

VCS Tool

VT0006

Tool for Calculating LULC Transitions and
Deforestation Rates Using Incomplete Remote
Sensing Images

Version 1.0

11 January 2016

Sectoral Scope 14

This tool was developed by:



Terra Global Capital

Table of Contents

1	Sources	4
2	Summary Description of the Tool.....	4
3	Definitions.....	4
3.1	Definitions.....	5
3.2	Acronyms	5
4	Applicability Conditions	6
5	Procedures	7
5.1	Selection of Approach A or Approach B	7
5.2	Approach A – Deforestation Rate by Compositing Images	7
5.3	Approach B – Pixel-Based Deforestation Rate Analysis	12
6	Data and Parameters	16
6.1	Data and Parameters Available at Validation	16
6.2	Data and Parameters Monitored	17
7	References	18
8	APPENDIX 1: Digital File	19

1 SOURCES

The following have informed the development of the tool:

- VCS methodology *VM0006 Methodology for Carbon Accounting in Project Activities that Reduce Emissions from Mosaic Deforestation and Degradation, v2.1*
- Intergovernmental Panel on Climate Change (IPCC) *Good Practice Guidance for Land Use, Land-Use Change and Forestry (GPG-LULUCF)*, 2003
- Global Observation of Forest Cover and Land Dynamics (GOFC) *Sourcebook: Reducing greenhouse gas emissions from deforestation and degradation in developing countries*¹

2 SUMMARY DESCRIPTION OF THE TOOL

This tool calculates historical deforestation rates using incomplete remote sensing imagery when complete scenes are not available. A remote sensing image may be incomplete due to (a) atmospheric conditions such as cloud and shadow cover, dust or smoke and/or (b) sensor-related errors such as anomalous speckles, data saturation, spatial offsets or missing data, and/or (c) seasonal effects due to phenology, fire, water saturation, snow (GOFC-GOLD Sourcebook). This module is intended to be used in regions for which limited archival imagery exists such as regions that have persistent cloud cover, or in regions where accessing a complete image archival is prohibitive.

This tool assumes that project proponents have already conducted a classification of the incomplete remote sensing images into appropriate land use/land cover (LULC) categories using established procedures². The tool describes how a series of classified incomplete remote sensing images are combined to calculate a robust estimate of historical deforestation and degradation rates and transition matrices. The land cover class used during classification of the remote sensing images must be compatible with the definitions from the IPCC's Good Practice Guidance for Land Use, Land-Use Change and Forestry 2003 report (IPCC GPG-LULUCF, 2003) for forest, cropland, grassland, settlement, wetland and other land. The deforestation rates and transition matrices calculated according to the procedures in this tool are subsequently used in calculations and LULC change modeling, according to the applicable methodology.

3 DEFINITIONS

In addition to the definitions set out in VCS document *Program Definitions*, the following definitions and acronyms apply to this tool:

¹ Available at <http://www.gofc-gold.uni-jena.de/redd/> at the time of publication.

² Established procedures are described in an approved VCS Methodology, Lillesand et al. (2008) and the GOFC-GOLD REDD Sourcebook

3.1 Definitions

Applicable Methodology

A VCS-approved methodology that requires the use of remote sensing images to calculate historical deforestation rates and land-transition matrices for determining the baseline scenario

Area of Interest

The area of concern to the image analysis such as reference region, project area, leakage belt or jurisdictional program area

Classified Image (same as LULC map)

An image in which every spatial location is assigned a specific discrete land cover class

Complete Remote Sensing Image (also Images or Imagery)

Remote sensing images in which not more than 20% of the data are missing. Data that are unavailable due to the rotation of a scene during orthorectification must not be used in the calculation of this ratio

Incomplete Remote Sensing Image (also Images or Imagery)

Remote sensing images in which more than 20% of the data are missing. Data that are unavailable due to the rotation of a scene during orthorectification must not be used in the calculation of this ratio

Land-cover Transition

A transition, or change, from one discrete land cover class to another discrete land cover class over two points in time

Missing Data

Data that is unavailable due to (a) atmospheric conditions such as cloud and shadow cover, dust or smoke and/or, (b) sensor-related errors such as anomalous speckles, data saturation, spatial offsets or missing data, and/or (c) seasonal effects due to phenology, fire, water saturation, snow (GOFC//GOLD Sourcebook)

Orthorectification

A process of removing sensor, satellite/aircraft motion and terrain-related geometric distortions from raw imagery and converting these raw images into planimetric maps. Orthorectified data sets are required for thematic image analysis, for data fusion and analysis of data from different sources or seasons, when overlaying images with existing data sets and maps, or using them for evaluations like change detection and map updating.

