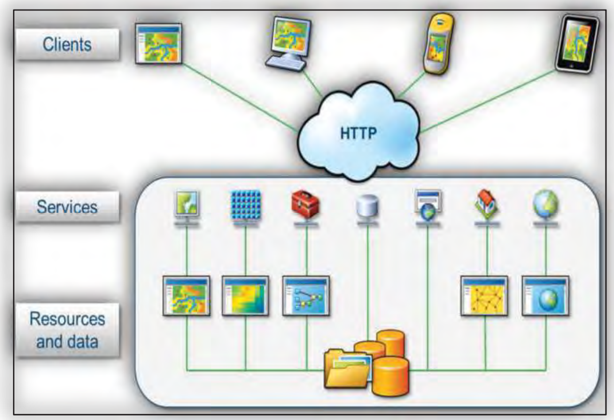


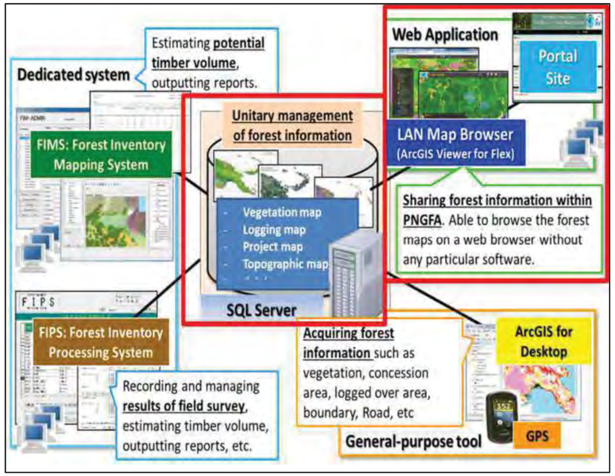
LAN map is a vital tool implemented in PNGFA that does great work through its goal, function, main objectives and main outcomes. Main purpose of the local network is to share Forestry information within PNGFA spatially.

Goal	Function	Main Objectives	Main Outcomes
To make the procedure of assessment and monitor logging operation plans more efficient	Shares and utilizes the forest information in PNG-FRIMS	- Overlay several forest information - Search location - Sketch map on web browser - Measure distance and extent - Print Maps	This function will help to assess logging plans
			This function will make it easy to find encroachment logging and overlapping of project boundaries by easy access to FRIMS through Web browser

Concept of LAN Map open with web browser from the computers, tablets etc..from authorised PNGFA authority.

Concept of LAN Map

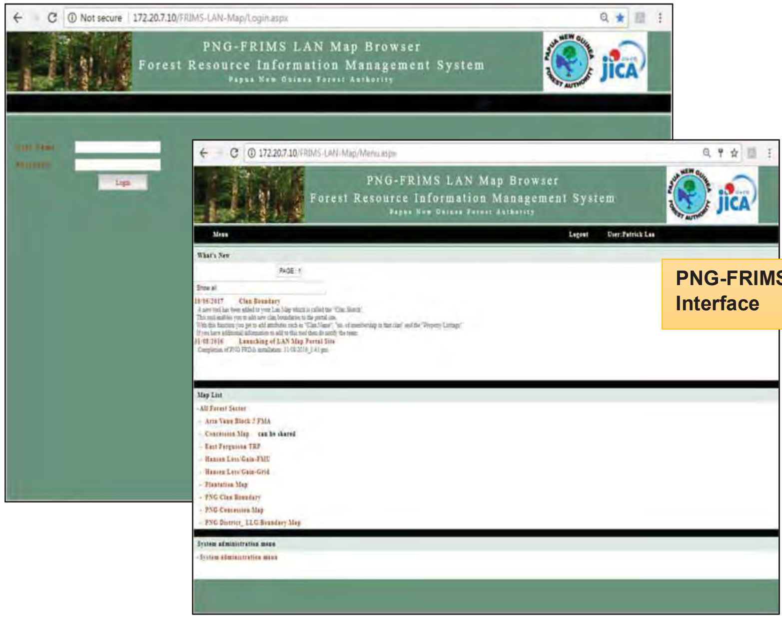




Information on Forest Area Map (Web Browser Map). It is noted that in next plan for adding information such as 'slope (over 30 degrees,20-30 degrees)', altitude (over 2400m), karst landform, inundation and mangrove are going to be added.

Category	Forest Information (Layer)	Attributes in Layer (You can see the following on the Map)	Remarks
Logging	Concession Area	Name, Type (TRP, LFA or FMA), Status (Concession or Proposed), Purchase Date, Expiry Date, Remarks (Current or Expired), Remarks2 (Detailed memo)	Managed by FIMS
Vegetation	ForestBaseMap.v1.1	-	2012 based
	FMU	Vegetation Type	1972 based
Project Area	FCA	Name	Created by I&M branch
	Forest Plantation	Name	
	Protected Area	Name	From DEC
Topography	Satellite	-	Rapid Eye Image Landsat
(Basemap)	Topomap	-	1/100,000
	Hillshade	-	Based on SRTM

PNG-FRIM LAN Map Browser Interface



PNG-FRIMS LAN Map Account Interface

PNG-FRIMS LAN Map Browser Tools/Functions

	Functions	Remarks
1	Layer List	To turn layers on and off.
2	Search	To search for the attribute "Name" in the concession area layer.
3	Measure	To measure length and area for simple graphics (line or polygon) drawn by users.
4	Sketch	To create simple graphics (point, line and polygon) for planning or monitoring.
5	Feedback	To create feedbacks (e.g. the data error which user noticed, the request for adding information or adding new functions) as new point features on the map.
6	Print	To print all visible map displayed.
7	Switch Basemap	To choose background topography.

Published Services (Maps)

Papua New Guinea Forest Authority under these respective directorates have published Maps:

1) Concession Map
2) East Fergusson TRP-*Project and Allocation Directorate*
3) Aria Vanu Block 2_FMA- *Project and Allocation Directorate*
4) Hansen Loss/Gain FMU AND Hansen Loss/Gain Grid-Forest Policy & Planning *Directorate-Redd Climate Change*
5) Plantation Map-*Forest Development Directorate-Plantations Branch*
6) PNG District Boundary Map- *Forest Policy & Planning Directorate-Acquisition Branch*

Procedure to see the map

1. Open a web browser

When Windows Security window open, you need to type ID and PW of internet access.

2.Access to the URL

http://172.20.7.10/flexviewers/ConcessionAreaMap/

- When Windows Security window open again, you need to type a domain user name and PW.

-The domain user name is part before @ of your email address.

**abc@pngfa.gov.pg → "abc" is a domain user name. You usually use it to log on your computer.*

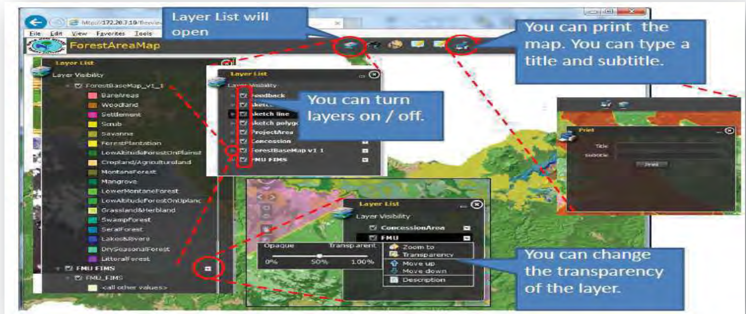
- If "Adobe Flash" window open, you need to install flash player.

-The installer is stored in L: ¥Kiyoshi Suzuki¥AdobeFlashPlayer

3. Open the map

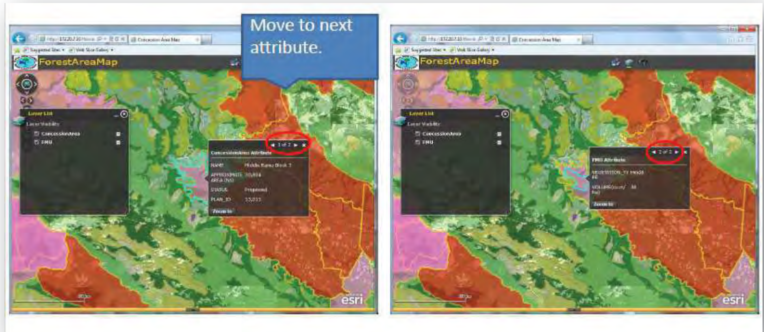
–You can zoom in / out the map using mouse scroll wheel.

–You can pan the map using the left mouse button.



4. See the attribute of the layer

–You click on the map, then attribute window will open.



5. See the Attribute Table

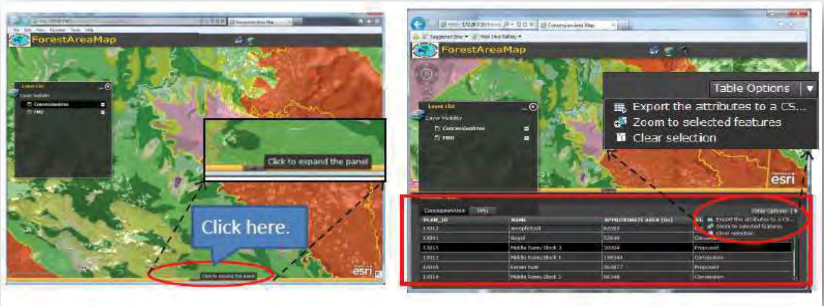
If you click on the bottom of the map screen, the Attribute Table will open.

You can see a tabular view of each layer's attribute.

The attribute table has "Table options" dropdown combo box. Export the attributes to a CSV file—Exports the attributes to a separate CSV file

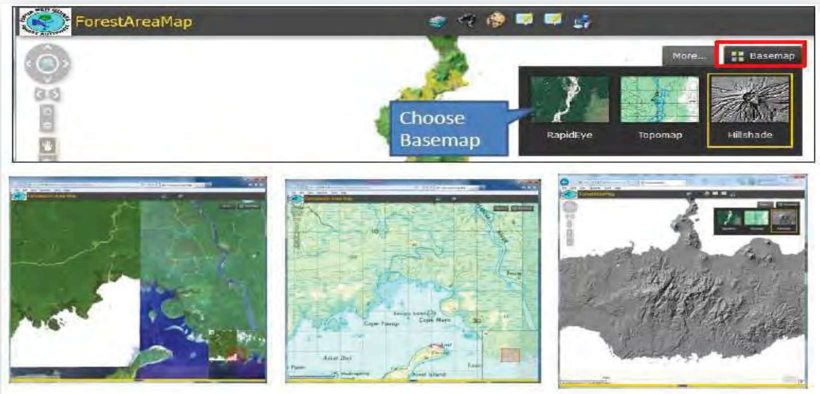
Zoom to selected features—Zooms to the extent of the selected features on a tabular view

Clear Selection—Clears the current selection



6. Switch Base map

You can choose the Basemap from among the satellite image, the topographic map and hill shade. The topomap will appear when you zoom in the map.

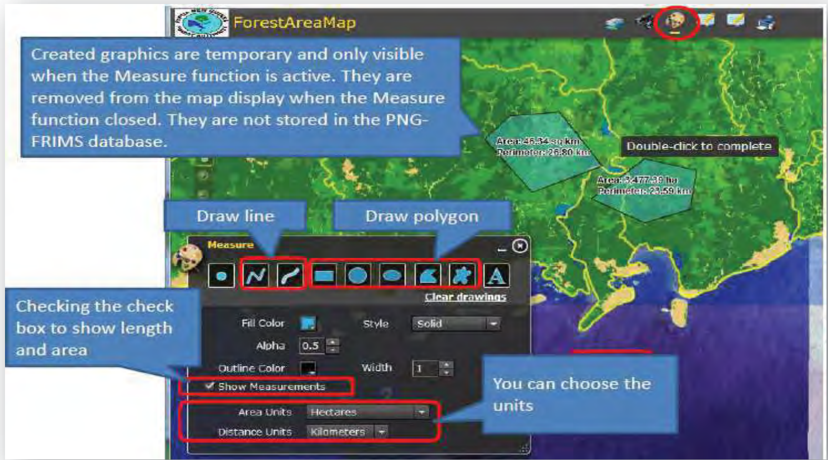


7. Search by name of the concession area

You can move to the concession area in which you are interested

8. Measure length and area of where you are interested in

You can measure lengths or Areas for simple graphics (line or polygon) drawn by users. Creates graphics are temporary, not stored into the FRIMS database.



9. Sketch forest information for planning or monitoring

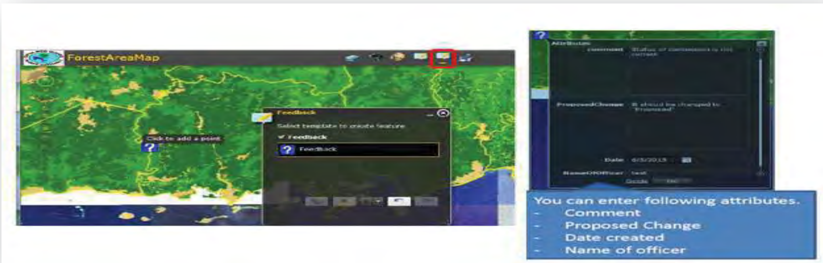
You can draw point, line and polygon on the map. Created graphics are stored into FRIMS database. They are shared on the map among all users.

Intended purpose of sketch layer: To draw strip line or boundary for project planning or monitoring, to record the location of issues we can share on the map such as forest fire, landslide, re-entry logging, etc

10. Feedback on the forest information inside PNG-FRIMS and the function of web browser map

- If you find an error of the forest map, please create a point data with comment and proposed change into Feedback layer.

- If you have a request for the current functions of web browser map, please create a point as same as above.



Your feedback will contribute to quality improvement of forest map information.

UTILIZATION OF UAV IN THE FOREST AREA

May, 2019

Papua New Guinea Forest Authority (PNGFA)
Japan International Cooperation Agency (JICA)

Table of Contents

1. Introduction

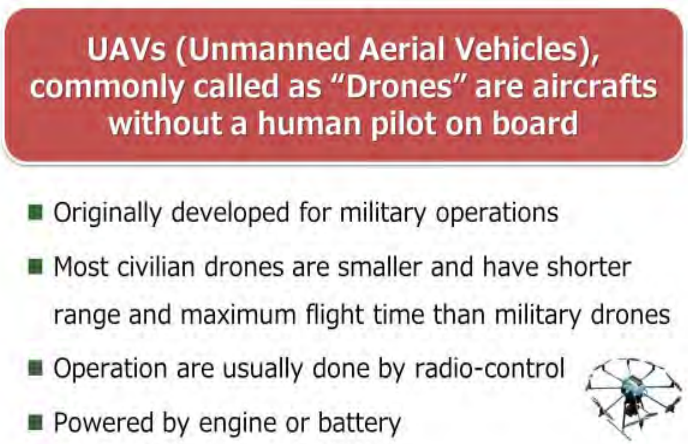
Papua New Guinea Forest Resource Information Management System (PNG-FRIMS) Project under JICA has been working closely with PNGFA to monitor the forest operation and the extent of forest and forest degradation and deforestation. Technically, PNG-FRIMS based on GIS system and remote sensing technology has sufficiently updating forest information and to fully operationalised and utilised PNG-FRIMS for promoting sustainable forest management and for addressing climate change. Drone training has been conducted to equipped skills to local forest officers on the usage of drone for monitoring forest.

This manual is developed for convenience of the local forest officers to understand and be guided on how to use drone which consisted in different parts; how to handle drone, safe administration, how to prepare automated flight plan, set the Flight course, Utilization of the ortho and Preparation of flight for Forest monitoring. Main purpose to develop this document was to acquire the capacity in basic drone usage and its data analysis using GIS which can be applied in the field task.

2. Definition of Drone

What is Drone?

