VCS Tool

VT0007

UNPLANNED DEFORESTATION ALLOCATION (UDEF-A)

Version 1.0

21 February 2024

Sectoral Scope 14

Version 1.0 of this tool was developed for Verra by J. Ronald Eastman and Robert Gilmore Pontius Jr. of Clark Labs and Rebecca Dickson of TerraCarbon with input from Carbon Decisions International. It is based on the JNR Allocation and Risk Mapping tools first developed by Lucio Pedroni and Juan Felipe Villegas Echeverri of Carbon Decisions International.

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CONTENTS

1   SOURCES

This tool uses the latest version of the following documents, methodological modules and tools*:*

- JNR Scenario 1 and 2 Requirements
- *VCS Methodology Requirements*
- *JNR Program Guide*
- *VM0048 Reducing Emissions from Deforestation and Forest Degradation*
- *VMD0055 Estimation of Emissions Reductions from Avoiding Unplanned Deforestation*

2   SUMMARY DESCRIPTION OF THE TOOL

The objective of *VT0007 Unplanned Deforestation Allocation* is to generate and select risk maps for unplanned deforestation activity data allocation for project baselines, including from jurisdictional forest reference emission levels (FRELs). The approach prioritizes unbiased allocations, identifies low-risk areas effectively and maintains broad applicability through minimal data requirements. The technical design emphasizes simplicity to reduce errors in application while effectively distinguishing areas with different risk levels.

This tool provides a standardized approach for:

1) Constructing benchmark jurisdictional maps of unplanned deforestation risk;

2) Comparing the benchmark map with alternative jurisdictional maps of unplanned deforestation risk to discern the best risk map for the jurisdiction; and

3) Using the selected risk map to proportionally allocate fractions of either the jurisdictional unplanned deforestation activity data baseline (in the context of *VMD0055*) or the jurisdictional FREL (in the context of the VCS Jurisdictional and Nested REDD+ framework) to projects or programs to be implemented within the jurisdiction.

VT0007 is intended for official use by service providers contracted to act on Verra's behalf. The activity data allocated by Verra take precedence over uses of this tool by other stakeholders.

3   DEFINITIONS AND ACRONYMS

3.1   Definitions

This tool uses the definitions set out in the latest versions of the *VCS Program Definitions*, *VM0048,* and *VMD0055*. The following definitions also apply.

Allocated risk

A quantified expression of deforestation risk, expressed as deforestation density (ha/pixel) over a defined period

Allocation

The process of spatially dividing a jurisdictional unplanned deforestation activity data baseline or forest reference emission level (FREL) into parts and assigning each part to lower-level programs and projects aimed at avoiding unplanned deforestation (AUD), according to the level of risk of unplanned deforestation that exists within each program or project area.

In the context of *VMD0055*, the allocated parts of projected deforestation are used, in conjunction with project-specific emission factors, to construct the baseline of standalone AUD projects.

In the context of applying the requirements of the VCS Jurisdictional and Nested REDD+ framework, the allocated parts of the FREL become the baselines of the nested programs and projects.

Deforestation risk

The probability of deforestation as estimated based on recent historical experience

Deforestation risk modeling regions

Portions of the jurisdiction that have similar situational and administrative characteristics. They are defined by an overlay (intersection) of two components – a map of administrative divisions and a map of deforestation vulnerability classes.

Negligible risk threshold

The distance from forest edge at which 99.5 percent of the deforestation experienced over the historical reference period has occurred

Vulnerability to deforestation

A measure of relative susceptibility to deforestation. It differs from deforestation risk in that risk is quantified on a ratio scale and expressed either as a probability or as an expected impact. Vulnerability is measured on an ordinal scale but otherwise does not represent a quantified measurement and should not be used to determine the distance between two categories or for comparison between models.

3.2   Acronyms

AD	Activity Data
BVP	Baseline Validity Period
FCBM	Forest Cover Benchmark Map
FREL	Forest Reference Emission Level
HRP	Historical Reference Period

ID   Identifier (e.g., for combinations of vulnerability zone and administrative divisions)

NRT   Negligible Risk Threshold

4   APPLICABILITY CONDITIONS

This tool is applicable under either of the following conditions:

1) The project is a standalone project meeting the applicability conditions for projects that aim to avoid unplanned deforestation as defined in *VMD0055* and is seeking allocation of jurisdictional unplanned deforestation activity data; or

2) A higher-level jurisdiction is seeking to allocate their FREL to projects or lower-level jurisdictions aiming to avoid unplanned deforestation.

5   PROCEDURES

Note – These procedures are intended to provide background to a general audience on the choices, approach and logic of the UDef-A. A Python-based implementation of the tool is available at https://github.com/Clark-Labs/UDef-ARP/. Additionally, the examples provided hereafter are intended solely for demonstrative purposes and do not represent usable data.

5.1   Risk Map Development Sequence

Allocated risk map development involves two phases (fitting and prediction; Figure 1) and two stages (testing and application).