Remote Sensing Data Archive

A collection or repository of historical remote sensing data

3.2 Acronyms

GOFC/GOLD Global Observation of Forest Cover and Land Dynamics

GPG	Good Practice Guidance
LULC	Land Use, Land-Cover Change
LULUCF	Land Use, Land-Use Change and Forestry
N/A	Not Applicable
RMSE	Root Mean Square Error

4 **APPLICABILITY CONDITIONS**

The tool is applicable under the following conditions:

- There is at least one incomplete remote sensing image in the area of interest due to reasons beyond the control of the project proponent. Reasons beyond the control of the project proponent comprise either (a) atmospheric conditions such as cloud and shadow cover, dust or smoke, (b) sensor related errors such as anomalous speckles, data saturation, spatial offsets or corrupt data, or (c) seasonal effects such as phenology, fire, water saturation, snow.
- During the time period during which incomplete remote sensing images are used, no other complete remote sensing images exist in a remote sensing data archive that is practically available³ to the project proponents at the time the classification work is conducted.
- All source imagery must be orthorectified to remove the effects of image perspective (tilt) and relief (terrain) effects for the purpose of creating a planimetrically correct image. The resultant orthorectified image has a constant scale wherein features are represented in their 'true' positions. It is recommended that the maximum off-nadir angle of source imagery is less than or equal to 30°.
- All source imagery must be co-registered into a common coordinate system to a RMSE of less than or equal to one pixel. The co-registration is the process of matching the location of an object across multiple images taken at different time⁴.
- All the classified remote sensing images must be re-sampled to a common pixel resolution matching the highest resolution (ie, smallest pixel size) of the images used. For example, if data sources are used when one image has a resolution of 30 m and another has a resolution of 15 m, the images must be resampled into a common spatial resolution

³ Practically available implies the project proponent should at least demonstrate that the complete remote sensing images were not available for the project area from Landsat image archive.

⁴ Most imagery from image vendors come co-registered. If the images are not co-registered, these images must be registered to a common coordinate system using appropriate image pre-processing techniques and using known sets of ground control points.

of 15 m. It must also be ensured that all the classified remote sensing images have same common origin.

- Available images that do not meet overall quality criteria are not to be included in this procedure. Quality criteria include seasonality effects (phenology, water saturation, and snow), overall cloud cover, and atmospheric distortion from haze and thin clouds such that remaining non-missing pixels are too few or too compromised to be useful in the analysis. Metrics for quality assessment are sometimes made available by the image producer. Other metrics can be contextual. For example, it is always preferred to use images from same season if seasonal effects on land cover assessment is significant. Therefore the project proponents must describe the quality criteria applied, and the scientific basis used to include or exclude the images especially when inclusion or exclusion were based on seasonality effects.

5 PROCEDURES

The tool provides two approaches to calculate historical transition rates, such as deforestation and reforestation rates using incomplete remote sensing images. Depending on the requirements of the methodology used, proponents may choose to use either Approach A creating a composite image or Approach B using a pixel-based analysis. Any discounting related to the number of time points utilized for assessing historical deforestation rates must be applied according to the applicable methodology. When this tool is used ex-post for monitoring purpose, areas from images/pixels that were already included in previous monitoring period must be excluded.