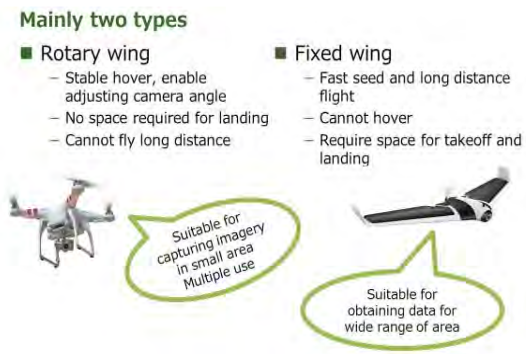
UAVs (Unmanned Aerial Vehicles), commonly called as "Drones" are aircrafts without a human pilot on board. UAVs are a component of an unmanned aircraft system; which include a UAV, a ground-based controller, and a system of communication between the two. The flight of UAVs may operate with various degrees of autonomy: either under remote control by a human operator or autonomously by on-board computers. It is powered by engine or battery. (Wikipedia)



2.1 Types of Drone

What is Drone (UAV)?

"**Drone**" can be classified into two main types; Rotary wing and Fixed wing.



Rotary wing are the most common types of drones that are used by professionals and hobbyists alike. It is stable hover that enable the adjustments for the camera angle. It's also doesn't need a landing space but suitable for capturing imagery in a small area and is of multiple use.

Fixed wing drones are different in design that build to multi-rotor types drone. Its wing is like an airplane which fly very fast in long distance. It is suitable for obtaining data for a wide range of area. But they cannot be used for aerial photography due that the drone is kept on air for a period of time.

3. Purpose of Drone

What can drones do?

Drone can be control manually with remote control and fly programme route automatically. It takes pictures with location and do video shooting. It does laser survey and do pesticide spraying.

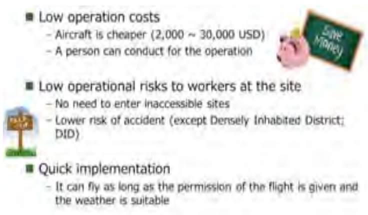
Drones have numerous uses in aerial photography, land surveying, maintenance assessment, scientific research, product deliveries, agriculture, defence & military, social activities out open air etc…

Following product can be obtained from the Aerial image taken by the drone (requires 3D production software)

Figure 1:shows different aerial image taken by drone

4. Advantages of Drones

Drones cost depend on the sizes and the quality. Hence, it is affordable to professionals and hobbyists around 2,000-3000 USD where it can be conduct for operation. Less risk to operational site workers as there is no need to enter inaccessible areas and hence seen as a lower risk to any accidents (except Densely Inhabited District; DID). It can fly as long as the permission of the flight is given and the weather is suitable. Drones can be visualised as it goes up to the atmosphere while being control by the users controlling them while capturing beautiful pictures and efficient videos.



Flying is the characteristic of it because it has the capacity to rise above the land by means of elevating the device from the ground and capture high quality data available for the area of interest or targeted area

Drone require less effort when operators plan a flight and using variety of tools select from the area of interest where a push of a button, users can already fly the drone and start moving the images to the surrounding in the lesser time. All recorded shots are stored in an external data storage USB are later transfer to the Laptop where the data is being proceed in less time.

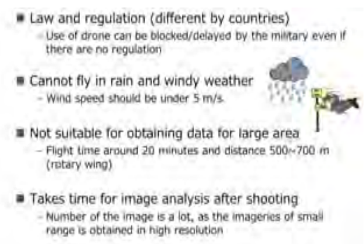
Flight of the drones are at lower altitude that is, has the ability to fly under cloud cover, their high-resolution cameras with different camera systems.

There are sensors attached to the all of drone so it detects obstructions if it comes closer to a building, tree etc.… or weather in sense of strong wind.

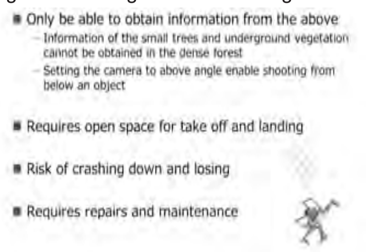
It can be used as a warning tool as well apprehend beautiful pictures/videos are worth thousand words. Drones are equipped with high-quality cameras capable of capturing great, amazing shots and videos the images are only so outstanding clear.

5. Limitation of the Drone

There is limitation to drone technology.



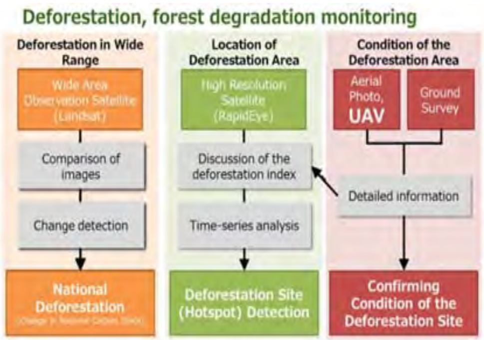
Laws and Regulations (different by countries) requiring commercial drone operators to obtain license to fly the drone. At a military level, usage of drone must be license to operate, otherwise it will be blocked or delayed to operate. The law has stated well for some countries for drone cannot fly during raining and windy weather and its fixed to under 5 m/s wind speed. For instance, in USA, drones' owners own a drone less 250g or heavier & less than 25kg aircraft which must register under Federal Aviation Administration (hereafter FAA) before any operation. It's not suitable for obtaining data for a large area with a maximum time of 20 minutes it captures photos and take time to analysis them and travel in a distance of 500-700m.Due to plenty photos, High resolution imaginaries are used for short ranges. Drone flight is ONLY being able to obtain information from the above. Information of the small trees and underground vegetation cannot be obtained in the dense forest. The camera is set to above angle shooting from below an object. Drone requires an open space for take-off and landing so it has less risk of crashing down and losing and finally, it requires repairs and maintenance once a fault is notified



6. Application of Drone in Forest Monitoring

Technologies is advancing such as GPS, small drones were initially developed for military use, but are increasingly on demand and being deployed in civilian application including mapping, monitoring and managing habitats and natural resources. Hence, these applications used in Forest Monitoring are vital in PNG forest especially in deforestation, forest degradation forest monitoring & Resource monitoring.

6.1 Deforestation, forest degradation monitoring

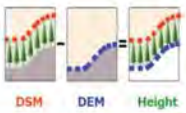


Deforestation in a wide range of disturbance to the natural environment due to human activities and natural disaster. While forest degradation monitoring is vital for sustainability of timber harvesting. Hence, massive land area requires an Observation Satellite (Landsat) to compare images and collecting data's relevant to deforestation area. There is more likely to have changes in detection of natural deforestation or in National Carbon Stock. In order to focus on the specific areas of deforestation, a High-Resolution Satellite or Rapid Eye is applied in discussion of the deforestation index where time-series are analysis to identify the hotspot site of deforestation. To get the confirmation condition of the deforestation site, the data of the aerial photo from UAV and the ground Survey produced a detailed information which can also discuss the deforestation index.

6.2 Resource monitoring

Resource monitoring

- Forest volume can be estimated from
  - Tree height (DSM-DEM)
  - Relational expression of height and volume



Survey Method	Data	Sensor	Price	Accuracy
Photo Survey	3D model	Camera	Low (Usually come together with drone)	Low in dense forest
Laser Survey	Laser data	Laser scanner	High (10,000-230,000USD)	Medium-high

Forest volume can be estimated from Tree height (DSM-DEM) and Relational expression of height and volume. Two types of survey method are used to collect data in forest resource monitoring. Photo survey produce 3D images capture from the sensor while the camera takes the photos as DSM. Accuracy of DSM aerial photos are very low at dense forest area. Lazer photo survey develop its data as lazer data which are capture through the scanner that cost is very high compared to DSM shots taken by drone. Hence, its accuracy is range from medium to high at the forest area monitoring. Major shooting items are useful in the application for forest monitoring.

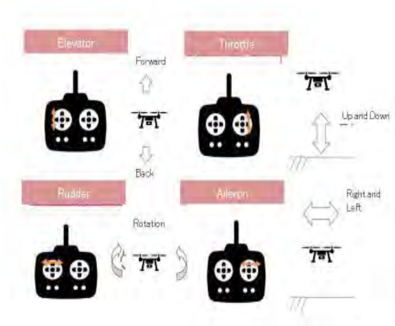
Major item	Item	Use	Method
Shooting	Grasping General condition	◎	From imageries and movies
	Change detection	◎	By comparison of the images obtained from the same route
Photo Survey	Stem number	○	By point data from 3D model
	Tree height	○	From point cloud data
	Tree crown density	△	Maybe possible by DSM data
	DBH	×	
	Tree volume	△	Possible from the difference of DSM and DEM or estimation from tree height
	Stand structure	○	From point cloud data
	Understory	×	Maybe possible in sparse stands

Figure 2: two major shooting items used by drone

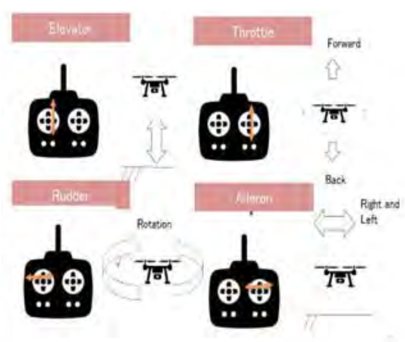
7. Manipulation Practice of the drone

How to handle the equipment?

1. Know the equipment necessary for flight
2. Know how to handle batteries
3. Understand how to start up
4. Understand the operation method



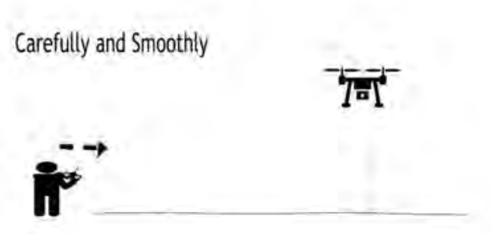
Mode 1: shows the Operation Method where the elevator moves back and forth and throttle moving up and down. The Ladder spins clockwise or anti clockwise and it's the angle of the head while Aileron for lateral move to the Right and Left.



Mode 2: Elevator plays the role controlling the flight of drone Up and Down. Rotation speed of all rotors are the same. Going up, down and hovering is possible depending on the rotation speed. The throttle moves the flight forward and backward while the rudder spins the drone flight in clockwise and anti-clockwise direction.

Practice 1: Takeoff and Landing

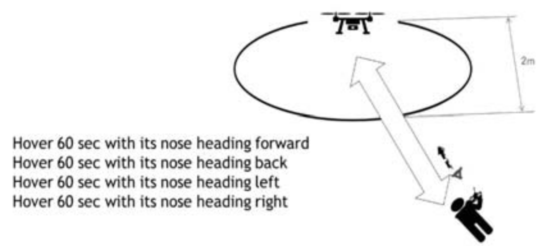
-taking off must be at perpendicular length before it starts its flight plan. Landing must as well be at perpendicular height before landing to its home base.



Practice 2: **Rotation**

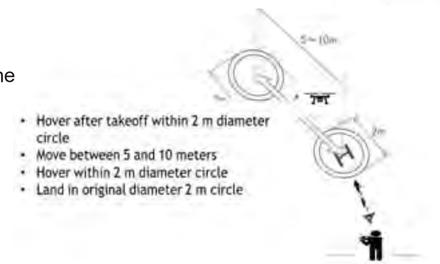
-Multicopter that flies while spinning 3 or more rotors at the same time. The name differs depending on the number of the rotor. It is formed by alternate rotor spinning clockwise (CW) and spinning counter clock wise (CCW)

Spin-it increases the rotation speed of rotor that are spinning in the opposite direction from the direction you want to spin the aircraft. It spins clockwise and counter clockwise. In practical demonstration, the drone hover 60 sec with its nose heading forward and backward. It hovers 60sec with its nose heading left and right.



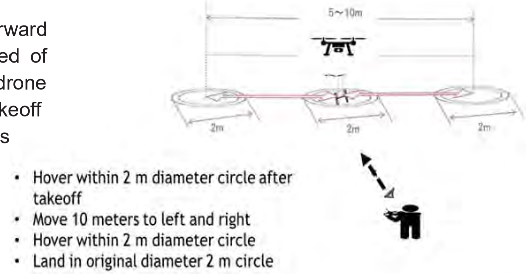
Practice 3: Forward and Backward

-Reduce the rotation speed rotor of the forward direction, and increase the rotation speed of alternative rotor. It hovers after take-off within 2m diameter circle and move between 5 to 10 meters. Hover is normally in the 2m diameter circle as well as landing.



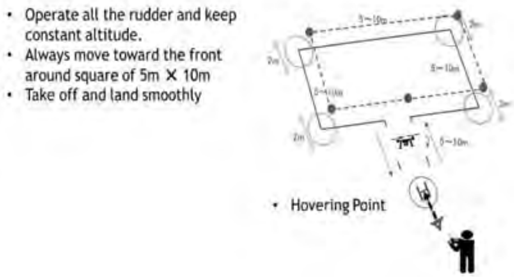
Practice 4: Left and Right

-Reduce the rotation speed rotor of the forward direction, and increase the rotation speed of alternative rotor. In real flight practice, the drone hover within 2m diameter circle after takeoff and move 10m left and right. It hovers within 2m diameter circle only.



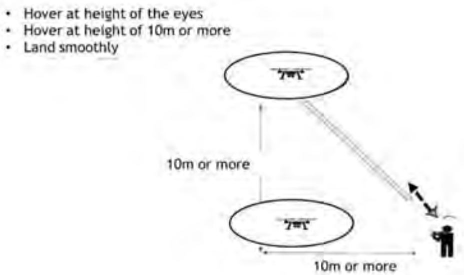
Practice 5: Combination

-operate all the rubber and keep constant altitude. Always move towards the front around square of 5m*10m and take-off and landing smoothly



Practice 6: Height

-Flight Height must hover at height of the eyes which is at 10m or more. So, a smooth landing is completed.



8. Safe Administration

8.1 Guideline

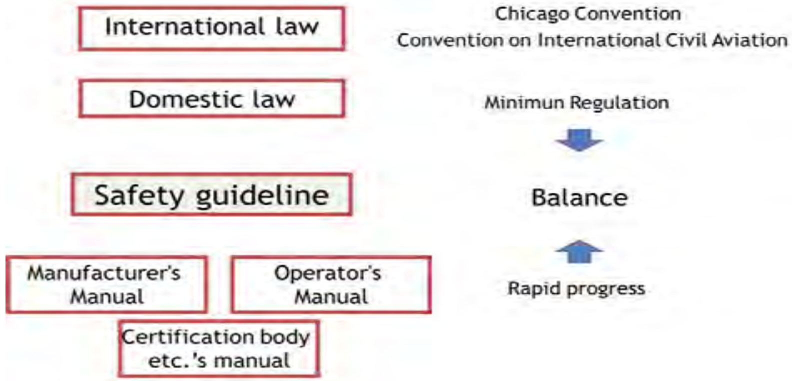


Figure 4:

Figure 3: displays a guideline abiding the ownership & operation of a drone

Chicago Convention-Convention on International Civil Aviation established international standard of design, manufacture, operation and maintenance of the aircraft. In 2018, Remotely Piloted Aircraft (RPAs) will be included in Chicago Agreement

Domestic Laws Related to Unmanned Aerial Vehicle-Aviation law, regulation, small sized unmanned aircraft flight prohibition, Road traffic law, Civil law, Personal information protection law, Foreign exchange control law, Industrial waste law, Criminal law and Agreement.

National Law of Papua New Guinea Amended Civil Aviation Act 2000, the Civil Aviation & Safety Authority of Papua New Guinea (CASA PNG) is responsible for the safety and security of all civil aircraft operations with Papua New Guinea navigable airspace from ground level to the upper altitude limits of Port Moresby Flight Information Region. The Act classifies all UAVs as aircraft and therefore subject to regulatory control by CASA PNG.