Figure 1: Fitting and Prediction Phases and Chronology of the Testing and Application Stages
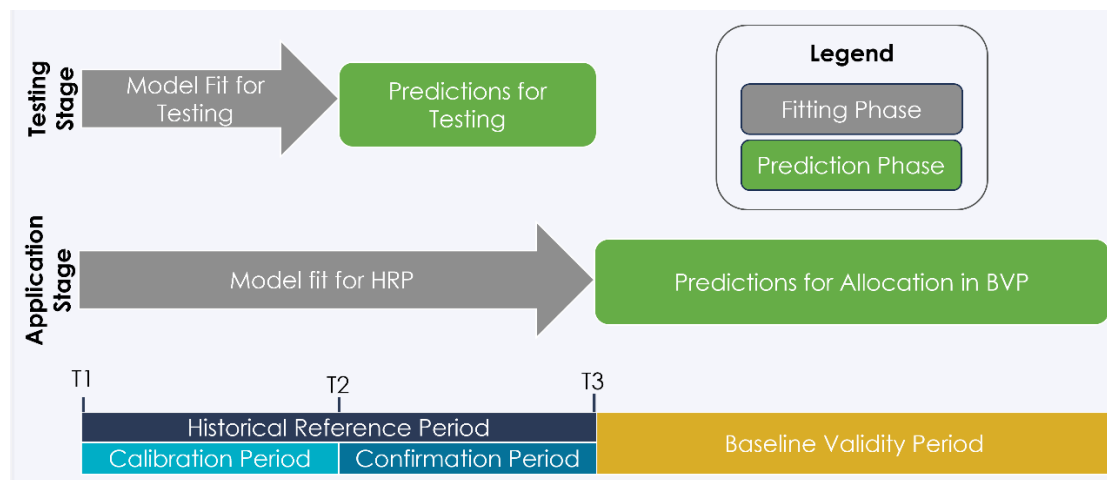
The first phase (hereafter referred to as the fitting phase) is a fitting operation in which a model is fitted to historical deforestation data. In the second phase (hereafter referred to as the prediction phase), the fitted model is used to predict future deforestation using updated data.

The testing stage is used for model selection among alternative models, while the application stage is analogous to model deployment.

The time periods involved in the fitting and prediction phases differ depending upon the stage. During the testing stage, the fitting phase uses historical data on deforestation experienced during the calibration period, which runs from T1, the start of the historical reference period (HRP), to T2, the mid-point of the HRP. The prediction phase of the testing stage is the confirmation period, which extends from T2 to T3, the end of the HRP. As actual deforestation data are available for the confirmation period, they are compared with data from the prediction phase of the testing stage to provide an assessment of model skill and facilitate model selection. In the application stage, the selected model is used to predict deforestation during the baseline validity period (BVP); the fitting phase covers the whole of the HRP, while the prediction phase covers the BVP.

The model used in the prediction phase is the same as for the fitting phase except that the values of any dynamic variables – maps that change over time – included in the model must be updated before the model is applied for prediction. All the same fitted model parameters are used to extrapolate over the confirmation and baseline validity periods, yielding the prediction.

5.2   Data Requirements

The *UDef-A* benchmark model requires the following inputs:

1) A wall-to-wall forest cover benchmark map (FCBM) covering the entire jurisdiction and meeting the specifications stated in Section A1.4.3, step 1 of *VMD0055*. The FCBM is a single map constructed by first mapping the presence or absence of forests at three time points: the start (T1), mid-point (T2) and end (T3) of the HRP, resulting in the eight forest transitions listed in Table 1. These eight transitions are aggregated into four simplified categories (stable non-forest, stable forest, deforestation in the first half of the HRP, and deforestation in the second half of the HRP) shown in the "Interpretation" column of Table 1.

Table 1: Interpretation of the Forest Cover Benchmark Map (FCBM) into Land Cover Classes for Use in *UDef-A* Models (F: Forest, NF: Non-Forest)

HRP Start Year Forest	HRP Midpoint Forest	HRP End Year Forest	FCBM Index	Allocated Risk Mapping Role			Interpretation
				Test Risk Map	HRP Risk Map	Validity Risk Map	
No	No	No	1	NF	NF	NF	Stable Non-Forest
No	No	Yes	2	NF	NF	NF	Stable Non-Forest
No	Yes	No	3	NF	NF	NF	Stable Non-Forest
No	Yes	Yes	4	NF	NF	NF	Stable Non-Forest
Yes	Yes	Yes	5	F	F	F	Stable Forest
Yes	No	No	6	F	NF	NF	Deforested T1–T2
Yes	No	Yes	7	F	NF	NF	Deforested T1–T2
Yes	Yes	No	8	F	F	NF	Deforested T2–T3

2) A map of administrative divisions one level below the jurisdictional level

3) A binary map (mask) of the entire jurisdiction

4) For T1, which is the start of the HRP and of the calibration period:

    a) A binary map of forest at the beginning of the HRP created by grouping FCBM classes 5–8 (Table 1) into a single class

    b) A binary map of non-forest at the beginning of the HRP created by grouping together FCBM classes 1–4 (Table 1) into a single class

    c) A map of distance from non-forest using input map 4b above, to serve as distance from the forest edge at the start of the HRP and calibration period