5.1 Selection of Approach A or Approach B

Approach A requires the creation of three composited LULC maps and two composited LULC change maps. These composited maps are created by extracting data from different years within one period into a single map. Except as stated in this tool, or when using this tool ex-post monitoring, three discrete periods with fixed starting and ending dates are required. When this tool is used for assessing LULC transitions and deforestation rates ex-post, ie, during monitoring there will only be one time period in Approach A. In contrast, Approach B fits a continuous non-parametric curve through LULC change data based on all available data without needing to create composite land-use change maps. Approach A is to be used in conjunction with methodologies that require discrete historical LULC maps and LULC change maps. Approach B is more flexible but does not produce any discrete historical LULC map and LULC change maps; Approach B only creates a pixel-based deforestation rate and may be used in conjunction with methodologies that do not require discrete historical LULC maps, but only deforestation and other LULC transition rates.

5.2 Approach A: Deforestation Rate by Compositing Images

The following stepwise procedure must be used.

- 1) **Acquire images** meeting quality standard from the start of the crediting period to 15 year prior to the start of the crediting period. Images may be acquired as separate complete

scenes or as a single composited image⁵ using pixel quality algorithms for pixel inclusion prioritization. If composite imagery is used the source date of all pixels is required to calculate the representative time point. Pixel quality selection may be based on atmospheric conditions, seasonal preference, sensor quality (eg, greater bit depth), and/or temporal proximity to period requirements (see classification temporal prioritization in step 3 below).

- 2) **Conduct classification**⁶ on all acquired images, individually or as composite images, according to the appropriate LULC class; classify areas with missing data according to the reason, eg, cloud, smoke, scan line correction problem, etc. The image classification must result in appropriate LULC categories using established procedures⁷. The land cover class used during classification of the Remote Sensing images must be compatible with the definitions from the IPCC's Good Practice Guidance for Land Use, Land-Use Change and Forestry 2003 report (IPCC GPG-LULCF, 2003) for forest, cropland, grassland, settlement, wetland and other land.
- 3) **Verify that 80% of all pixels within the area of interest have an identified LULC class** in one or more images within time periods required by the applicable methodology. If the applicable methodology requires that the deforestation rates must be assessed from three different time periods representing up to 15 years prior to the project start date then images must be present from each of the following three periods:
 - a) Period 1 - from 5 until 15 years before the start of the crediting period;
 - b) Period 2 - from two years until 5 years before the start of the crediting period,
 - c) Period 3 - start of the crediting period until 2 years⁸ before the start of the crediting period.

If the applicable methodology only requires that deforestation analysis be based just on a pair of images representing two time points, or be based on 4 pairs of images representing four time points, or more than 4 pair of images representing more than four time points, the images for creating composite images must be selected such that the composite images conforms with the requirement of time periods specified in the methodology. Note that a composite image applicable under this tool is considered equivalent to a single image representing one time point referred in methodology that do not use composite image.

⁵ For example, pixel quality prioritization was employed for the cloud free Landsat composites used to produce the Global Forest Change time-series analysis. Hansen, M. C., P. V. Potapov, R. Moore, M. Hancher, S. A. Turubanova, A. Tyukavina, D. Thau, S. V. Stehman, S. J. Goetz, T. R. Loveland, A. Kommareddy, A. Egorov, L. Chini, C. O. Justice, and J. R. G. Townshend. 2013. "High-Resolution Global Maps of 21st-Century Forest Cover Change." *Science* 342 (15 November): 850–53.

⁶ Image classification is the task of extracting information classes from a multiband raster image. The result of image classification can be used to create thematic maps such as land-use or land-cover maps.

⁷ Established procedures are described in an approved VCS Methodology, Lillesand et al. (2008) and the GOFC-GOLD Sourcebook

⁸ Years are to be counted as common years. For example, if the starting date is March 11, 2013, the three periods namely 1, 2 and 3 are respectively (Period 1) March 12 1998 – March 11 2008, (Period 2) March 12 2008 – March 11 2011, and (Period 3) March 12 2011 – March 11, 2013.

If the applicable methodology does not specify the time periods, but only specifies the number of images, the time periods must be set such that the images in recent time period are not older than 2 years from the project start date, images from oldest time period (ie, Period 1 in three time periods) are not older than 15 years and intermediate periods that fall between oldest and latest periods must be established such that the length of periods are equal.