Use of drones and other UAV's restricted

8.2 Third Principal of Aviation Safety

8.3 Regulation

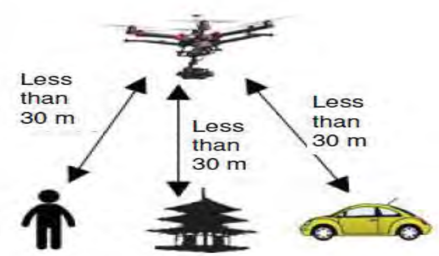
8.3.1 Guideline in Japan

1) **Areas where flights are prohibited**

Figure 4: Restricted Areas to fly drone

Standard: Flight around the airport vicinity is strictly prohibited for drone.

Flying of drone more than 150m is against the law or over DID area. To fly drone, it needs Minister approval is given before a flight is taken at these areas respectively. Drone is acceptable to fly at daytime and within visual observation with the secure distance of 30m from the third party, (human, building etc.). Flight prohibited in items transportation or drooping, it has to be separated and be mounted, regardless of the distance from the ground. Drone is prohibited in events, festival, demonstration, sport competition etc. venues.



Flight within 30m must be limited to more than 30m distance between the third person, and the objects such as the third buildings and the third vehicle's third person refers to those who has nothing to do with the flight. Operator self is not included.

2) **Method of the flights**

Flight over event site where a lot of people gathers in the occasion such as festive. The clear standard of ''event'' is defined getting permission is difficult.

A flight is prohibited in Transporting dangerous objects like; knife, cigarette, alcohol etc. In the plane. Dropping objects through cutting itself is not allowed.

DID: Densely Inhabited District

- A unit area with a population density of 4,000 people / km2 or more in the area of municipalities is set as a neighborhood adjacent to each other and a population of 5,000 or more.

  However, basic unit areas such as airports, harbors, industrial areas, parks are included in the population concentration district even if the population density is low

  Visual flying of drone is important. The eye has to be focused on the distance from the person controlling the as well the drone visually goes up to the height set.

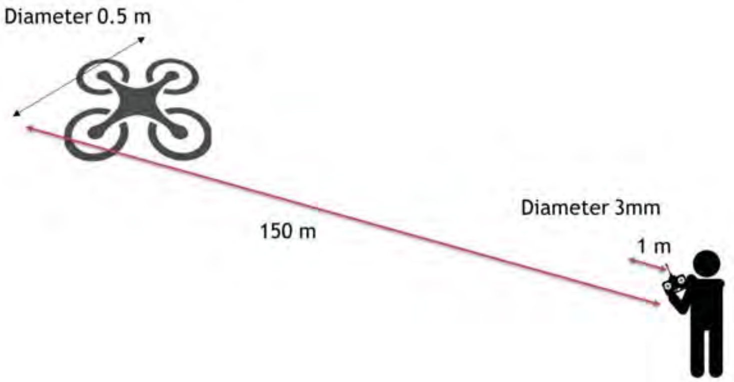


Figure 5: illustrating the operator in visual contact when flying the drone

Flight Area

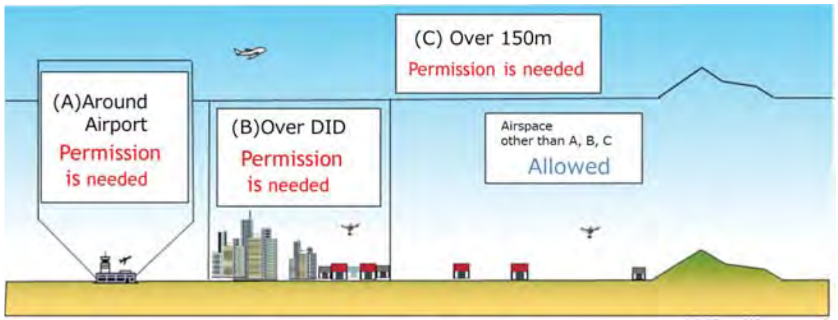


Figure 6: showing restricted areas which needed approval to fly drone

9. Risk/Hazard during drone flight

Weather/Wind Speed

Change in wind speed(Altitude, topography, structure)

Aircraft/Parts

Lithium Polymer Battery remaining

Posture Stabilization/Control

Throttle strength

9.1 Weather

Weather does affect the drone performance. The best weather for drone flying is when it is sunny, a reasonable temperature (for instance;75 degrees), and little to no wind, the reasons for this are simple: sunny days are beautiful,75 degrees is the perfect temperature, and in flying the wind is a pain in the rear.

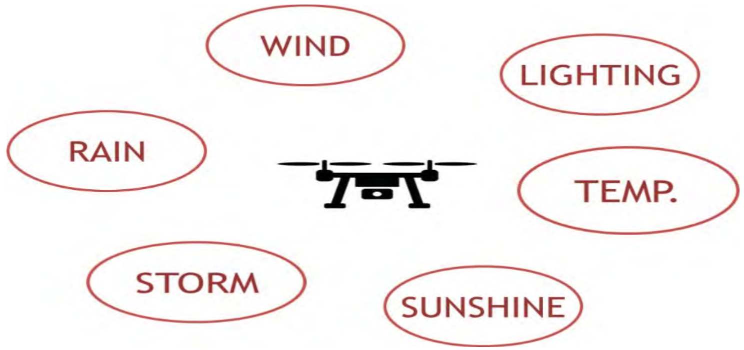


Figure 7: showing different weather patterns suitable and not suitable to fly drone.

Wind - changes in wind speed (i.e. Altitude, topography, structure) does cause flying difficulty and will drain your drone battery faster than normal. Cold temperature cause batteries to lose charge faster. Rain is detrimental to anything electronic and high heat isn't because drone produce quite a bit of heat on their own. Extreme heat can put unnecessary wear and tear on batteries and computers.

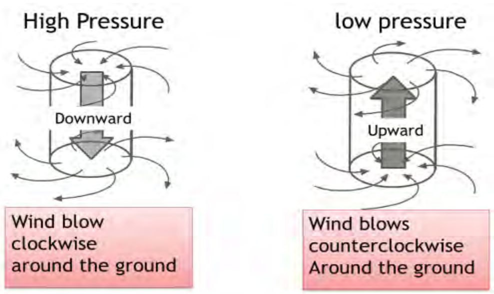


Figure 8: showing high pressure and low-pressure movement

Hence, take note on windy days which sometimes comes with rain. Flying in wind requires a lot of practice, patience and back up batteries. The drone will blaze through batteries trying to maintain any sorts of position on a windy day. If plan to fly on a windy day, watch the batteries and the building.

Temperature-the cold and hot temperature has to impact the flying of the drone. When the temperature is low, it causes the high pressure to the air. This may develop a storm or cyclone where a flight of drone cannot be conducted. However, in high temperature, a clear hot **sunshine** day, where it has a low air pressure up in the air. This is a perfect time to fly the drone, hencing producing perfect images.

Rain-Flying in rain is a surefire way to ruin a drone for good. It goes without saying that water and electronics don't mix. Most drones are not waterproof, or water resistance. A little bit of water is going to bring the drone to dramatic end. When it's raining, don't fly the drone.

Movement of hot air during the day from the sea moving inland while the cold air moving from the mountain down has a great influence on the weather pattern. Likewise, the movement of cold air from the mountain moving down during the night while the hot air from the sea moving upwards.

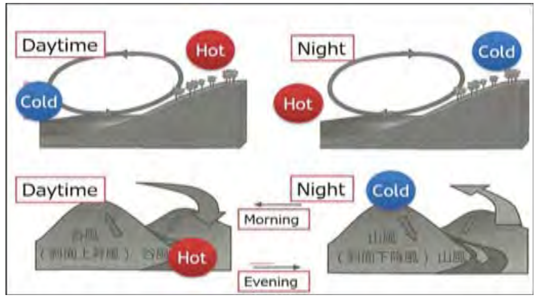


Figure 9: showing the day and night cold air and hot air from the sea moving up the mountain and vice versa in the night.

Cumulonimbus-occur under decaying cumulonimbus with a wind speed may exceed 50m/s in some cases. Accompanied by heavy rain that leads to accident of takeoff and landing of the aircraft.

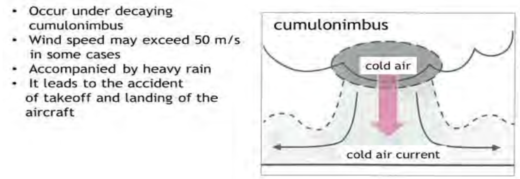


Figure 10: illustrate the movement of cold air

Hurricane-happen because the two cold air pressure coming against each other. To fly a drone in a cold climate is very scary and dangerous where accident will occur.

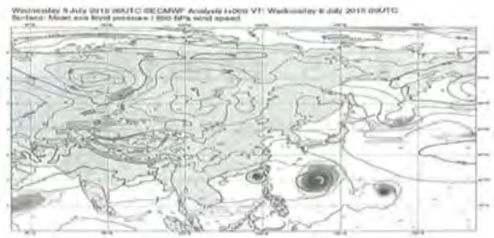


Figure 11: shows hurricane formed that caused distraction in drone flight

Aircraft /Parts-Lithium Polymer Battery remaining is a rechargeable battery of lithium-ion technology using polymer electrolyte instead of a liquid electrolyte. High conductivity semisolid polymers form this electrolyte. These batteries provide higher specific energy than other lithium battery types are used in application where weight is a critical feature.

Posture Stabilization/Control-Throttle strength is very responsive and can adjust the throttle at max thrust. It is aim for full throttle to be a fast rise and mid to high throttle to give a steady rise.

10. Flight Plan

When planning to fly a drone, flight has to have a mission. Mission to inspect a building, do inspection on a disaster area, capture an area of ground for survey and capturing photo for monitoring purposes. Flight planning in some cases choose a specific area, which assist in achieving mission goals, however, avoid restricted air, keep track of flying height restriction, battery life etc. When using drone for survey, mapping, it can be useful to plan out an area to be flown, number of flight paths, the number of photos, and the overlap between images.

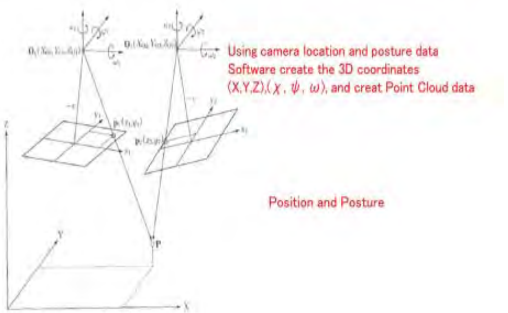
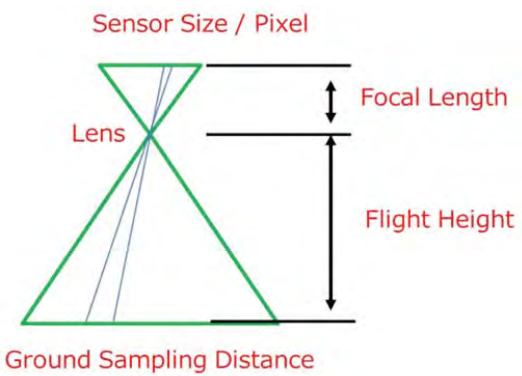
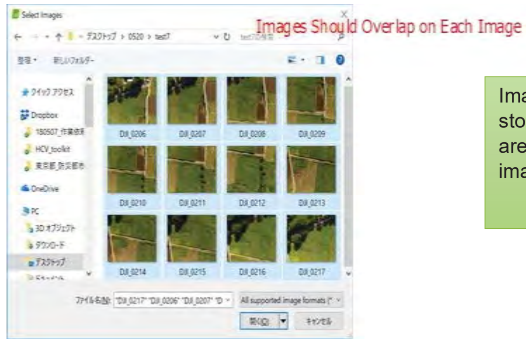


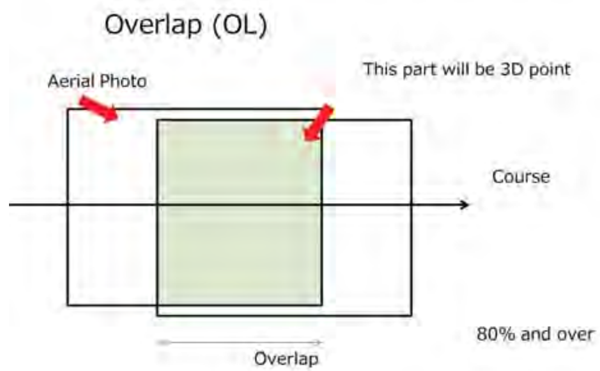
Diagram shows the flight plan using camera location and posture data. Software create the 3D coordinates (X, Y, Z), (x, y, z), and create Point Cloud data. Google Map is used for creating a flight plan which are then saved into save files to produce an automated plan. Hence the drone is acquiring 3D images



Ground Sampling Distance is the distance between centre points of each sample taken of the ground. Each sample is a pixel. The Lens, Sensor Size/Pixel, Focal Length and Flight Height are set to standard measurement so as to give a positive effect on the ground resolution. Images taken should overlap horizontally while side lap shows images vertically must be sufficient for generating digital surface model. There are images taken where it shows some Red parts that have only one AERIAL Photo, such part won't create 3D.



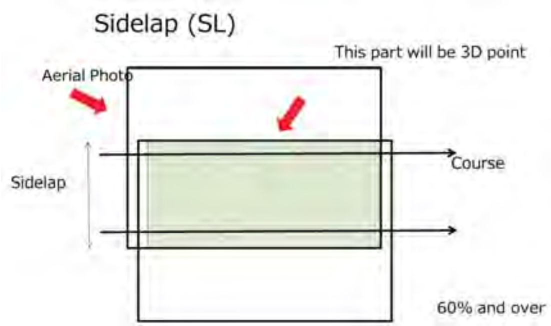
Images capture by the drone and stored in the internal storage device are showing their overlapping on each image.

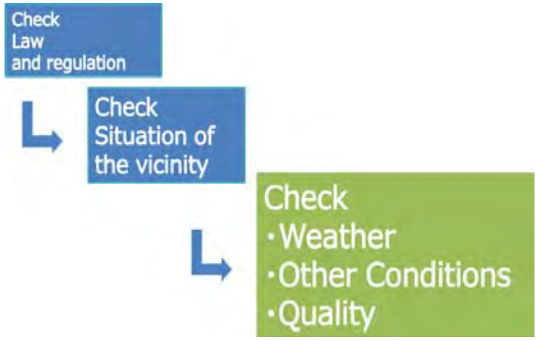


Overlaps contain both the front-overlap and side-overlap.

Frontlap means the percentage of overlap between one image and the next, and both images are taken by the drones when flying in the same direction. If the shaded area in the picture is 80% of the rectangle, it means the frontlap will be 80%.

Sidelap refers to the percentage of overlap between different flight legs. Just as the below picture shows, the same size of image (which is represented by the rectangle) is captured on each spot



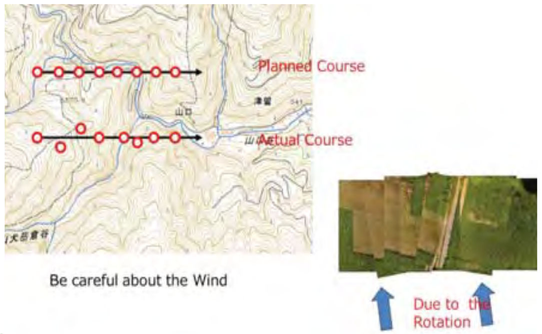


10.1 Condition

Before the actual operating of the flight to the area of interest. Condition are applied, especially to check Law and Regulations that of certain operable guideline of drone usage. Checking the situation of the vicinity is free to use and the weather condition and other external condition that might disturb the flight. Quality conditions are allowed check to ensure data collected is accurate

10.2 Planning

Planning of the flight are done using the iPad Phone. It is either the planned course or the Actual course. Planned course shows a straight route the flight will take while the actual route shows the drone being flight on air and taking the shots. Photos taken on the planned flight are not in order due that rotation.