5) For T2, which is the start of the confirmation period:

    a) A binary map of forest at the beginning of the confirmation period created by grouping together FCBM classes 5 and 8 (Table 1) into a single class

    b) A binary map of non-forest at the beginning of the confirmation period created by grouping together FCBM classes 1–4 and 6–7 (Table 1) into a single class

    c) A map of distance from non-forest using input map 5b above, to serve as distance from the forest edge at the start of the confirmation period

6) For T3, which is the start of the BVP:

    a) A binary map of forest at the beginning of the BVP created by isolating FCBM class 5 (Table 1) into a single class

    b) A binary map of non-forest at the beginning of the BVP created by grouping together FCBM classes 1–4 and 6–8 (Table 1) into a single class

    c) A map of distance from non-forest using input map 6b above, to serve as distance from the forest edge at the start of the BVP

7) For the HRP (T1–T3):

    a) A binary map of deforestation during the HRP created by grouping together FCBM classes 6–8 (Table 1)

8) For the calibration period (T1–T2):

    a) A binary map of deforestation from T1 to T2 by grouping FCBM classes 6 and 7 (Table 1)

9) For the confirmation period (T2–T3):

    a) A binary map of deforestation from T2 to T3 by isolating FCBM class 8 (Table 1)

Alternative vulnerability models will typically require additional explanatory variables other than distance from the forest edge. Data layers containing values for such variables must be provided as described in Appendix 4 of *VMD0055*.

5.3 Benchmark Risk Mapping

5.3.1 The Fitting Phase

Given the absence of established accuracy thresholds for risk maps, the benchmark is intended to act as a well-understood point of comparison for alternative risk maps. The development of alternative vulnerability models is described in Section 5.4.

The benchmark modeling approach described in this tool adopts a relative frequency approach – a straightforward and powerful non-parametric modeling strategy that, in extensive testing, has proven to yield effective results. This approach looks at recent history to calculate the relative frequency of deforestation within small modeling regions that have common situational and administrative characteristics. That relative frequency of deforestation is then applied, with suitable adjustment for quantity, to modeling regions with matching situational and administrative characteristics in the future period to be predicted. The result is a map of deforestation probabilities that may be converted to densities of predicted deforestation per map pixel. These steps are described in detail below.

5.3.1.1 Step 1: Create the Fitting Phase Vulnerability Map

The single variable underlying benchmark risk mapping is Euclidean distance to forest edge. The benchmark approach to the vulnerability component is based on the observation – drawn from many case studies of tropical deforestation – that forest loss tends to be most frequent near to the forest edge, with a rapid decline in frequency as distance from the forest edge increases.[1] The nature of this distribution is an exponential decay. Figure 2 shows a histogram of the frequency of deforestation in an example jurisdiction during a six year period. The benchmark approach recognizes this skewed distribution as a function of distance from the forest edge.

Figure 2: Histogram of the Frequency of Deforestation (y, in 30 m Pixels) Observed in an Example Jurisdiction During a six year period, Against Distance from the Forest Edge (x, in Meters)

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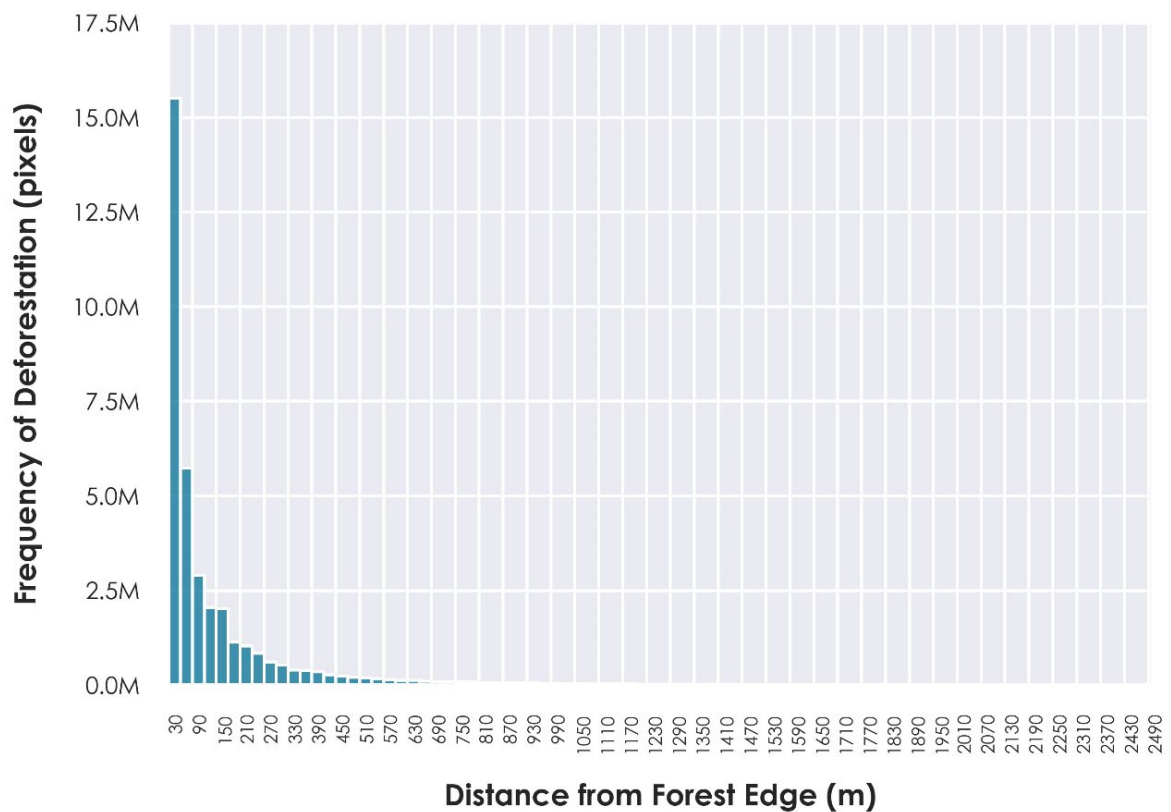
[1] (Fischer et al. 2021) found that up to 77 percent of deforestation happened within 100 meters of the forest edge. Within the context of deforestation risk modeling, multiple studies have identified distance to forest edge as the most important covariate for predicting deforestation risk (Linkie, Rood, and Smith 2010; Mertens and Lambin 2000; Vieilledent et al. 2022) and in some instances, simple models based only on the distance to forest edge exhibit comparable predictive skill to multivariate regression models (Cushman et al. 2017).