If for one of the three periods, more than 20% of all pixels within the Area of Interest are classified as missing data within all images of that time period, Approach A is not eligible or additional remote sensing imagery must be obtained for that time period or project areas must be reduced by excluding areas classified as missing data.

- 4) **Create composite LULC maps**, one representing each of the time periods defined in Step 3. When not using composite source imagery the selection of the specific images to use within each of these periods must be done on a per-pixel basis and is dependent on which images contain non-missing data for each individual pixel. Specifically, for 3 periods representing recent to 15 years old images:
 - a) For oldest (ie, period 1), the oldest image with non-missing data must be selected.
 - b) For intermediate (ie, period 2), the image that is closest to the mid-point of the oldest and the latest period must be selected.
 - c) For most recent (ie, period 3), the most recent image in which an LULC class is assigned for that specific pixel must be selected.

If there are only two periods, then period 2 will be discarded. On the other hand, if there are more than three periods, then multiple intermediate periods must be added following the procedure described in previous step.

For each pixel from the composite map, proponents must record both the LULC class as well as the date of the image from which the LULC class was extracted. The composite LULC maps are referred to with the symbol p in subsequent equations.

- 5) **Calculate the representative time point** for each composite LULC map. Since a LULC change map assembles pixels that were acquired at different times, an average of the dates weighed according to the number of pixels associated with that date is the most logical way of calculating a representative time point.

$$t(p) = \frac{\sum_{i=1}^{pixels(p)} t(i)}{pixels(p)} \quad \text{[EQ. 1]}$$

Where:

$t(p)$ = Representative time point for a specific composited LULC map p year]

$pixels(p)$ = Number of valid (i.e. complete) pixels in the composite LULC map p [-]

$t(i)$ = Date of pixel i in the composited LULC map p [year]

The representative time point must be used wherever the Applicable Methodology requires an absolute time point for each of the maps.

- 6) **Verify that representative time point of period 1** is between 55-15 years prior to the start of the crediting period.
- 7) **Create composited land-use change maps** based on the composite maps from step 4, one representing the change from period 1 to 2, a second representing the change from period 2 to 3 and a third representing the change from period 1 to 3 and so on. Only when no data is available for intermediate period (such as for period 2) for a specific pixel, must that pixel be represented in the land-use change map from first and last period (i.e., from period 1 to 3). Proponents must record both the composited change map as well as timespan (expressed in fractional years by unrounded decimals) between the “from” and “to” images selected in each period.⁹ If relevant, apply any spatial or temporal filters or any other relevant post-classification procedures. The composited LULC maps are referred to with the symbol $p1 \rightarrow p2$ in subsequent equations.
- 8) **Calculate the transition rate** (eg, deforestation rate, reforestation rate, etc.) for each composite land-use change map created in step 7, by applying the following formula across all pixels of the composited land-use change map. Note: remember this is occurring at a pixel by pixel basis for each transition and the parameter V is used to weight the average rates in these time periods :

$$\begin{aligned}
 tr_{LULC1 \rightarrow LULC2}(p1 \rightarrow p2) &= \left(A \cdot \sum_{i=1}^{pixels} \frac{i = LULC1 \rightarrow LULC2}{\Delta t(i)} \right) && \text{[EQ. 2]} \\
 &* V(p1 \rightarrow p2)
 \end{aligned}$$

Where:

$tr_{LULC1 \rightarrow LULC2}(p1 \rightarrow p2)$ = LULC change rate for transition from LULC class 1 to LULC class 2 [ha / year⁻¹]
 A = Area of one pixel [ha pixel⁻¹]
 $\Delta t(i)$ = Time span (elapsed time) between the date of “from” image

⁹ For example if the date of the “from” image were Feb 15, 2000 and the date of the “to” image were Nov 15, 2005, the fractional years are 2000.126 and 2005.874, respectively and the difference in fractional years is 5.748.

and the date of “to” image for a LULC transition for pixel i .
[year]

- $i = LULC1 \rightarrow LULC2$ = Convenience function of pixel i that is 1 when pixel i is transitioning from $LULC1$ to $LULC2$ in the composited land-use change map and 0 if this pixel is not undergoing this transition or when the pixel contains invalid or no data in the composited land-use change map.
- $V(p1 \rightarrow p2)$ = Proportion of total number of valid pixels to total number of pixel that were used in preparing the composite land-use change maps (i.e., to normalize for remaining cloud/shadow cover).