10.3 Ground Control Points

Ground control points are large marked target on the ground, spaced strategically to the area of interest. The GCP and their coordinates are used to help drone mapping software accurately position the map in relation to the real existing pictures around. It is also helpful as GCP as series of thumbtacks place on the drone map so that map can pick up the exact location of these thumbtacks, which can be reference their location when it matches with other points on the map.

There are various types of Ground Control Points which reflect actual coordinates on the images to be taken. They improve the quality of the 3D point (ortho image) and sometimes verify the quality.

10.4 Preparation for Forest Monitoring

10.4.1 Map for Preparation

Map preparation is usually done using the iPad phone. Contour line are use in flight preparation. There is a standard scale preferable to go on the map.

10.4.2 Preparation

The following process and steps shown the summary of organizing data using the respective application software to analyzing at GIS. Before acquiring the final data output, order of step/process are vital for preparation. Diagram illustrate the methodology used in preparation for analyzing data in Forest Monitoring.

1. **Prepare Set-up Boundary**
Soft data for Google Earth (KML, KMZ)
2. **Make Set-up Boundary as KML**
Google Earth Pro or QGIS(Shapefile)
3. **Import KML (or Shape)**
Through Wifi (using Cellular)
4. **Create Mission**
GS Pro
5. **Analyse images captured by drone**
Pix4D

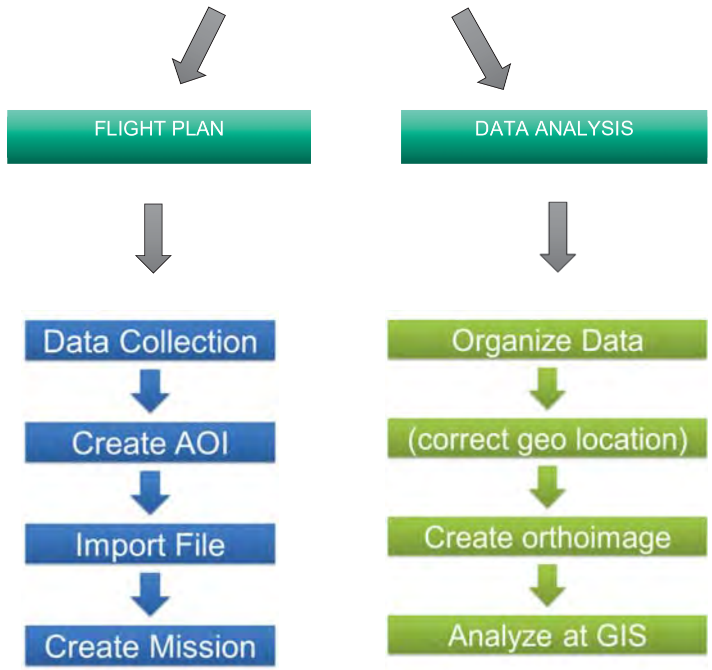


Figure 12: Methodology used in data analysis.

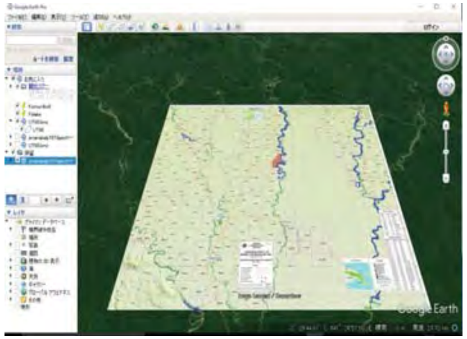
11 GS PRO for Ortho Photo

DJI GS PRO (also known as Ground Station Pro) is an iPad app designed for industrial applications including but limited to, aerial imaging, architecture, precision agriculture, electrical inspections, search and rescue, safe control, and more. It provides easy mission planning through different methods such as tapping on the map, setting points using the aircraft, or importing files, and automated aircraft control during the planned mission. DJI GS Pro is compatible with the iPad product line and many DJI aircraft, flight controllers, cameras and accessories.

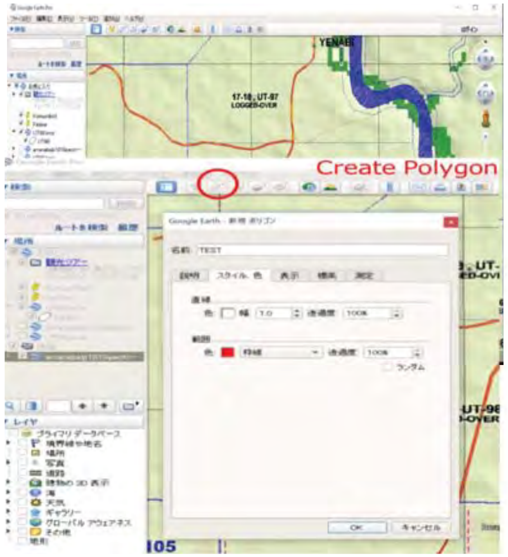
11.1 Create AOI

The Dji GS is collecting the GIS data around the area of interest (AOI). Hence, ***Google Earth Pro*** application then draws the area of interest. A ***setup boundary or polygon*** is created on the google map which are then save as **kml files** and calculates the flight path of the drone, capturing images automatically with 60% overlap from the previous shots. This overlap acquired by drone is needed for the 3D constructions.

1. Open the *Google Earth Pro*
2. Then draw the *area of interest*

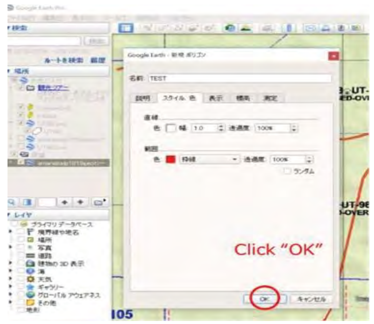


3. Go *Add Polygon* and create the boundary polygon on the google map. Name the polygon (eg.TEST). And click ok.

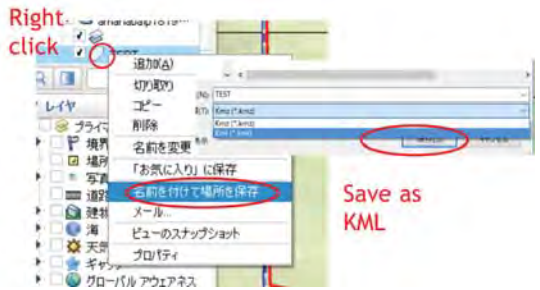


4. In the shape of the setup, *right click to add color* to the boundary/polygon created and adjust the thickness of the boundary.

5. Then click, *Ok*

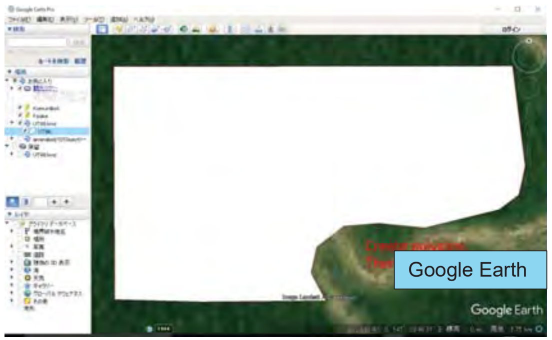


6. To save the file, right click on the named boundary (TEST), dropdown box appears and *save as kml* save.

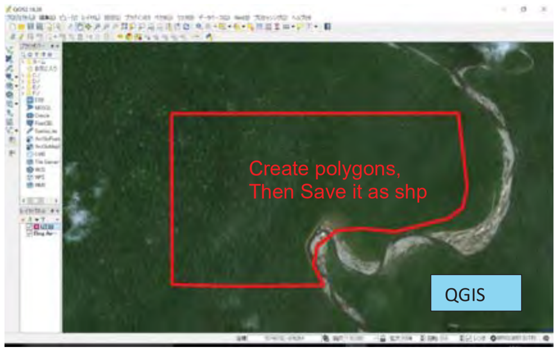


7. Polygons are created in 3 application and saved as;

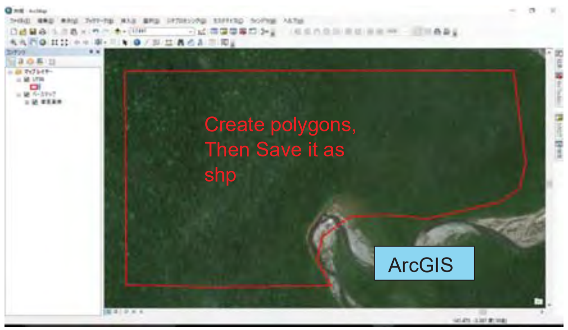
I. Google Earth, as kml



II. QGIS, as shapefiles

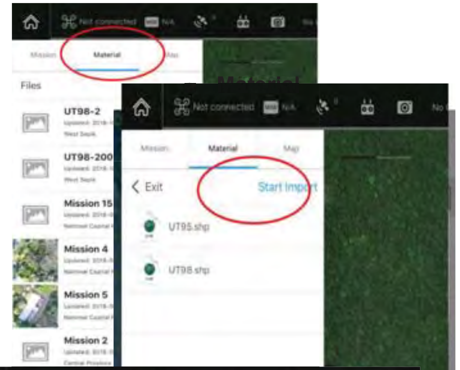


III. Arc GIS, as shapefiles.



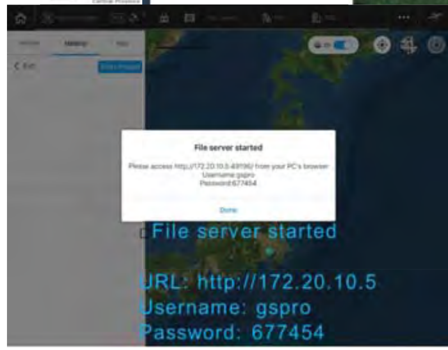
11.2 Import File

IV. On the iPad, click on ***Material,*** a drop-down list contains files/folders. Tap *"files".*



V. Then go to ***Start Import*** to import *KML/SHP files.*

VI. File server started showed on the screen, appeared showing out the ***Uploading file*** and then ***Select kml saved files*** and open.

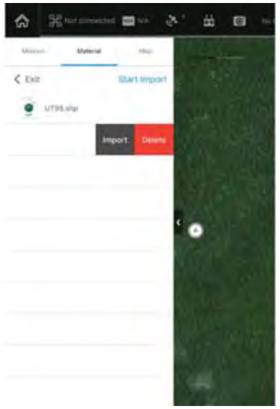


VII. In PC browser, click ***'Upload Files'*** Then select your file

11.3 Create a Mission

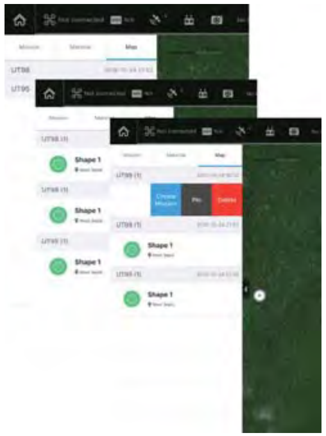
To create mission, In the iPad, saved mission named is shown and ***click Import*** then go to the ***Map*** and select images. On the images, swipe across to ***Create a Mission***.

VIII. To *create mission*, In iPad, *saved mission named* is shown. ***Click Import.***



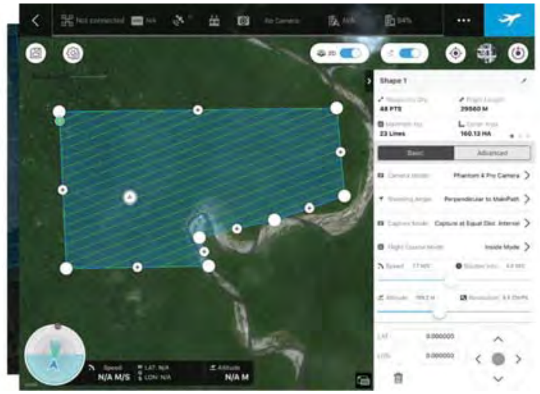
IX. Then go to the ***Map*** and select images.

X. On the images, swipe across to ***Create a Mission***



XI. On ***settings*** > named mission, important features are setup. For instance, the mission shows the waypoint quantity, flight length, main path (number of lines), cover area, camera model, shooting angle capture mode, speed, altitude etc.…***Select 3D Map Area*** as mission type to produce the

XII. An ***established mission*** to leave the home base is ready for the flight.



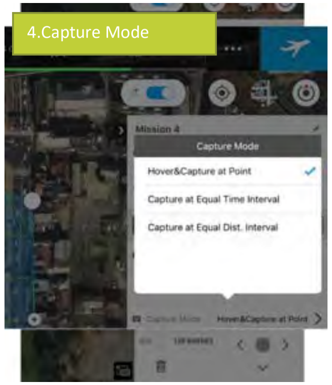
Basic- shows the camera model where it will automatically change when connected to UAV.The shooting angle is checked as a Parallel to Main Path that is the angle of the camera pan axis is the same as the angle of the main path. The pictures are shown in order. Capture Mode selected as Hover and Capture at Point as the application calculate the flight path and waypoint quantity according to the parameters. In Practical, Speed limited is set under 5m/s is preferable with Altitude at 60m from the home point depending on the resolution. Flight Course Mode in 3D Map Area choose Inside Mode, where every part of the flight course generated will be inside the area. Low altitude takes many photos which are sufficient for data processing.

1.Camera Model

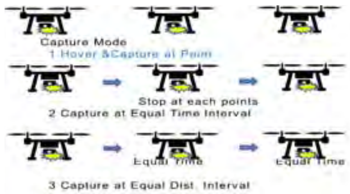
2. Two Main Path

3. Shooting Angle

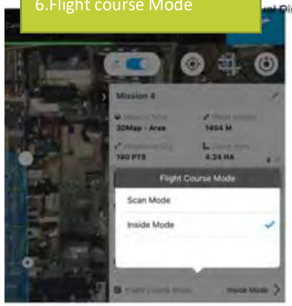
4.Capture Mode



5.Hover & Capture, Capture at equal time and distance Interval



6.Flight course Mode



7.Speed and Altitude

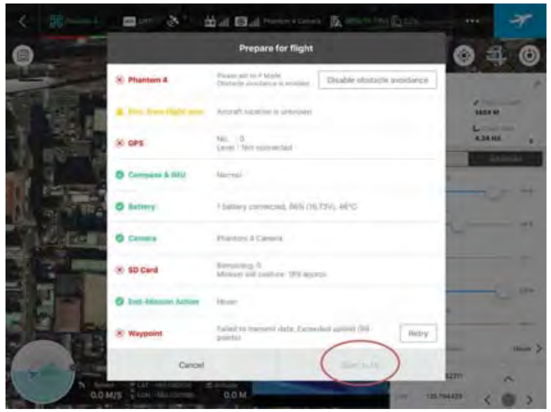
Advanced - Camera Model has set its parameters according to camera and lens used in order to calculate the optimal flight path. Flight Course Mode is set as Vertical to the Main Path which the mission type changes automatically to 3D Map POI.
Front Overlap Ratio 80% (to 90%). Side Overlap Ratio 60% (to 70%). Course Angle is 0° which changes the Angle of the flight as well the flight Length. Margin is 0.0m. Course is adjusted.

1.Front overlap & Sidelap Overlap Ratio

2.Course Angle & Margin

3.End-Mission Action-Return to Home-Hover/Land

4.Prepare for Flight



11.4 Mission Type

Under the Map tag, swipe the desired geometry file (“Create Mission”). Choose an appropriate mission type. Mission types will vary according to different geometries. Select Photo Map, Virtual or 3D Map Area for polygons or waypoints Flight for line strings. The mission’s types are shown below. Hence the most preferred mission type to create 3D map during the training was 3D Map Area.