As Figure 2 shows, the frequency of deforestation tends towards zero as distance from the forest edge increases; at some point, the frequency of deforestation is so low that it becomes negligible. To scale the vulnerability map, vulnerability is highest (a value of 30) immediately adjacent to the forest edge and lowest (a value of 1) between what is defined as the negligible risk threshold (NRT) and the furthest extent of the jurisdiction.

The NRT is defined as the distance from forest edge at which 99.5 percent of the deforestation experienced over the HRP has occurred.

Figure 3 shows a cumulative histogram of deforestation by distance from non-forest for a sample jurisdiction over the same period as in Figure 2. Beyond the NRT, the density of deforestation drops below 0.5 ha/km², where 0.5 ha divided by 100 ha (1 km²) yields a proportion of 0.005 (0.5 percent). For the example jurisdiction, 99.5 percent of deforestation over the period occurs within the cumulative histogram bin ≥2160 m and <2190 m. Therefore, the NRT is set at 2175 m (the midpoint of the bin).

To determine the NRT:

1) Create a map of distance from non-forest at the beginning of the HRP.

2) Considering only areas that were deforested during the HRP, create a cumulative frequency histogram of the distance map from step 1, ranging from the minimum distance to the maximum distance (as in Figure 3).

    a) If the GIS histogram utility used for mapping includes the option to specify a mask, utilize it to consider only the deforested pixels.

    b) If the GIS does not offer the mask option, modify the distance image to set all non-deforested pixels to zero before calculating the histogram.

3) Set the minimum distance for histogram calculation to be the same as the resolution of the data (e.g., 30 m).

    a) Avoid setting the minimum distance to 0 because pixels that are non-forest at T1 must be eliminated.

4) Set the class width of the histogram to match the spatial resolution of the map (e.g., 30 m).

5) Examine the histogram numerically and search for the distance at which the cumulative total equals or slightly surpasses 99.5 percent.