Report the results for each transition separately (ie, both deforestation and reforestation) as in Table 1. The table must contain the representative midpoint of the time periods, period of coverage, representative start point, representative end time point, and total ha of transitions occurring during time periods for a given land use change. The table must be sorted by ‘representative mean time point’ in ascending order.

Table 1: LULC Transition reporting

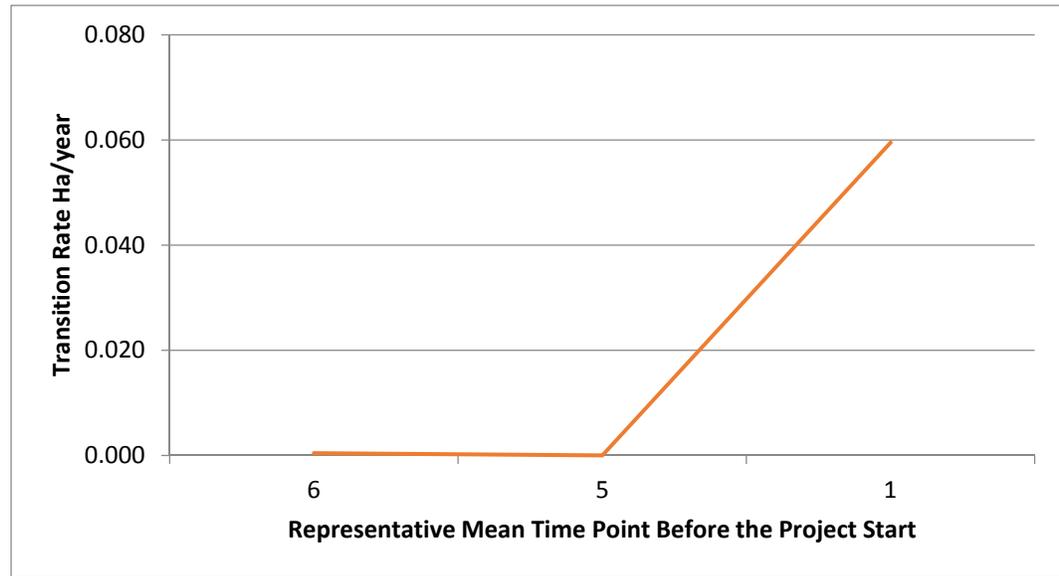
Representative mean time point [t(p)]	Period coverage	Representative time point of start period	Representative time point of end period	$tr_{LULC1 \rightarrow LULC2}(p1 \rightarrow p2)$
t1	-15 to -5			
t2	-5 to -2			
t3	-2 to 0			

Values of $tr_{LULC1 \rightarrow LULC2}(p1 \rightarrow p2)$ are in hectares per year and represent absolute transition rates. When the methodology requires to use transition rates in % per year, or relative transition rates, values of $tr_{LULC1 \rightarrow LULC2}(p1 \rightarrow p2)$ are to be divided by the area in ha covered by number of pixels representing LULC class $LULC1$ in the composite LULC map of $p1$.

The information represented in table 1 must be sorted by representative time point i.e. t(p) in the increasing order (i.e. earlier to later representative time periods).

The transition rates must be plotted as line graph or scattered points where x-axis represents the time, and y-axis represents transition rates. This information is then used for assessing the future deforestation through the use of regression tool or using simple average (according to the specification of applicable methodology).

Figure 1: Example Plot for Graphically Presenting the Transition Rate



When used ex-post, the dates of pixels must not be older than the most recent image used in the previous monitoring period or last historical image date. During monitoring only one period with its length matching the length of monitoring period must be used. For estimating transitions during monitoring, estimate transitions from composite image for the current monitoring period and composite image of the immediately preceding monitoring period or the latest composite image created during the historical assessment, whichever is latest.