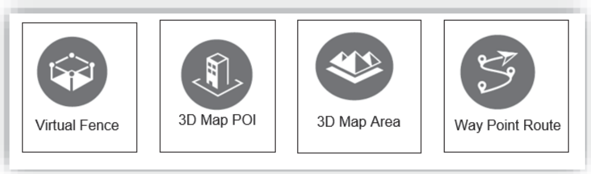
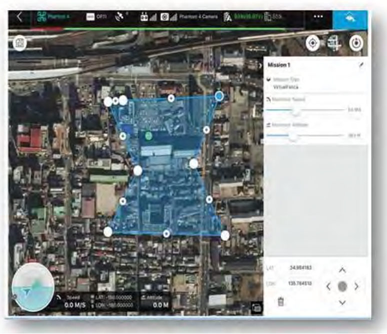


Figure 13: shows different mission types



11.4.1 Virtual Fence

A virtual fence defines a specific area of flight and is useful in scenarios where some areas of a site are no-fly zones or if flight should only happen within one area, such as during manual pesticide spraying or flight training. As the aircraft approaches the boundaries of the virtual fences it will slow to the hover, ensuring it stays with the flight area.

11.4.2 3D map POI

3D Map POI excel at gathering critical data from the physical structures. Its parameters settings are similar to 3D Map Area, such as flight area and action, parameters, and over ratio. With new customizable features like Circle and Verticle,3D Map POI provides complete accuracy for effective structural management.

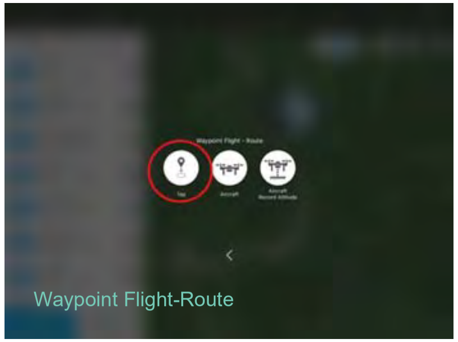
11.4.3 3D Map Area

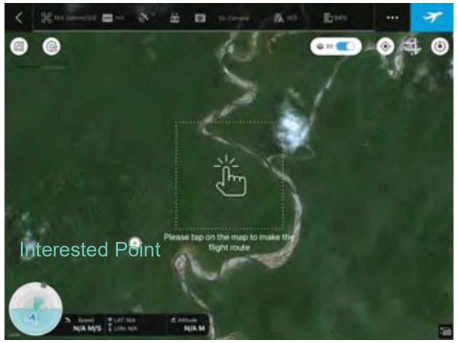
DJI GS Pro automatically generates efficient flight paths after the user has set their required flight area and camera parameters. The aircraft will then follow this route throughout its mission. The image data captured during these flights can be input into 3D reconstruction software to generate 3D maps.

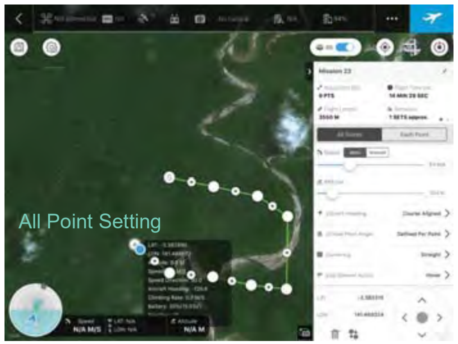
Main Path: The flight path on which the shooting is required is called the Main Path in a 3D Map mission. Flight Path Display is generated when the path is enabled.

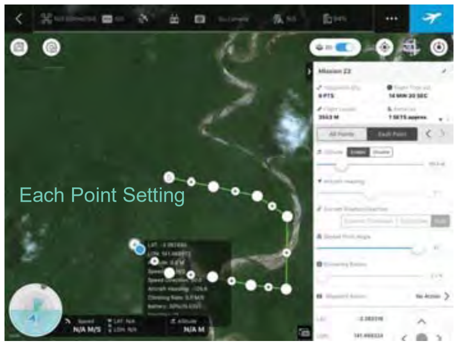
11.4.4 Way Point Route

Way Point Route is tap appearing is the Way Point Setting screen, All Points is selected. Automatically, the speed of the aircraft to fly at the constant speed during a Waypoint Flight mission is 5m/s and relative altitude between the aircraft and take off point during the flight is set to 50m.Images are checked after the flight. There could be some differences in images of cloud cover, noise, out of focus or blurring due to instability of drone. Hence, Each Point Setting also displayed to select a waypoint then set waypoint parameters. Tap “< or >” on the right of “Each Point” to switch to enable the altitude is set as 101.0m. Aircraft Heading is and Gimbal Pitch Angle is 0^0. There is no way point action.









12 Pix4Dmapper for Data Analysis-Process

Pix4D Mapper is the only drone mapping and photogrammetry software tools with a flight app, desktop, and cloud platforms. It creates the 3D Models.

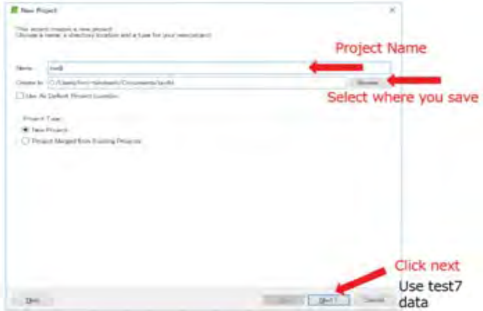
12.1 Pix 4Dmapper

- Data Analysis is captured in a number of steps using the Pix4D mapper. To create a new project:

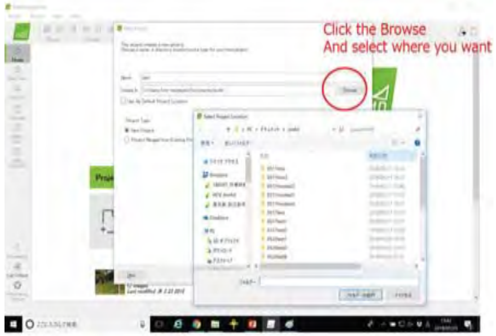
1. To start Pix4Dmapper, it is needed to login. User name and Password is entered with the access of internet to open the Pix4D account.

2. On the Menu bar of the Pix4D Mapper, Click **Projects** and create a **New Project.**

3. The **New Project** wizard opens:
4. *In Name*: type a specify "*Name*" for the project (eg.test)
5. *In "Create in"*: click Browse…On the *Select Project Location* pop up, navigate to select the folder (your saved work).
6. *Select the check box Use As Default Location to save all new projects in the selected folder*
7. *In Project Type,* keep the dealt option *New Project* selected*.*
8. *Click Next*



- Open Browser, dropdown the folder where it's selected to save your work.

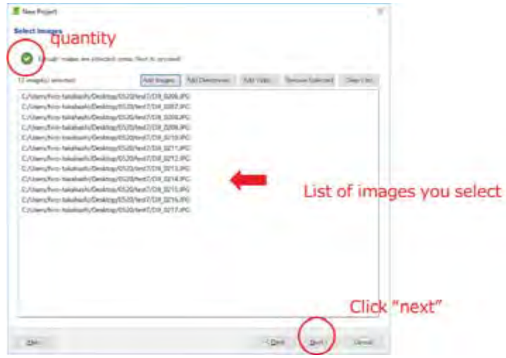


- On the Select Images window:

9. Click ***Add Images (eg Test 7)*** to add the images

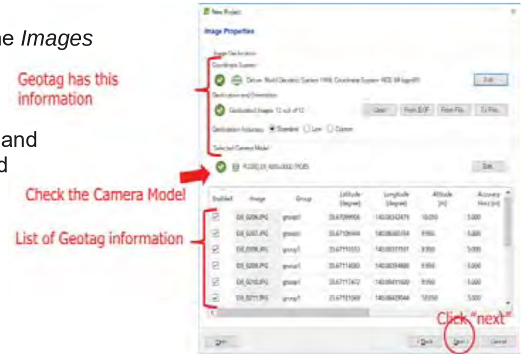
10. On the ***Select Images*** pop-up, navigate to select the folder where the images are stored, selected the images to be imported and *click Open*.

11. *Click Next*



12. The *New Project* wizard displays the *Images Properties* window, click ***From File***. In ***Select Geolocation File*** dialogue, click browser to find the CSV file(eg.GCP.csv) and select it and **open**. Then click OK (importing and exporting the coordinate (longitude & latitude)

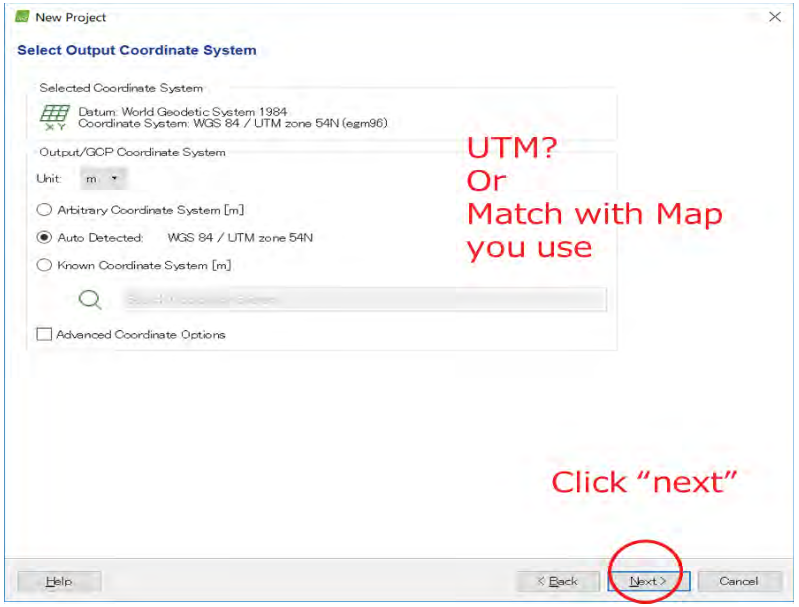
13. Then click ***Next***



14. In the Select Output Coordinate System window:

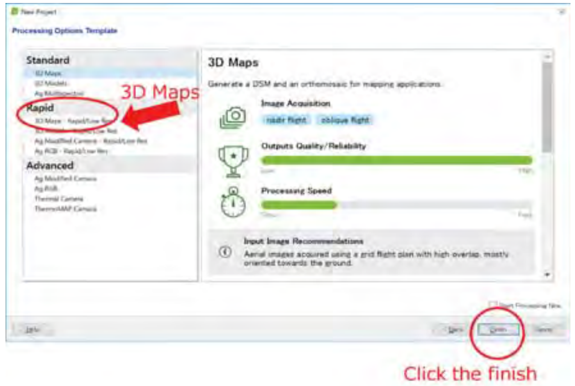
1. Change the output/GCP coordinate system to ***Auto Detect***

2. *Click **Next***

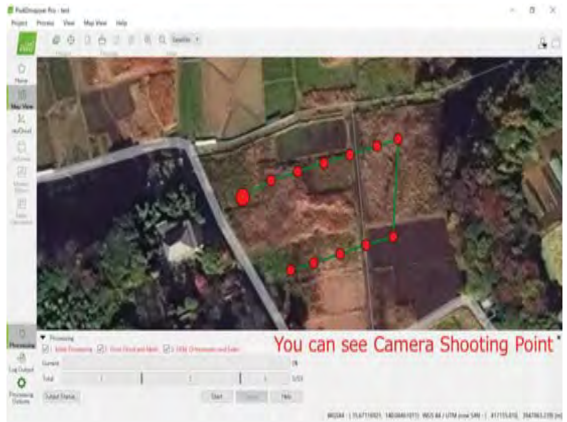


15. In the window ***Processing Option* Template**, dialog box, select **3D Maps-Rapid/Low Res in Rapid** options shown below

16. Click ***Finish*** to close the wizard and start the project

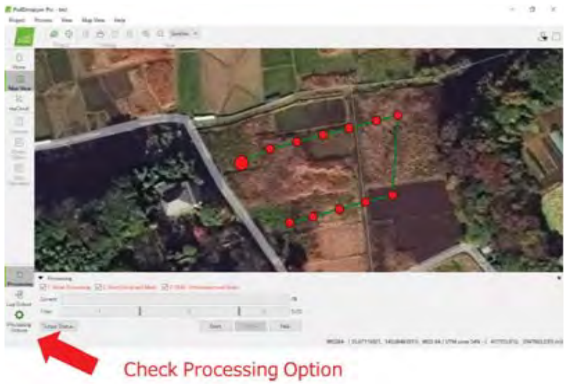


17. Once the project is developed after clicking finish, The Pix4D Mapper dialog box opens with the **Map View** is displayed.

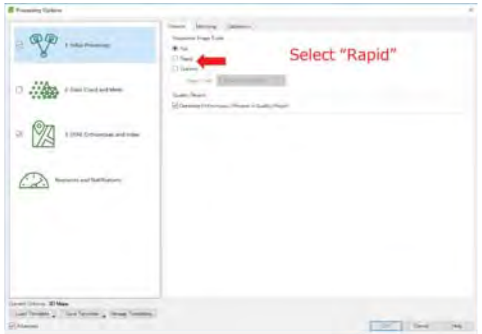


18. **Pix 4D Processing**

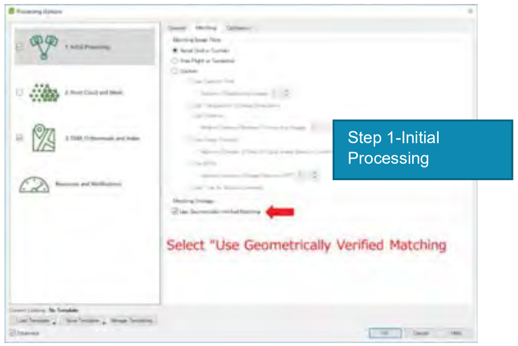
1. Processing can be done one step at a time followed by checking Processing Option or all steps checked and processing option checked at the same time. Here, Processing is done with all steps checked at once, Step 1 **Initial Processing**, Step 2 **Point Cloud and Mesh** and Step 3.**DSM, Orthomasaic and Index,** then click **Processing Options**



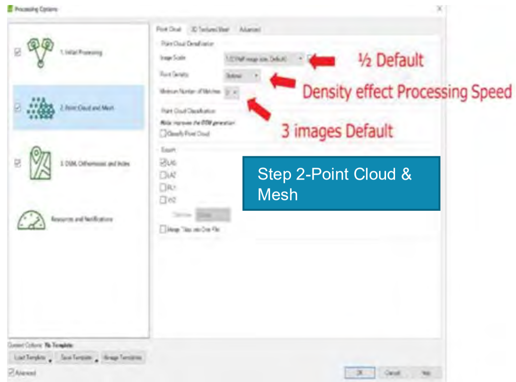
2. In the **Processing Option**, dialog Box, leave everything as *default* and click **ok**



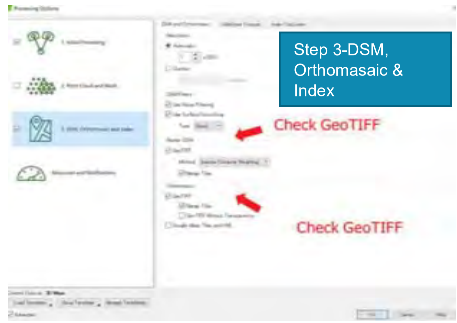
3. The Initial Processing checked to use *Geometrically Verified Matching* and click **ok**



4. **Point Cloud and Mesh** processing option is checked and set image scale to ½ *Default*, *Point density to optimal that gives density effect processing speed* and checked the box of minimum number of matches to *3 images default* and click **ok**.



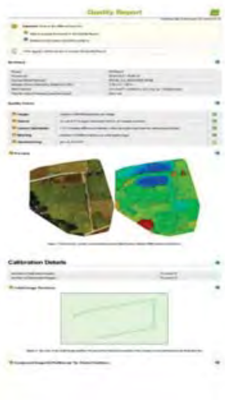
5. **DSM, Orthomasaic and index** is processing option *GeoTIFF* is checked and click **ok**.