Figure 3: Cumulative Histogram of Historical Deforestation Against Distance from Non-Forest and the Negligible Risk Threshold (NRT, the dashed line) for the Example Jurisdiction for the 6 year period
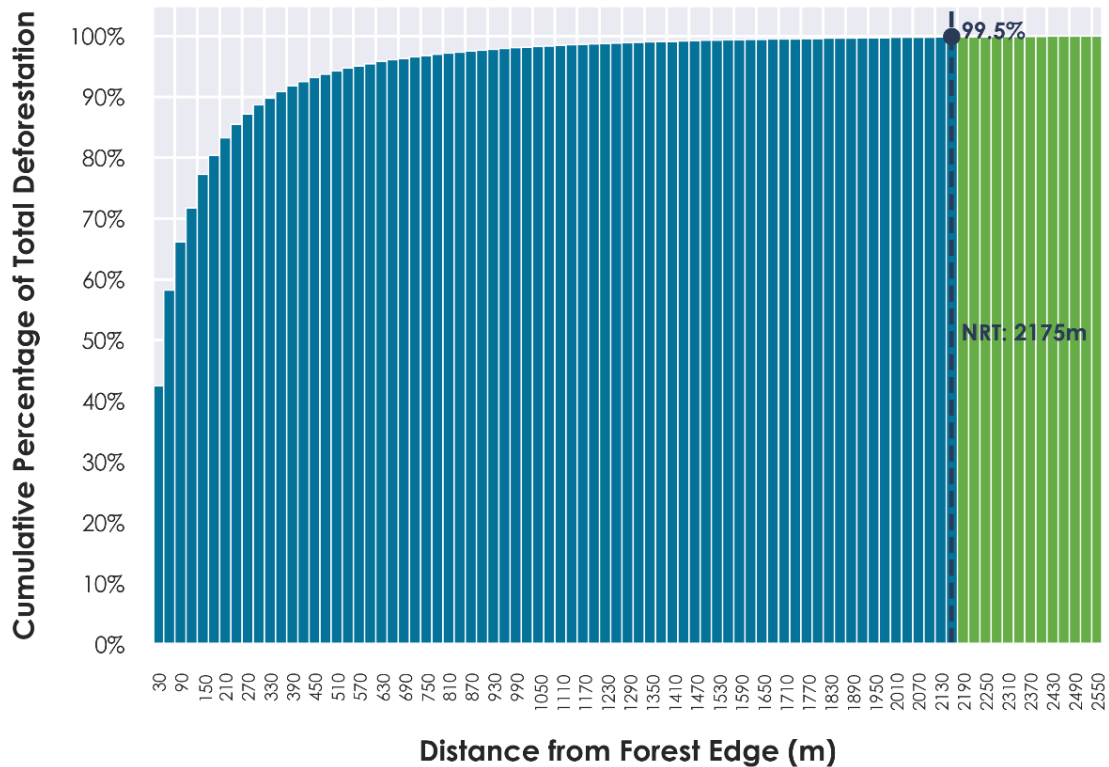
In the fitting phase of both the testing and application stages, use distance from non-forest at T1. For the prediction phase, this variable will have changed and must be updated. For the testing stage in the prediction phase, the updated variable is distance from non-forest at T2. In the application stage of the prediction phase, the updated variable is distance from non-forest at T3.

For the testing stage, using the example jurisdiction, the NRT of 2175 m, along with a map of distance from the forest edge at T1, would be used to construct the fitted benchmark vulnerability map. The same NRT and a map of distance from the forest edge at T2 would be used to create the prediction benchmark vulnerability map.

In all these cases, regions within the jurisdiction that are further from the forest edge than the NRT are assigned to vulnerability class 1. Areas closer to the forest edge are assigned to higher vulnerability classes, with the most vulnerable class being 30. Areas to be excluded from consideration (such as areas of planned deforestation or areas of non-forest) are assigned class 0. The easiest way to develop the map is described in the following steps.

1) Create a binary map of the jurisdiction with a value of 1 for areas inside the jurisdiction and 0 outside.

2) Create a map of vulnerability classes with values ranging from 1 to 29 in a geometric series between the forest edge and the NRT, following the procedure described below. Areas beyond the NRT are not included in the geometric classification and thus are assigned 0. The result is a 30-class map with values that range from 0 to 29.

3) Using raster addition, add this map to the map produced in Step 1 to yield a new map with values from 1 to 30 inside the jurisdiction.

4) From the result of Step 3, mask out any areas to be excluded from consideration by assigning them to class 0.

The geometric classification used in Step 2 to produce the vulnerability class map ranging from 1 to 29 will have narrow intervals where the deforestation frequency is expected to be highest (near to the forest edge), progressing smoothly to wider intervals where the expected frequency is lowest (the NRT). It has the following form:

$$ar^0 .. ar^1 .. ar^2 .. ar^3 .. ar^4 .. ar^5 ...$$

where r is the common ratio and a is a constant.

Using any two values in the series and the number of classes to create between them, the common ratio, r, is determined using Equation (1).

$$r = \left(LLmax/LLmin\right)^{1/n\_classes} \tag{1}$$

Where:

r	=	Common ratio (unitless)
$LLmax$	=	Lower limit of the highest vulnerability class (m)
$LLmin$	=	Lower limit of the lowest vulnerability class = NRT (m)
$n\_classes$	=	Number of vulnerability classes

For the example jurisdiction, the resolution of the mapped data is 30 m, the lower limit of the highest vulnerability class ($LLmax$) is 30 m (the minimum distance possible without being in non-forest) and the lower limit of the lowest vulnerability class ($LLmin$) is 2175 m (the negligible risk threshold). With the number of classes ($n\_classes$) equal to 29, the common ratio, r, is:

$$r = \left(30/2175\right)^{1/29} = (0.013793)^{0.034483} = 0.86268$$

Note that while the example of Equation (1) for the example jurisdiction is illustrated here with six significant figures, the equations should be processed using double precision (float64) numbers with a minimum of 15 significant figures.

The lower limit of each vulnerability class, LL_c, is then calculated using Equation (2).

$$LL_c = LLmin \times r^c \qquad (2)$$

Where:

LL_c	=	Lower limit of the cth vulnerability class (m)
$LLmin$	=	Lower limit of the lowest vulnerability class = NRT (m)
c	=	Class number (unitless)
r	=	Common ratio (unitless)

Table 2 shows the class limits of the resulting 30 vulnerability classes for the example jurisdiction, where classes 0 to 29 have been added to the binary jurisdiction map (1 indicates inside the jurisdiction, 0 indicates outside), giving classes from 1 to 30. The class limits are used to reclassify the map of distance to forest edge to create a categorical vulnerability map with 30 categories of vulnerability. Areas to be excluded from consideration are assigned to class 0.