5.3 Approach B – Pixel-Based Deforestation Rate Analysis

The description of Approach B uses the same notation as Approach A, with the exception that p in Approach B signifies a non-composited LULC map, whereas p in Approach A signifies a composited LULC map. The first two steps of Approach B are identical to Approach A.

- 1) **Acquire images** meeting quality from the start of the crediting period to 15 year prior to the start of the crediting period. Images may be acquired as separate complete scenes or as a single composited image¹⁰ using pixel quality algorithms for pixel inclusion prioritization. If composite imagery is used, then pixels representing different time points must be isolated as individual images such that each image represent one time point.

¹⁰ For example, pixel quality prioritization was employed for the cloud free Landsat composites used to produce the Global Forest Change time-series analysis. Hansen, M. C., P. V. Potapov, R. Moore, M. Hancher, S. A. Turubanova, A. Tyukavina, D. Thau, S. V. Stehman, S. J. Goetz, T. R. Loveland, A. Kommareddy, A. Egorov, L. Chini, C. O. Justice, and J. R. G. Townshend. 2013. "High-Resolution Global Maps of 21st-Century Forest Cover Change." *Science* 342 (15 November): 850–53.

- 2) **Conduct classification**¹¹ on all acquired images, individual or as composite images, according to the appropriate land use, land-cover change (LULC) class; classify areas with missing data according to the reason, eg, cloud, smoke, scan line correction problem, etc. The image classification must result in appropriate land use/ land cover change (LULC) categories using established procedures¹². The land cover class used during classification of the Remote Sensing images must be compatible with the definitions from the Intergovernmental Panel on Climate Change’s Good Practice Guidance for Land Use, Land-Use Change and Forestry 2003 report (IPCC GPG-LULCF, 2003) for forest, cropland, grassland, settlement, wetland and other land. The classified images are referred to with the symbol p in subsequent equations of Approach B.

- 3) **Create a transition dataset** for each relevant transition from one LULC class to another LULC class ($LULC1 \rightarrow LULC2$). The transition dataset in the format outlined in Table 2.

Table 2: Transition Dataset

Starting time point	Ending time point	Average time point	Image pair	Number of Pixels $LULC1 \rightarrow LULC2$	Number of Pixels $LULC1 \rightarrow LULC1$	$tr_{LULC1 \rightarrow LULC2}(p1 \rightarrow p2)$
$t(p1)$	$t(p2)$	$\frac{t(p1) + t(p2)}{2}$	i	$n1$	$n2$	$\frac{n1}{(n1 + n2)(t(p2) - t(p1))}$

Specifically, for each subsequent pair of LULC maps, calculate the number of pixels $n1$ that transition from LULC class $LULC1$ in map $p1$ to LULC class $LULC2$ in map $p2$ as well as the number of pixels $n2$ from LULC class $LULC1$ in map $p1$ that remain in the same LULC class $LULC1$ in map $p2$. It is permissible to skip one or more maps in between LULC maps $p1$ and $p2$ when the data are missing for specific pixels.

- 4) **Report the relative transition rate.** The relative transition rate is estimated as $\frac{n1}{n1+n2}$. However, the number of points used in the calculation of the relative transition rate may vary as a function of the amount of data that is non-missing. Therefore, subsequent calculations must be based on statistics that are using sum of $n1 + n2$ as weights when compiling different values of the relative transition rates into an aggregated rate.
 - a) If the methodology requires transition rates in specific time intervals or periods (P), calculate the transition rate as the weighted average of values of $\frac{n1}{n1+n2}$ from the transition dataset created in step 3, using $n1 + n2$ as weights. The number of time intervals or periods must be set so as to conform to the requirements of the methodology. For example, if the methodology requires that the transition rates

¹¹ Image classification is the task of extracting information classes from a multiband raster image. The result of image classification can be used to create thematic maps such as land-use or land-cover maps.