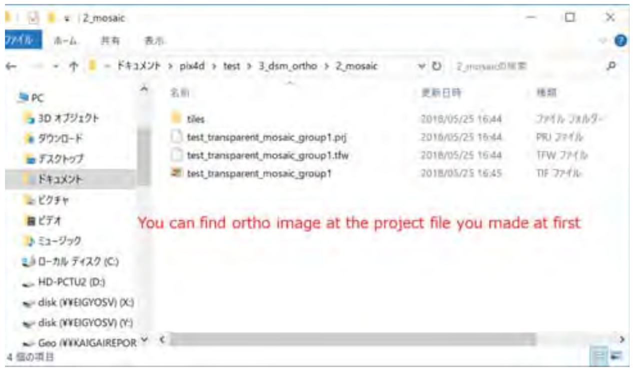


19. To start processing the project:

Once step 1. Initial Processing is completed, the Quality Report is automatically, unselect the Display Automatically after Processing box at the bottom of the Quality Report.

Quality Report





Compiled by Aida KAI

13 Reference

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2. Takahasi H, 2019 March. Power Point Presentation -Drone Training, PNGFA HQ
3. DJI GS PRO, User Manual, 2018.Version 2.0.
4. Pix4Dmapper 4.1, Homepage. User Manual.pdf.

添付資料12

PNG の天然林への伐採による炭素影響を減らすための

政策・措置と PNG-FRIMS の貢献可能性

Japan International Cooperation Agency / Papua New Guinea Forest Authority

JICA-PNGFA capacity development project for operationalization of the PNG Forest Resource Information Management System to address Climate Change

Policies, Actions and Measures for reducing the carbon impact of logging in natural forest in Papua New Guinea and possible contribution from PNG-FRIMS

First version 2015. Last revision 2017.

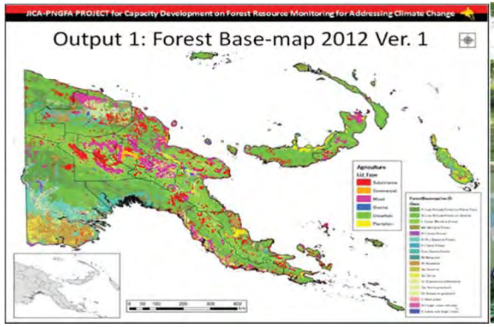


Table of contents

Introduction

Forests in Papua New Guinea (PNG) represent more than 37 Mha (80% of the country's area) and 5% of the world's biodiversity with a high endemism (JICA, 2014). Resources are essential for local livelihoods, national economy, global climate and ecological equilibrium. However this resource is threatening, already 25% of forests are degraded and half from logging. Logging impact is caused by timber extraction as well as collateral damages. Consequences can be significant on biodiversity, watersheds and carbon emissions.

PNG's REDD+ Strategy logically identified sustainable timber production as priority for reducing forest carbon emissions (CCDA, 2017). The Green Climate Fund (GCF) is solicited to "improve the management of production forests" through the development of SFM capacities, forest plantations and alternative production/processing systems. The first priority deals with logging in natural forests and systems for monitoring and law enforcement. In this context, JICA-PNGFA project (referred as "the Project" hereafter) is developing capacities for promoting sustainable forest management and addressing climate change issues. The project targets the Forest Authority of Papua New Guinea as it oversees the planning, monitoring and control of operations in natural forest.

The enhancement of forest data in PNG Forest Resource Information Management System (PNG-FRIMS) is expected to facilitate forest management and REDD+. The design (or adjustment) and implementation of relevant Policies, Actions and Measures (PAM) can be facilitated by a better understanding of forest resources and their evolution. The stakes are very high because SFM approaches can have wide benefits. At the national/provincial level, logging regulations can be strengthened. And at the field level, reduced-impact logging (RIL) practices can improve post-harvest environmental and carbon conditions. For instance, the adoption of RIL methods could reduce CO_2 emissions by 30-50% (Ellis et al, 2013).

So what we need to detail next is some examples of PAM promoting SFM approaches and facilitating the dissemination of RIL methods. Another question is to understand the contribution that PNG-FRIMS and the Project can bring to facilitate the identification and implementation of relevant PAM. These two questions can help clarifying remaining needs for forest management and related PAM expected to be developed in future REDD+ activities. As such, the first section provides a literature review on PAMs that promote sustainability in Planning, Monitoring and Control of logging. The second section describes main potentialities in PNG (including from the project) for implementing PAM conducive to sustainable management. The last part shows supports expected from future REDD+ activities to fill remaining challenges in achieving SFM.

Section 1: recommendations of policies from international literature

The international literature provides recommendations for a sustainable management of production forests. The first objective is to strengthen institutional capacities to organize logging. The second objective is to generalize good practices among logging operators. This section shows recommendations for planning, implementing, monitoring, controlling and valorizing harvest operations (fig.1).

Figure 1: Components of sustainable forest management

1-1: Planning of the Forestry sector

Institutional management of forest generally follows a top-down approach. The application of good practices on the field is pre-determined by realistic yet ambitious functioning rules established at national and/or provincial level. This part summarizes main recommendations for geographical and regulatory planning of the logging sector (fig. 2).

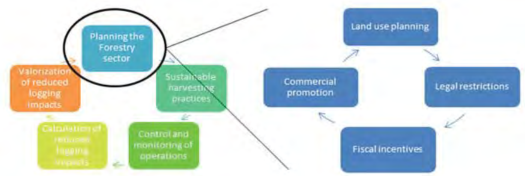


Figure 2: Regulatory and geographical organization of production activities in natural forest.

Land use plans should include a careful consideration of land potentialities and risks as they determine the spatial repartition of human activities and their effects on landscapes. Multi-sector approaches are recommended to limit the encroachment of land uses such as agriculture and mining in forests. In the Forestry sector, national and provincial management plans are key elements to explicit planning. CIFOR (2009) showed that management plans should take into serious consideration the natural resources to avoid any overlaps between production and protected areas. Furthermore, forest mapping and data management systems are critical assets to organize the activities and minimize the impacts.

Legal restrictions are the first PAM option to limit impacts from logging. One of the most utilized harvesting quotas is the Annual Allowable Cut (AAC). AAC enables a limitation of volumes harvested at the level of the country, province or concession. Also the Minimum Merchantable Diameter (MMD) limits exploitable trees to facilitate regeneration. Constraint areas (buffer, sloppy, erodible and inundation areas) are determined to restrain zones of exploitation. Furthermore, specific PAM can promote SFM approaches such as the ones which attempt to make RIL practices, wood certification, training of forest workers or fire control systems, mandatory or at least highly recommended.

Incentive systems from fiscal PAM can play an important role in urging logging operators to comply with national standards. The following examples are adapted to different contexts:

- Reduction of export taxes for compliant projects;
- Application of fines for non-compliant projects;
- Calculation of royalties based on standing instead of exported volumes to avoid waste;
- Performance bonds deposited in a government account at the beginning of the concession period and gradually returned when good practices are reported.

Commercial standards can complement further PAMs by fostering or rewarding SFM/RIL practices. The objective is to secure an access to premium prices and preferential buyers to cover possible loss from efforts. The Forest Stewardship Council (FSC) is the first standard for certifying tropical forest management. FSC principles (2015) urge for respecting laws, forest groups (workers, communities and indigenous peoples) and the multiple benefits of forest such as environmental services and biodiversity. They guarantee good practices in planning, implementation but also assessment of operations. Sustainable Forestry Initiative (SFI) and Tree Farm System are other famous standards although less relevant in tropics. Timber Legality Traceability Verification standards from the EU FLEGT initiative (European Union Forest Law Enforcement Governance and Trade) are basically design to address illegal logging. But these standards can be useful to demonstrate compliance of operations (another form of legality).

1-2: Planning and implementation of harvest

A sound spatial and regulative organization of the Forestry sector facilitates the application of good practices on the ground. Most of the tropical countries integrate Reduced Impact Logging (RIL) standards in their guidelines or codes. RIL practices are described by ITTO (ITTO website) and FAO (Killmann, FAO website) as an intensively planned and carefully controlled implementation of timber harvesting to minimize waste and the environmental

impact on trees and soils. This part provides a summary of recommendations [Sist et al. (1998), IUCN/ITTO (2009) and Applegate et al. (2001)].

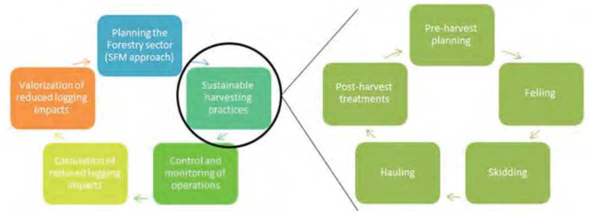


Figure 3: Harvesting steps

Pre-harvest planning should include:

- Long term plans (> 10 years; 1/50000) that identify protection and production areas;
- Mid-term plans (3-10 years; 1/25 000) that delimit coupes and estimate volumes;
- Annual plans (1/1-5000) that map units (streams, roads, landing areas and skid trails) and plan inventories of sound, inaccessible and protected trees, the cutting of vines and the detection of hollow trees (to avoid felling defective trees).

Felling recommendations are as follow:

- Directional felling to minimize gaps and protect future harvest trees (fig. 4 and 5);
- Improvement of bucking to recover all commercial round wood;
- Cutting of stumps low to the ground to avoid waste.

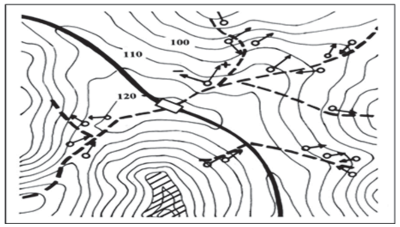
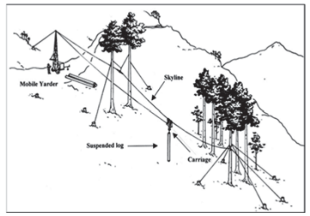


Figure 5: Directional felling planning. Arrows indicate felling, solid line roads and dashed lines trails (Plist, 1998)

Figure 4: Harvesting neck used to facilitate directional felling (Tiger Cat website)

Skidding (felling sites to trucks) should:

- Minimize skid length by planning bulldozer trails;
- Ensure dozers remain on skid trails/roads all time;
- Use long line winching in sloppy fields (fig. 6).



Hauling (trucks to ports) should narrow width of road corridors and limit number and area of log landings.

Figure 6: Skidding by log line winching (Sist, 1998)

Post-harvest treatment is highly recommended by taking into consideration the following:

- Areas to treat: landing areas and further gaps;
- Techniques of planting (gap or line) according to the area to treat (Maswar, 2001);
- Spacing types and fertilizer dosages as appropriate (Widiyatno, 2013);
- Role of assisted natural regeneration (native species), fast growing plantation (exotic species) and agro-forestry (mixed trees/crops).

1-3: Control operations and monitor forest degradation

Policies promoting a strengthening of monitoring capacities are also very relevant PAM for SFM. The variation of carbon stocks from logging is due to (1) wood extraction (for timber) and (2) damages collaterally caused by this extraction. Wood extraction is usually assessed by actual harvested or exported volumes. Collateral damage is due to log roads, landings, trails and tree damages. Monitoring is more challenging. IPCC (2006) suggest three methods:

1. Field inventory from a whole inventory (for limited areas) or sampling;
2. The utilization of proxy and indicators;
3. Forest cover assessment from Remote Sensing technologies.

Field inventory

- Scale: local (the scale of logging setups).
- Accuracy in determining collateral damage: high as even damaged trees are assessable.
- Challenges: consuming in time and manpower so that the generalization is difficult.
- Parameters to monitor collateral damages such as suggested in guidelines and codes:

✧ Felled trees abandoned (number, H and DBH)
✧ Logs abandoned excluding entire trees felled and abandoned (number, H and DBH)
✧ Stumps wasted, greater than 30cm above fluting (number, H and DBH)
✧ Trees (DBH> 20 cm) damaged by skidding, dead trees only (number, H and DBH)
✧ Average width of roads (m)
✧ Length of roads (m)
✧ Total landings area (m2).

Proxy method

- Scale: local (records in setups) to provincial or national (province/country statistics).
- Accuracy in determining collateral damage: medium as it corresponds to an evaluation
- Challenges: find relevant or reliable indicators.

There is only one carbon methodology in the Land sector dealing with RIL and collateral damage, from VCS (Verified Carbon standards) using a mix proxy-inventory method (tab. 1).

Table 1: Logging impact parameters used in the methodology "VM0035: Reduced Impact Logging practices that reduce carbon emissions" (Terra Carbon/TNC, 2016). In blue, none inventory is needed.

Logging impact parameters = Proxies	Baseline (Borneo)	Target
- Av % of felled trees abandoned	25%	5%
- Av. % of trees where vines were cut 3 - 6 months before harvesting	10%	100%
- Av. number of trees (DBH > 20 cm) destroyed by skidding per ha	20 trees/ha	5 trees/ha
- Av. % of bulldozer skidding area employing planning standards	5%	100%
- Av. % of concession area logged with long line system	< 5%	15 to 50%
- Mean width of haul road corridors (m)	40m	20m
- Mean size of log landings (m2 / ha of setup)	100-900 m2/ha	30 m2/ha

Remote Sensing (RS) method

- Scale: national to local according to sensors resolution;
- Accuracy in determining collateral damage: low to medium (tree damage not detectable);
- Challenges: availability (and price) of high resolution images and time series.

RS detection of forest degradation is possible from sampling, wall-to-wall mapping or a combination of the two methods (IPCC, 2006). Medium (30m) or better spatial resolution is preferential. Therefore wall-to-wall approaches coulb be onerous. Because of that plus the practicability (for statistical analysis), sampling methods are preferred (cf details in sec. 2).

1-4: Measuring and valorizing reduced impacts from logging

Measuring emission reductions achieved through RIL. Carbon is an interesting factor to appraise the state of forests as it federates (i.e. it has a strong correlation with) several key environmental parameters such as biomass, biodiversity, forest cover, shadow, water services, etc. According to IPCC (2006), carbon performances can be calculated as follow: Emission Reductions = AD x EF.

- *AD* (Activity Data) corresponds to the area of land transition. It can be determined through Remote Sensing or proxy methods;

- *EF* (Emission Factor) that corresponds to the carbon content in converted lands. It is determined by following the calculation steps below:
  - Step 1: measure tree height and diameter at breast height (dendrometric measure);
  - Step 2: calculate biomass from diameter and/or height (allometric equations);
  - Step 3: calculate carbon content from biomass (conversion)
  - Step 4: calculate Below (BGC) from Above Ground Carbon (AGC) (Root/Shoot ratio).

One example of measurement of Emission Reductions (ER) is provided below (VCS, 2016). It shows the reduction in emissions from improved felling. The same methodology can be applied for ERs from AGC or BGC due to an improvement of skidding or hauling.

Possible valorization of forest management and practices improvement are shown below (tab.2).

Table 2: Means to valorize Forestry/Climate benefits from SFM/RIL. *(*SEM: Stock Exchanges Markets)*

Elements to be valorised	*Place for valorisation*	*Rewarding types*	*Beneficiaries*
Forest management practices compared to FSC standards	Wood SEM*	Wood certification	Logging operators (private companies or communities)
Emission reductions compared to a project baseline (ex.: VCS project covering one or several logging sites)	Carbon markets (Voluntary)	Carbon credits	Carbon project developers and indirectly project stakeholders
Emission reductions compared to a jurisdiction baseline (VCS Jurisdictional Nested REDD or WB Carbon Fund)	Carbon markets or fund	Carbon credits	Carbon project developers and indirectly stakeholders in the sub-national jurisdiction
Emission reductions compared to a national (or provincial) Forest Reference Level	UNFCCC (fund or market)	REDD+ finance	Institutions at the national (or provincial) level and indirectly other stakeholders

One of the main challenges for valorizing PAM promoting sustainable forest management may lie in quantifying sustainability. This appears particularly important in the context of REDD+ Result Based Payments. Deforestation, Forest degradation or Carbon stock enhancement can be defined based on a rate. At contrary, to define SFM based on a rate, threshold or point is difficult. In reality, the definition of the level of sustainability in forest management is closer to a combination of relative parameters or a grey zone. One suited approach could be to attribute to each Planning, Monitoring, Control component an indication of sustainability based on indicators. For example: has the "land use planning" activity been carried out in a concerted manner? Are harvesting quotas strict compared to international values? Etc. Figure 8 is an attempt to summarize the concept.