Table 2: Class Limits of the Final Vulnerability Map for the Example Jurisdiction. Classes Include Data Values That are Greater Than or Equal to the Lower Limit and Less Than the Upper Limit.

Class	Lower Limit	Upper Limit		Class	Lower Limit	Upper Limit
0	30.00	34.78		15	275.02	318.80
29	34.78	40.31		14	318.80	369.54
28	40.31	46.72		13	369.54	428.36
27	46.72	54.17		12	428.36	496.55
26	54.17	62.79		11	496.55	575.59
25	62.79	72.78		10	575.59	667.21
24	72.78	84.37		9	667.21	773.41
23	84.37	97.80		8	773.41	896.52
22	97.80	113.36		7	896.52	1039.23
21	113.36	131.41		6	1039.23	1204.65
20	131.41	152.32		5	1204.65	1396.40

19	152.32	176.57	4	1396.40	1618.68
18	176.57	204.68	3	1618.68	1876.33
17	204.68	237.26	2	1876.33	2175.00
16	237.26	275.02	1	2175.00	No upper limit

Figure 4 shows the benchmark vulnerability map fitted for the example jurisdiction, as well as a detailed view of a typical location in the benchmark vulnerability map. Black areas (class 0) are excluded or non-forest areas. Dark blue areas (class 1) are those deemed to be of negligible risk as they are located beyond the NRT. The vulnerability classes are seen radiating away from the non-forest areas. The progressive change in the width of the bins is clearly evident, with the narrowest bins near to the forest edge and the widest next to the region of negligible risk.

All areas that are not logically excluded must belong to one of the ordinal vulnerability classes where the highest value (i.e., 30) denotes the highest vulnerability to deforestation. Some of the classes closest to the forest edge may not appear on the map because of the limited ability of raster map images to express very small values of distance.

For example, in Figure 4, class 29 describes a very narrow range below the possible distance values due to the 30 m resolution of the map. This is not a problem for the *UDef-A*, and missing classes are typically very few (only two in this example). Finer pixel resolution maps are progressively less likely to experience this.

Figure 4: Vulnerability Map for the Example Jurisdiction Featuring an Enlarged Inset. Class 0 (Black) is Used to Indicate Non-Forest Areas and Any Excluded Lands. Class 1 (Darkest Blue – Bottom Portion of Inset) Indicates Areas Beyond the NRT. Classes 2–30 Follow a Geometric Series.
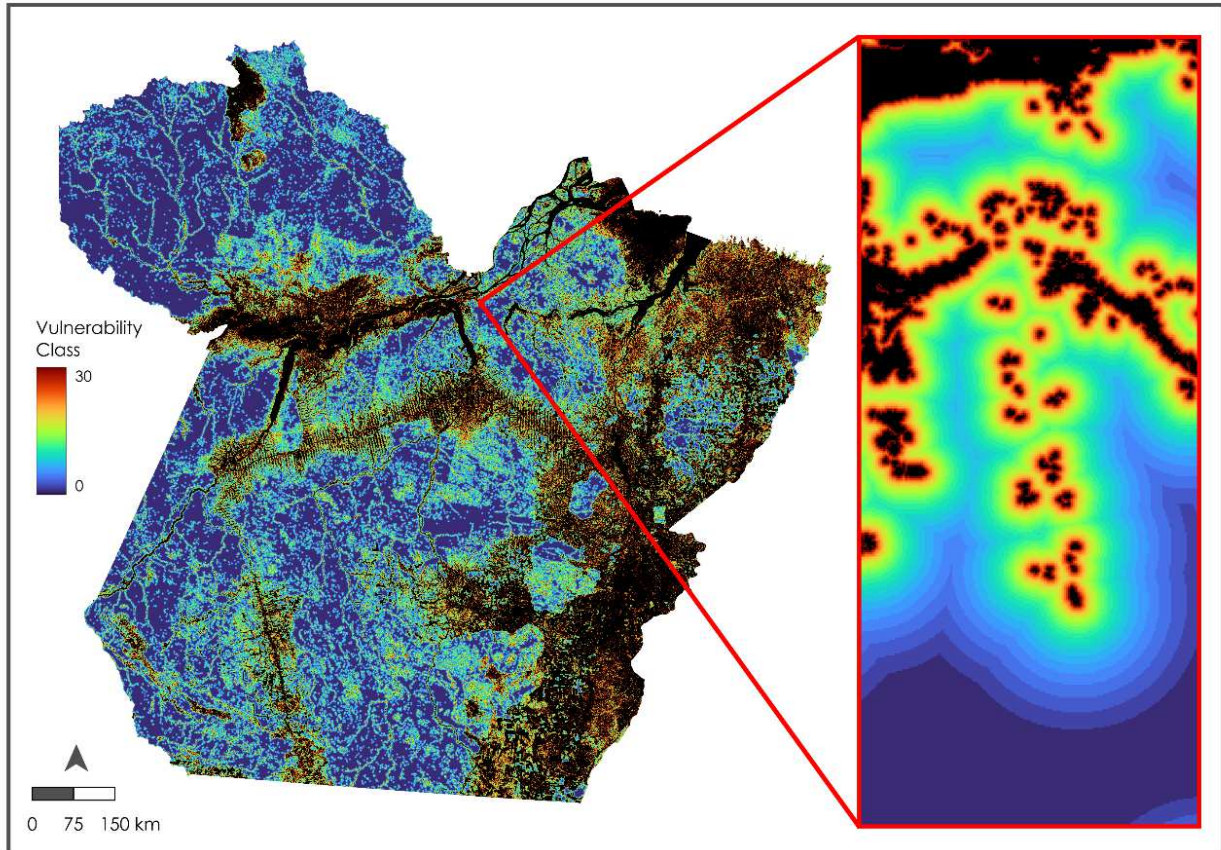
5.3.1.2   Step 2: Create the Benchmark Modeling Regions Map