¹² Established procedures are described in an approved VCS Methodology, Lillesand et al. (2008) and the GOCF-GOLD Sourcebook

be reported in three time periods where time intervals are -15 to -5, -5 to -2, and -2 to 0 year before the start of the project then mean transition rates from all the image pairs falling within these three time intervals or periods must be estimated. The transition rate per period is estimated using EQ 3.

$$\overline{tr_{LULC1 \rightarrow LULC2}(P)} = \frac{1}{\sum_{i=1}^{imagePair(P)} ((n1, i) + (n2, i))} * \sum_{i=1}^{imagePair(P)} \frac{n1, i}{(t(p2, i) - t(p1, i))} \quad [EQ. 3]$$

Where:

$\overline{tr_{LULC1 \rightarrow LULC2}(P)}$ = Mean LULC change rate for transition from LULC class 1 to LULC class 2 in time period P [-]

$n1, i$ = The number of pixels that transition from LULC class $LULC1$ in map $p1$ to LULC class $LULC2$ in map $p2$ for image pair i that are within the time interval or period P .

$n2, i$ = The number of pixels from LULC class $LULC1$ in map $p1$ that remain in the same LULC class $LULC1$ in map $p2$ for image pair i that are within the time interval or period P .

$t(p1, i), t(p2, i)$ = Time point of map $p1$ and $p2$ respectively for image pair i .

i = Image pair belonging to period P from 1, 2, ... to $imagePair(P)$.

Calculate the uncertainty as the non-parametric bootstrap confidence interval.¹³ The bootstrap technique (Efron 1987, Efron and Tibshirani, 1993) is a data-based method of simulating an empirical distribution of results through a resampling process. The idea of bootstrapping is to start with a sample (the original sample), then create a new sample (the bootstrap sample) by sampling with replacement from the original sample. The process is repeated a number of times to generate a series of bootstrapped samples, and the statistic of interest (in this case confidence interval) is computed for each sample. Because the

¹³ A bootstrap confidence interval is calculated by calculating the mean of sampled transition rates multiple times but each time with data that were resampled with replacement from the original distribution of transition rates, resulting in a set of potential mean values. The bootstrap confidence interval is then calculated as the 5% and 95% percentiles of this set of potential mean values.

sampling is with replacement, the bootstrap sample will likely contain several duplicate observations from the original sample, and nearly each bootstrap sample will be unique. Each bootstrap sample represents a plausible alternate sample from the original population, and the set of calculated statistics yields information about variation in the original sample. At least 30 randomly selected transition rates must be used to start the bootstrapping process unless total number of transition rates per period are less than 30, in which case at least 90% of the rates must be used in each sample. The sample size may be incrementally added to cover 100% of the transition rates. While n^n unique replicates can be obtained, it may take large computing time to get such a large number of replicates. Either 90th or 95th percent confidence interval must be estimated. Suggested minimum number of replicates is 1000. Report both weighted average rate and confidence interval in the format outlined in Table 3.

Table 3: Report on transition rate¹⁴

Period (years)	$tr_{LULC1 \rightarrow LULC2}(P)$	Confidence interval (95th or 90th)
-15 to -5		
-5 to -2		
-2 to -0		

- b) If the methodology permits the use a trend of deforestation over time, conduct a loess regression¹⁵ of $\frac{n1}{n1+n2}$ from the transition dataset created in step 3 as the dependent variable, the average time point $\frac{t(p1)+t(p2)}{2}$ as the independent variable, and weighted by $\frac{n1+n2,i}{\sum_i n1+n2,i}$. Once the rates are weighted, the transition rates are equal to $\frac{n1,i}{\sum_i n1+n2,i}$.

Loess is a bivariate smoother for drawing a smooth curve through a scatter diagram. Loess is a locally weighted scatter plot smoothing process which is an outlier resistant method based on local polynomial fits (Cleveland 1979). Like linear regression (in which the “curve” is a straight line), the smooth curve is drawn in such a way as to have some desirable properties. In general, the properties are that the curve indeed be smooth, and that locally, the curve minimize the variance of the residuals or prediction error. In loess regression method, weighted least squares is used to fit a linear or quadratic functions of the predictors at the centres of the neighbourhoods. The radius of each neighbourhood is chosen so that the neighbourhood contains a specified percentage of the data points. The fraction of the data, called the smoothing parameter, in each local neighbourhood

¹⁴ Period ranges offered in the table are only examples.