Figure 7: evaluation of improvement in forest planning, monitoring and control (PMC)

<u>Section 2: potentialities from PNG-FRIMS for supporting SFM policies</u>

Planning, Monitoring and Control activities conducted by the Forest Authority in Papua New Guinea are summarized in figure 9. PNG potentialities, including from JICA/PNGFA project support and PNG-FRIMS, are shown for each component of forest management.

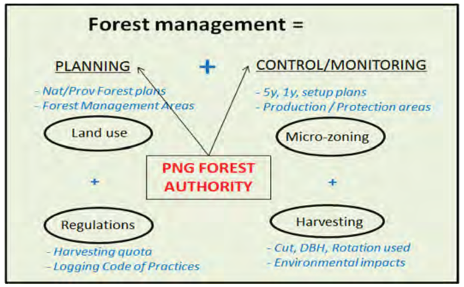


Figure 8: procedures of forest management led by PNGFA. They include the planning of land uses and regulations, and the control of zoning and practices realized by logging companies.

2-1: Potentialities to support land use planning

Forest plans: geographical repartition of activities is explicit in PNG's national forest plan, provincial forest plans and forest management plans. To improve suitability of production areas, both national and provincial plans are currently under review, along with the support from the Project. This review is based on improved decision-making tools detailed below.

PNG forest cover mapping system is:

- Based on the Forest Map 1996 and FIMS (Forest Inventory Mapping System) that provides an estimate and cartography of timber volumes; and
- Developed in the 2012 Forest Base Map (FBM) that offers a benchmark of land covers with detail on forest strata. Two JICA projects (from 2011 and 2014) enhance PNGFA capacities to create, update and utilize FBM.

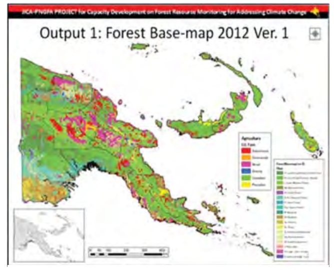


Figure 9: Forest Base Map as a new key planning tool in Papua New Guinea.

PNG management system of forest data (and logging data in particular) is:

- Based on FIPS (Forest Inventory Processing System) that reports timber volumes from field surveys (without mapping info); and
- Developed in PNG-FRIMS (Forest Resources Information Management System) which is the main outcome of the current Project. It integrates pre-existing applications (FIMS and FIPS) and new functions for editing (Arc GIS) and browsing (Lan Map) forest information.

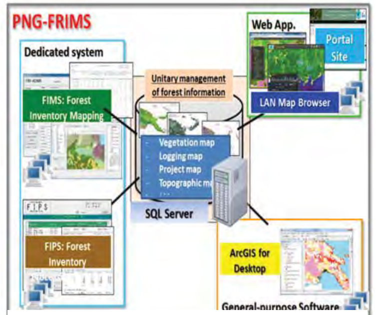


Figure 10: PNG-FRIMS components

Possible support from the Forest Base Map and PNG-FRIMS in land use planning (N.B: this aspect is detailed in further documents from the project).

i- Facilitate proposing new logging concessions at the national or provincial scale by integrating information on land potentialities and risks such as:

- Vegetation maps and information: timber volumes, carbon stocks and regrowth
- Information on constraint areas: FCA, plantation, wildlife management, mining areas...

ii- Facilitate planning logging activities within concessions by integrating such information:

- "Topography" information as roads, rivers, villages, slopes and hill shapes;
- Information on logged-over areas, current concessions and planned areas;
- Degradation thanks to three time series of forest cover maps (2000, 2005 and 2011).

2-2: Potentialities for PAM promoting Reduced Impact Logging

Quotas used in PNG to limit wood extraction are presented in table 3.

Table 3: Harvesting quota in PNG and related decision documents and makers.

Regulations	*Policy documents; policy makers*
AAC (Annual Allowable Cut)	National and provincial forest plans; PNGFA Forest Policy and Planning directorate, Forest Inventory & Mapping Branch, National Forest Board
Number of permit	Provincial Forest Management Committee; National Forest Board
Volume allocated	FMA (Forest Management Agreement) and 5-year plan; PNGFA
Constraint areas	FMA, Logging Code of practices (LCoP), should appear in the 5y plan; PNGFA
MMD	LCoP (new version only) and 5-year plan; PNGFA
Rotation cycles	FMA; PNGFA

Possible needs in amending quotas are currently being reviewed, in particular the method to determine AAC used in forest plans. The process may be coming with the review of LCoP.

The project is expected to raise awareness and knowledge on deforestation, degradation and climate change issues. This should strongly influence decision makers so then decisions. Ex.: the selection of bidder companies from Province Forest Management Committees.

PNG fiscal PAM to incentivize good practices

Table 4 sets out what modalities would be operated and what institutions involved if fiscal PAM options as recommended in section 1 were implemented in PNG.

Table 4: Tentative fiscal policies, modalities for RIL and non-RIL concessions, and the institutions involved.

PAM options	*For **low impact** projects*	*For **high impact** projects*	*Possible institutions*
Fiscal	Subsidies / rewards	No	PNGFA?
	Income tax reduced	Income tax not reduced	Budget, Finance?
	Export tax reduced	Export tax not reduced	Commerce?
	No fine	Fine	Forest, Justice?
	Performance bonds returned	Bonds not returned	Forest, Finance?
Commercial	Premium price	Regular/low price	Stock Exchange Market, FSC
	Preferred buyers	Buyers/traders	

		uncertain	

The table above can be a good basis for examining the feasibility of fiscal options. The priority is for policies that directly relate to the Forestry sector (subsidies and rewards). Exploring other options is beyond the scope of the Project and sometimes beyond the scope of PNGFA as it is shown. Multi-sector approach like REDD+ can be supportive (see Section 3).

PNG commercial PAM to promote RIL practices

FSC has established an office in PNG. Voluntary certification is now recognized (EU-FLEGT, 2016). Three concessions are currently under FSC certification:

- 10 000 ha in Eastern New Britain (Open bay timber, Japan, Sumitomo group);
- 20 000 ha in West New Britain (Stetin Bay Lumber Company, Malaysia); and
- 5000 ha developed by a national company (3 A Composite PNG Ltd).

ENB and WNB concessions are plantations of Camarere (*Eucalyptus deglupta*).

Also, standards under the Decision Support System (DSS) are tested in two concessions. Consultations are on-going regarding the application of Timber Legality Standards (regrouping FSC and EU-TLTV standards) to decide whether they will be voluntary or mandatory. In relation with this, RAFT-2 project (2012-15) realized capacity building on RIL techniques. RAFT-3 project is currently under consideration (EU-FLEGT, 2016).

The collaboration (or at least relationship) existing with private loggers in the Project pilot provinces is a good opportunity to heed their interests and challenges in certification. The Project may also participate in facilitating inputs from the PNG FSC office in the LCoP update process. FSC input can be critical to ensure PNG standards are compatible with the most recent recommendations and to accelerate leverage of green investments.

2-3: Systems and capacities to control logging activities

Assessment of the zoning in Forest Management Agreements (FMA)

Forest Management Plans (FMP) are reviewed and approved by PNGFA 'Forest Policy and Planning' directorate (FPPD), five-year and one-year plans by the 'Project Allocation' Directorate (PAD) and setups plans by project supervisors.

Main challenges identified in the Project when reviewing FMPs are as follow:

- Maps provided by logging managers are often in analog format. This issue may have consequences on the uncertainty of boundaries and time for analysis;

- Reference maps used for review may be outdated and/or imprecise (contours) and the scale of the maps too small.

The Project may facilitate assessing the impact of the FMA zoning by:
- Identifying potential overlapping of logging projects' boundaries;
- Identifying potential encroachment of production with protection areas;
- Validating road alignment and overlapping with the help of field records of boundary.

New PNG-FRIMS functions are expected to facilitate this assessment through the following:
- Manage PNG-FRIMS and FBM data and maps thanks to FBM Portal site;
- Update information in PNGFA headquarter thanks to Web GIS function;
- View information in field offices thanks to Lan Map (Web browser map);
- Detail and validate information based on field observation thanks to GPS.

Control of the actual application of the Logging Code of Practices

PNGFA is decentralized in areas (area managers) and provinces (project supervisors and inspectors) to respond to the important number of logging business projects (more than four concessions per province in average). The application of logging standards is controlled by local officers supposedly before, during and after operations.

Table 5 regroups challenges in control as shown in discussion with local officers. It is noteworthy that a further in-depth gap analysis is needed for more accurate conclusions.

Table 5: Examples of identified challenges in the control of logging operations in PNG

Examples of challenge	*Possible reasons*
Resources (man / day)	Time (several set-ups can be opened at the same time), distance between sites, availability of vehicles, monitoring tools and technical capacities.
Independence of supervisors	Logging companies in some cases provide logistics including accommodation to supervisors.
Capacity of operators to apply recommendations	Regular re-affectation of logging managers and not systematic training of logging companies' workers
Follow-up of recommendations	Supervisor recommendations are often limited to oral suggestions (rare penalties). Follow-up application of recommendations is time consuming
Stopping operations in case of non-respect	Consequences for local economy i.e. for companies, landowners and/or local communities (when employed in logging sites)

Realization of post-harvest control	Time consuming and not priority when new setups open in the same time (or further reasons leading to over workload)

2-4: Capacities for monitoring forest degradation

Field monitoring of the logging impact in PNG

PNG standards are described in the 1996 Logging Code of Practices (PNGFA & DEC, 1996) annexed to "Planning, Monitoring and Control procedures for natural forest logging operations under timber permit". They integrate international RIL recommendations. Many standards relate to pure environmental criteria such as soil, water and disposal. Some standards specifically concern the degradation of trees or vegetation and thus have a direct relation with carbon stocks. Based on LCoP standards, project supervisors have practically to report in "Field assessment sheets" whether the following conditions are met:
- Wasted logs < 3% of total extracted logs;
- Number of stumps above 50cm is not important;
- Number of trees not felled into gaps created by harvesting is not important;
- Roads width < 40m;
- Roads area < 10% of setup area; and
- Number of landings < 3 and area < 2500 m2 (0.25ha).

As a result, field assessments collect a lot of useful information for evaluating the impact of logging on forest carbon.

Main challenge for carbon monitoring is that field assessment method is qualitative. Field assessment sheets are often filled with Yes or No and not with numerical values. This certainly provides a good ratio of "time spent for assessment" *versus* "indication on compliance". In other words, this information is sufficient to determine whether or not the operations comply with threshold values fixed in the LCoP and can be approved. However, it is difficult to exploit such information for measuring carbon loss and providing a consistent basis to performance-based payments. But the quantitative methods (providing numerical values) may also suffer from challenges, such as set out below:

1. Demanding in time and human resources to:
   - Count/measure H and DBH of wasted logs, trees felled and stumps above 50cm;
   - Measur roads width in several points (to get mean values);
   - Measure landings' length and width.
2. Demanding in capacities to apply certain rules specific to carbon assessment that may differ from forestry methods (ex.: determine carbon pools or impact parameters).

The Project does not directly support field carbon monitoring. But PNG-FRIMS include functions such as GPS, GIS and Lan Map that can enable identifying positions and calculating distances. This support can be useful in estimating the length of logging roads and size of landings, locating damaged trees and checking if boundaries overlap. REDD+ may be critical to provide complementary supports to this issue (section 3).

Methods using Remote Sensing

Several activities in the Project participate in improving PNGFA capacities to analyze forest degradation through RS analyses:

i. Integration into PNG-FRIMS of spatial parameters (indicated in carbon methodologies) required to determine boundaries, forest stratification, DD location and drivers;
ii. Consensus within PNGFA on forest definitions and categories useful for analyses;
iii. Training on the delimitation of logged-over areas and logging history;
iv. Evaluation of different types of sensor and resolution to detect degradation spots and drivers. Medium and high resolution images are used in the Project: Rapid Eye (5m pixels), Hansen data (30m, loss of forest covers) and Collect Earth (fig. 12);

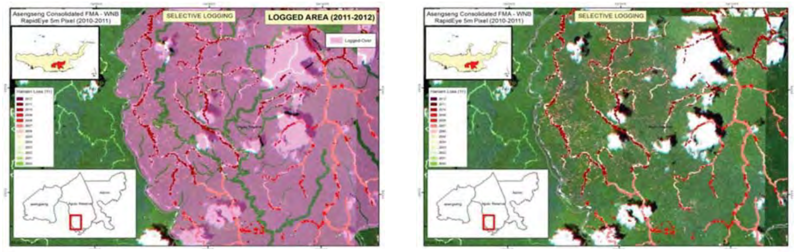


Figure 11: Examples of RS analyses conducted in the Project

v. Dissemination of RS and GIS tools in PNGFA local offices (fig. 13):
   - Provision of material (PC and GPS) and software to Area and Province offices;
   - Development of capacities to analyze degradation from RS and GIS analyses.

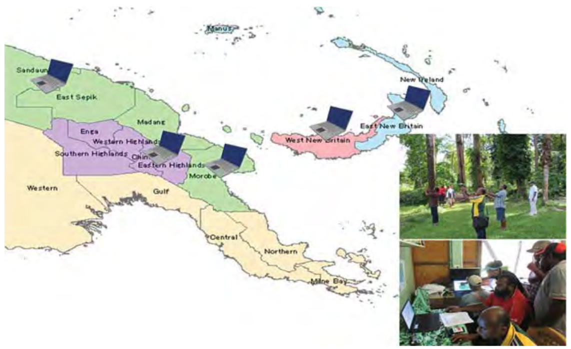


Figure 12: RS/GIS trainings conducted by the Project in several locations in 2016. PCs indicate locations.

To conclude this section, PNG fills many conditions that are required to efficiently plan land uses, set up adapted regulations, control operations and monitor forest degradation. Forest plans, harvesting standards and decentralized offices are important assets to achieve SFM. The Project is expected to bring an improvement in forest information, data management and mapping systems. The objective is to support PNGFA in planning the logging sector at provincial and national levels, and in controlling the planning and execution of local operations. Nevertheless there remain several challenges in forest management such as a multi-sector planning of land uses, amendment of harvest quota or activation of fiscal levers. One further critical challenge is the monitoring of logging impacts.

<u>Section 3: expected support from future REDD+ activities</u>

REDD+ aims at identifying, and facilitating the implementation of, low emission development options in land sectors. One objective is to attract investments for sustainable businesses. In the Forestry sector, SFM corresponds to a critical approach of low carbon activities because integrated approaches in the organization of logging seem to have the potential to lower impacts. Therefore, PAMs conducive to SFM appear very relevant targets for REDD+ support. Figure 14 highlights close ties between SFM and REDD+ and the virtuous cycle allowed by performance-based supports.

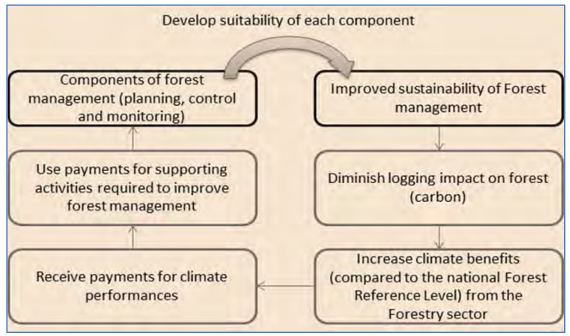


Figure 13: Virtuous cycle of improvement in forest management allowed by performance-based systems.