Once the 30-class benchmark vulnerability map has been created, the associated modeling regions map is created by overlaying the vulnerability zones onto the administrative divisions. This is known as an "intersection," "cross-classification," or "cross-tabulation" operation. The goal is that every unique combination of vulnerability zone and administrative division has a unique identifier (ID). The specific numbering system for the IDs is not important, but a simple logic for creating this map is as follows:

1) Multiply the vulnerability zones map by 1000.

2) Add the administrative divisions map (assumed to have IDs in the 1–999 range).

3) Reclassify all output values from 1–999 to be 0 (because these are excluded and non-forest areas (class 0) within various administrative divisions).

The resulting map indicates the vulnerability zone with the first one to two digits and the administrative division with the last three digits of the ID. The third step above ensures that

excluded areas remain in class 0. In the example for the example jurisdiction, where there are 144 municipalities in the state, the resulting modeling regions have IDs ranging from 1001 (vulnerability zone 1, division 1) to 30144 (vulnerability zone 30, division 144).

Figure 5 illustrates the modeling regions map of the example jurisdiction for the fitting phase. The map looks similar to the vulnerability map shown in Figure 4 because the thousands digit of the ID corresponds with vulnerability.

Figure 5: Modeling Regions for the Example Jurisdiction, Where ID Represents Vulnerability and Administrative Division
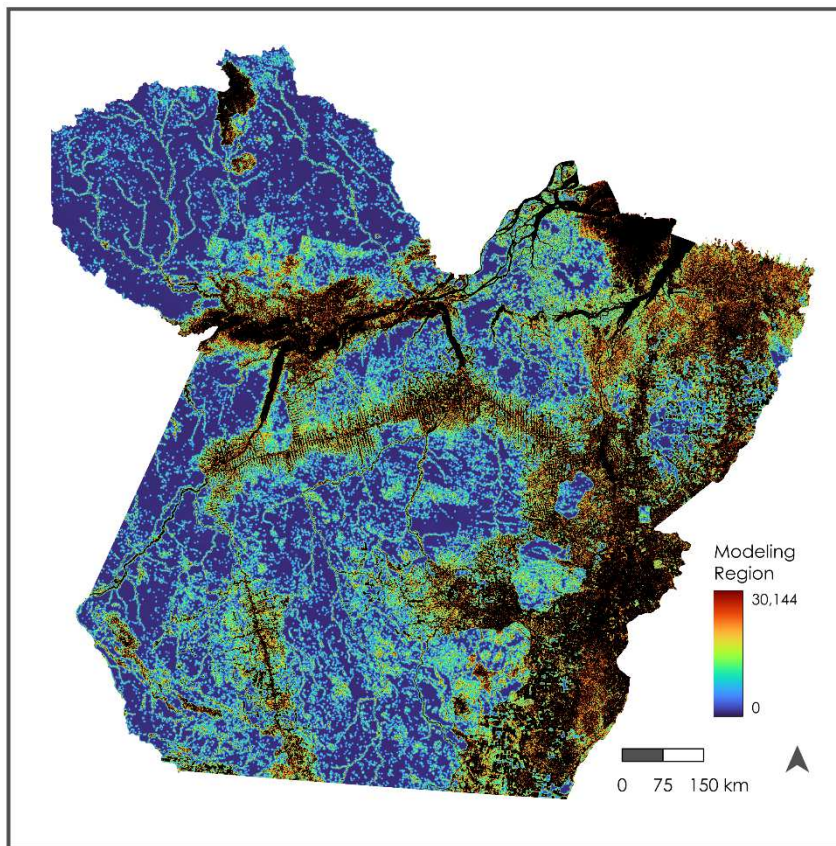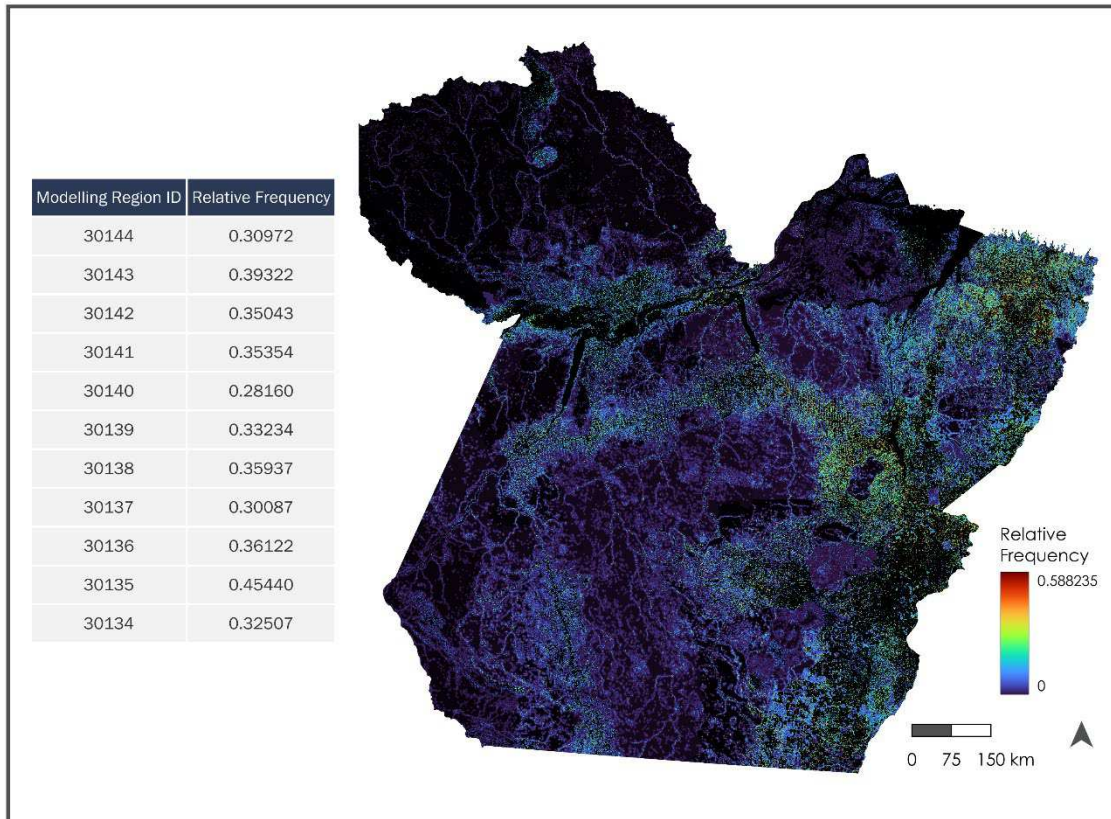

5.3.1.3 Step 3: Calculate the Relative Frequencies of Deforestation within the Modeling Regions