¹⁵ A loess regression is a regression in which the 2-degree model should be used in the loess regression as well as a smoothing parameter of 0.75, unless project proponents justify that a value of 0.75 for the smoothing parameter leads to unrealistic or unreasonable results.

controls the smoothness of the estimated surface. Data points in the given local neighbour are weighted by a smooth decreasing function of their distance from the centre of the neighbourhood. The output from loess regression is a generally smooth curve (or a function), the value of which at a particular location along the x-axis is determined only by the points in that vicinity. The method consequently makes no assumptions about the form of the relationship, and allows the form to be discovered using the data itself.

Finally, produce a plot of the transition rate from which the trend can be deduced. Ensure that a confidence band around the loess regression is calculated.

Report the relative reforestation rate. The relative reforestation rate is estimated as $\frac{n_2}{n_1+n_2}$. However, the number of points used in the calculation of the relative transition rate may vary as a function of the amount of data that is non-missing. Therefore, subsequent calculations must be based on rates that are weighted using weighing procedure described in (a) above.

When used ex-post, the dates of pixels must not be older than the most recent image used in the previous monitoring period or last historical image date.

6 DATA AND PARAMETERS

6.1 Data and Parameters Available at Validation

Data Unit / Parameter	$t(p)$
Data unit	[-]
Description	Representative time point for a specific composited LULC map p [year]
Equations	1
Source of data	Calculated year, Output of Eq. 1
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied:	Use the origin dates of images used. The LULC map assembles pixels that were acquired at different times, an average of the dates weighed according to the number of pixels associated with that date is a logical way of calculating a conservation representative time point.
Purpose of Data	To estimate a representative time points for LULC maps that were prepared from multiple images corresponding to a range of time periods.
Comments:	N/A

Data Unit / Parameter	$tr_{LULC1 \rightarrow LULC2}(p1 \rightarrow p2)$
Data unit	[-]
Description	LULC change rate for transition from LULC class 1 to LULC class 2 [ha / year ⁻¹].
Equations	2
Source of data	Calculated rate from Eq. 2
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	The transition of LULC class from one time to another time is used as the basis for estimating the historical rate of deforestation.
Purpose of Data	To estimate the rate of deforestation between two periods.
Comment	N/A

Data Unit / Parameter	$\overline{tr_{LULC1 \rightarrow LULC2}(P)}$
Data unit	[-]
Description	Mean LULC rate for transition from LULC class 1 to LULC class 2 in time period P [-]
Equations	3
Source of data	Calculated rate from Eq. 3
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	Some methodologies may use an average rate of deforestation as a basis for estimating the baseline rate of deforestation. The mean transition rates derived the transition rates from multiple time periods weighted across the number of pixels used provide a conservative estimate of average rate of transitions.
Purpose of Data	Derive an average rate of transitions from rates of deforestation estimated for two more time periods.
Comment	N/A

6.2 Data and Parameters Monitored

None.

7 REFERENCES

- Cleveland, W.S. (1979). Robust locally weighted regression and smoothing scatterplots. J. Amer. Statist. Assoc. 74(368): 829-836.
- Efron, B. 1987. Better bootstrap confidence intervals (with discussion). J. Am. Statist. Assoc. 82, 316-331.
- Efron, B., Tibshirani, R.J. 1993. An Introduction to the Bootstrap. Chapman and Hall, New. York.
- Global Observation of Forest Cover and Land Dynamics (GOFC) Sourcebook: *Reducing greenhouse gas emissions from deforestation and degradation in developing countries*
- Intergovernmental Panel on Climate Change (IPCC) Good Practice Guidance for Land Use, Land-Use Change and Forestry (GPG-LULUCF), 2003
- Lillesand, T., Keifer, W, Chipman, J. 2008. Remote Sensing and Image Interpretation, 6th Edition. Wiley Interscience.
- VCS Methodology VM0006: Methodology for Carbon Accounting in Project Activities that Reduce Emissions from Mosaic Deforestation and Degradation, v2.0

APPENDIX 1: DIGITAL FILE

See digital file. Excel workbook "Tool Demonstration.xlsx"

DOCUMENT HISTORY

Version	Date	Comment
v1.0	11 Jan 2015	Initial version