3-1: PAMs to address remaining challenges in planning

Land use planning

First target is to develop land use planning in a development strategy that is common to all land sectors and that promotes carbon neutrality. Factors to consider are as follows:

- Ensure political engagement to avoid overlapping between sector activities;
- Facilitate pluri-disciplinary dialogue between main agencies (PNGFA, DAL, DEC, etc.)
- Exchange consistent data between sectors like during the preparation of FBM and Terra PNG (defined below).

Second target is to mainstream SFM principles into national and provincial forest plans. The planning of initiatives relevant for SFM can be facilitated by the utilization of FBM and Terra PNG. Terra PNG is displayed in the REDD+ Web portal and regroups simple but time series wall-to-wall maps, sector activity data and land cover changes. Main initiatives are:

- Initiatives supporting RIL and regeneration in the logging and logged-over areas;
- Conservation initiatives in the high-value areas (notably high spots of biodiversity);
- Agro- and forest plantations valorizing grasslands and heavily disturbed forest areas.

Forestry regulatory framework

A holistic approach expected to bring a global impact in limiting degradation can consist in:

- Restrictive approach supported by legal PAMs that limit extracted volumes;
- Incentive approach supported by fiscal/commercial PAMs that foster good practices;
- Advisory/advocacy approach supported by PAMs that facilitate the implementation of good practices (ex.: guidelines, trainings and awareness rising). See figure 15.

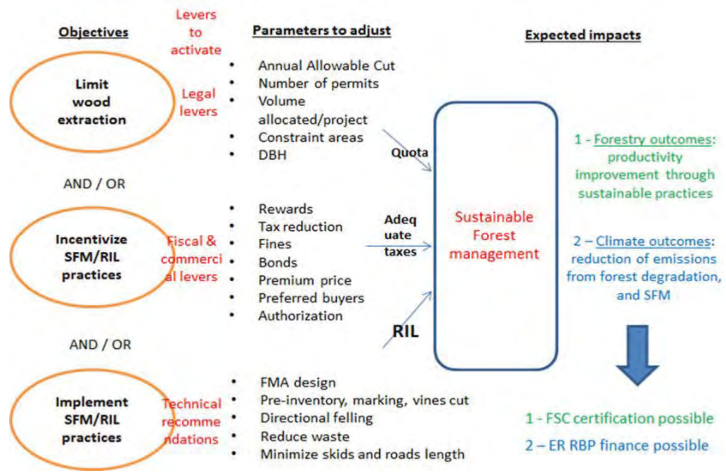


Figure 14: Levers to activate for reducing degradation from logging (holistic approach)

Significant changes in legal, fiscal or commercial policies cannot be processed without prior feasibility studies that discuss the following in detail:

- Involved stakeholders by mapping and identifying their role and capacities;
- Opportunity costs for each policy option by modeling changes in both economic and ecological aspects. For instance, reducing export taxes for compliant concessions may cause a direct loss in the country's budget. Such opportunity costs can be evaluated and a covering (compensation) system can be elaborated accordingly.

3-2: PAMs to address remaining challenges in control and monitoring

Control of logging

PAM with a high potential for improving the quality of control are presented here (tab. 6). To increase the efficiency of future supports, realistic interventions must be designed. Feasibility studies are thus necessary notably to determine the associated risks, costs, practicality and potential benefits for each option.

Table 6: PAMs to overcome challenges in the control of logging as identified in table 5 (section 2)

Challenges	*PAM options (expected to have a high potential of change)*
Independence of supervisors	- PNGFA facility (supervisor housing/office) in each logging concession - Regular re-affectation of PNGFA project supervisors (every 3/5 years)

Efficiency of forest workers	- Nomination by logging companies of one focal point for the whole project duration - Regular trainings to field workers with possible external support (funds, trainers)
Post-harvest control	Operator contribution for post-logging inventory (compulsory in LCoP) and relevant treatments such as assisted regeneration or agroforestry (voluntary)
Consideration of PNGFA supervisor recommendations by operators	Standardized response to non-compliance based on three levels (tentative): 1. Notice to field managers 2. Notice to permit holders and fines 3. Temporary then definitive suspension of the permit
Cover impact of punitive measures	System of subsidy to provinces to compensate their income losses (taxes, royalties, local community employments, etc.) associated with operation stopping

Carbon monitoring

The first target is to quantify collateral damage. Figure 16 shows how to monitor carbon by adding few (but resource-demanding) activities to routine assessments done by supervisors.

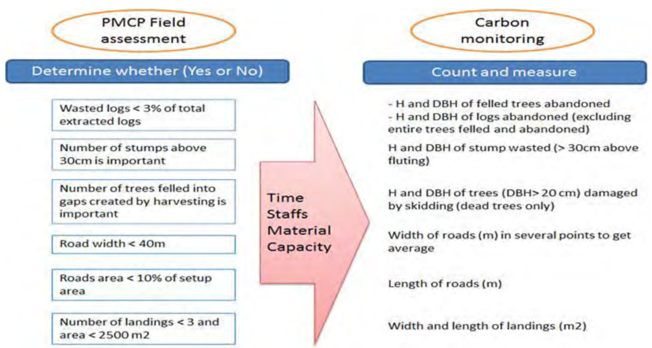


Figure 15: Additional activities to include carbon monitoring component into routine assessment.

PMCP: Planning, Monitoring and Control Procedures realized by PNGFA.

The potential parties to carry out carbon monitoring are presented below:

- PNGFA project supervisors to oversee or realize inventories;
- Logging company workers for inventory, and/or
- Local communities living and/or working in concessions (community monitoring).

Main needs are as follow:

- Funds to cover the costs from additional staffs;
- Materials for instance: information (maps and forest data) and technologies (GPS, etc.);
- Capacities and training on carbon monitoring and specific carbon parameters;
- Regulations by integrating a climate component into PMCP documents:
  - Additional module in PMCP related to the carbon monitoring procedure;
  - Additional parameters in the checked items list (PMCP field assessment sheet).

The second target is to determine forest degradation at the scale of a province or the country. As such, setup data need to be scaled up and data issued from different scales and methods homogenized

The scale for measuring the performance of interventions is the province or the country because the benchmark of emissions is a provincial or the national Forest Reference Level (UNFCCC). Thus, collateral damage data recorded in setups cannot be directly used to calculate Emission Reduction performances. Nevertheless, if data are systematically monitored in setups, they can be "accumulated" at the concession level, assuming there is no degradation in the concession other than in setups. Then, concessions' values can be accumulated to get degradation values in each province, assuming there is no degradation in the province other than in concessions. Both assumptions are logical because the objective here is to evaluate the degradation from commercial logging rather than from other drivers. Eventually, provincial or national data on collateral damage (field methods) can be added to data on exported volumes (proxy) and observed logged-over areas (RS).

Then at the national (or provincial) scale, RS data can be used to determine the extent of logged areas (Activity Data). Data of collateral damage and proxy of export volumes can be used to determine the carbon content of logged forests (Emission Factors). As such, the emissions from forest degradation due to registered logging can be appraised, and the effect from interventions measured. See figure 17.

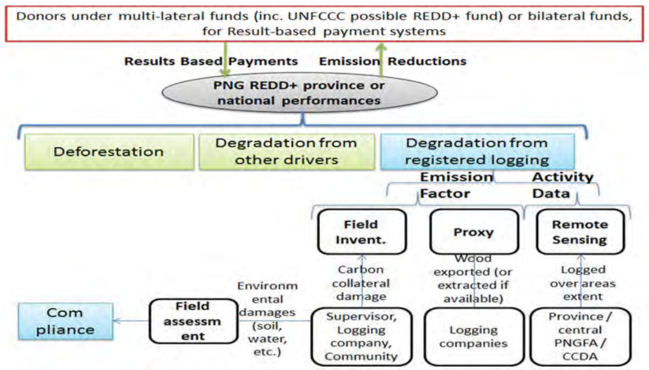


Figure 16: Collateral damage integrated in the calculation of provincial / national Climate performances.

3-3: PAM to valorize ERs and share benefits

There are two levers to reduce forest degradation from logging: to improve forestland use (referring to institutional organization and policy regulations) and to improve field harvesting practices. Valorization systems should reward both types of effort. The costs to fill institutional gaps are due to the design and implementation of PAMs while the costs to follow good practices are mainly due to additional materials and resources. This part discusses REDD+ Benefit Sharing and Distribution systems to promote SFM/RIL efficiently and fairly. Prior to it, this part shows the prerequisites for REDD+ support (Forest degradation / SFM should be in REDD+ scope and interventions respect safeguards).

SFM is not one of the 5 REDD+ activities selected by PNG. But the activity "reduction of forest degradation" is selected, and SFM can have for effect to reduce degradation. So SFM efforts could be actually accounted and rewarded. CCDA (2016) highlights the importance to address commercial logging as the first driver of emissions. PAMs prioritized in PNG are in line with the promotion of SFM and RIL:

- The prescribed "clarification of forest legislation" can indeed contribute to strengthen forest management components (notably regulations and land use planning);
- The prescribed "strengthening of applications" can step up the implementation of logging standards.

SFM approaches (including RIL practices) are respecting REDD+ safeguards, notably the standards related to:

- The Environment by limiting the erosion of biodiversity, soils and hydrologic services;
- Stakeholders by enhancing worker safety, land tenure and conflict regulation;

- National regulations by promoting a reinforcement of forest standards and laws.

Key factors to be considered while designing Benefits Sharing and Distribution Systems are discussed below. Figure 18 shows benefits that the interventions addressing logging issues could receive. For practicality, the representation is provincial. The price of the carbon ton does not intend to suggest market approach. It only aims to estimate the financial benefit.

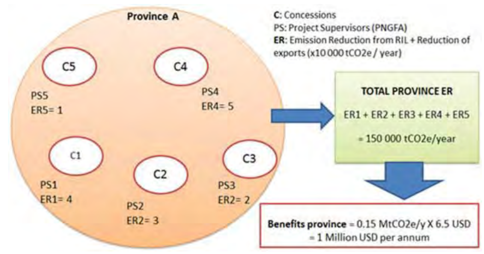


Figure 17: Factors for consideration in Benefit systems in a province program. 1tCo2e = 6.5USD.

Figure 19 indicates the arrangements of benefit sharing to support key components of forest management as identified along this paper.

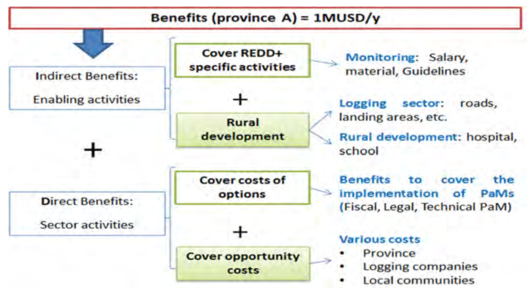


Figure 18: Factors for consideration in Benefit Sharing systems

Figure 20 describes costs related to policy implementation and opportunity costs.

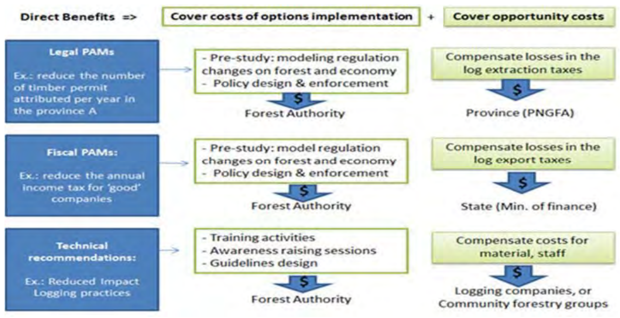


Figure 19: Factors for consideration in Distribution systems. $ = Financial support.

Figure 21 shows rewarding systems that REDD+ can activate to cover both costs to institutions for policy implementation and costs to logging operators for new practices.

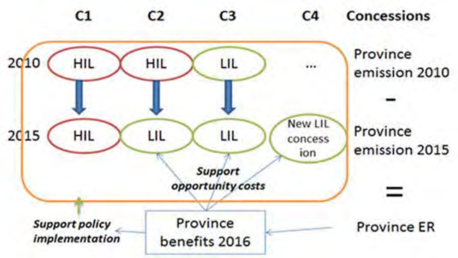


Figure 20: Factors for consideration in the Rewarding systems to foster SFM and RIL practices.

C: Concessions; HIL: High Impact Logging; LIL: Low Impact Logging; ER: Emission Reductions.

In conlcusion, REDD+ seems particularly relevant to support the following components:

- Parts of the forest management components that are still considered challenging such as the planning and control of operations, carbon monitoring and reporting;
- Activities that involve different land sectors (ex.: land use planning) or institutions (ex.: fiscal and commercial policies) because of their multi-sector dimension;
- Activities that are particularly relevant in a programmatic or pilot approach such as feasibility studies, legislation amendments' test, trainings and awareness raising.

However, REDD+ is not an ultimate response. The proposed supports must be inserted in suitable arrangements. The promotion of SFM and RIL should be included into the country's scope of REDD+ activities, respect strict Safeguards and be associated with adapted benefit sharing and rewarding systems. SFM approaches can allow aligning forest activities (and timber businesses) with social and environmental considerations. This perspective can

produce a leverage in other land sectors (which depend strongly on forest) to facilitate a sustainable and climate compatible development of the economy and the country.

CONCLUSION

This section presents a summary of opportunities, challenges and recommendations highlighted in the paper. The lists are not exhaustive but try to show the main elements.

Opportunities for achieving SFM in PNG:

1. A strong institutional background with national standards that incorporate international recommendations and the decentralized institutions of PNGFA;
2. A number of international literature proposing guidelines in SFM and RIL practices as well as specialists in South-east Asia and the Pacific region;
3. The capacities related to the National Forest Monitoring System (NFMS);
4. Past relevant initiatives such as land use planning in the Madang province (USAID) or training sessions on RIL practices (Australia cooperation);
5. The FSC office in the country, and potential rewards for the good management of forests, in complement (no double counting) of REDD+ funds rewarding carbon benefits; and
6. The support to the Forestry sector from the international organizations, initiatives and frameworks such as EU-FLEGT, REDD+, etc.

Challenges for SFM in PNG

1. The logistic and financial supports for integrating carbon components in the routine assessment of logging setups;
2. The combination of different scales and methods of forest monitoring to be able to integrate local information on collateral damage into the calculation of FRLs and the performance of interventions;
3. The availability and collection of consistent and homogeneous information on the activities and boundaries of different land sectors in order to develop the national and provincial land use planning with a multi-sector approach;
4. The complexity (and the demand in resources) of the feasibility studies necessary to model changes from policy amendment; and
5. The design and implementation of policies involving different land sectors (Forestry, Agriculture, etc.) or different economic sectors such as Economy, Finance or Justice.

Recommendations for additional PAMs

1. To involve the private sector (and logging operators in particular) in discussions, training and awareness-raising activities as a key factor to tackle degradation;

2. To gather in a national workshop stakeholders of the logging sector (companies, land owners, communities, institutions and international organizations) to evaluate the needs, and share knowledge on practice details and Climate benefits;
3. To study feasibility to add a module of carbon assessment in the PMC procedures;
4. To develop guidelines for monitoring carbon in logging setups, for different parties such as PNGFA supervisors, logging companies and community groups;
5. To provide training for trainers (project supervisors) and project operators on RIL practices;
6. To consider the potential support from the improved conditions and management tools for further Forestry options that can reduce logging impact; for instance, forest plantations (that allow to move logging out from natural forests) or the reforestation of logged over areas (that facilitates regeneration);
7. To conduct Research experiments on PNGFA or private sites to test harvesting practices and use these sites as demonstration sites to logging companies and actors of the development in PNG or in the neighboring countries;
8. To evaluate solutions for increasing the actual application of the "procedures for assessing post-logging waste in set-ups" (in PMCP) to improve the recording of collateral damage; and
9. To foster post-harvest treatments such as assisted natural regeneration, plantation, agroforestry or agro-ecology from institutions, communities and logging companies.

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