Once the benchmark modeling region map has been created, the relative frequencies of deforestation during the historical period (the calibration period for the testing stage, or the full HRP for the application stage) are calculated. With a binary map of deforestation over the historical period, the relative frequency of deforestation within each modeling region is calculated by computing the mean of the pixel values. Since the pixel values are either 0 (not deforested) or 1 (deforested), the mean will indicate the relative frequency of deforestation within each modeling region. This averaging is achieved by using a GIS operation called "zonal

statistics" or "extract," whereby the mean is computed over all pixels within each modeling region. A table is produced indicating the ID and relative frequency of deforestation for each modeling region. This table is used in the prediction phase. Figure 6 illustrates the relative frequency map for the example jurisdiction for the fitting phase, as well as a portion of the tabular output.

Figure 6: Relative Frequency Map for the Fitting Phase for the Example Jurisdiction (right) and a Portion of the Associated Table (left)

Modelling Region ID	Relative Frequency
30144	0.30972
30143	0.39322
30142	0.35043
30141	0.35354
30140	0.28160
30139	0.33234
30138	0.35937
30137	0.30087
30136	0.36122
30135	0.45440
30134	0.32507

5.3.1.4 Step 4: Convert Relative Frequencies to Deforestation Densities

The benchmark relative frequency map produced in Section 5.3.1.3 is multiplied by the area, hereinafter referred to as areal resolution, of the pixels. For example, a map with pixels that measure 30 m × 30 m has an areal resolution of 0.09 hectares. Thus, a pixel where the relative frequency of deforestation is 0.20 is converted to a deforestation density of 0.018 ha/pixel. The resulting map is the deforestation density map.

5.3.2 The Prediction Phase

Once the fitting phase has been completed, the prediction phase may be started. For the benchmark approach, new vulnerability and modeling region maps must be created. The resulting prediction modeling regions are then assigned the relative frequencies from the corresponding regions listed in the relative frequency table produced in Section 5.3.1.3. These frequencies are adjusted as necessary to yield the projected quantity of change, thus producing
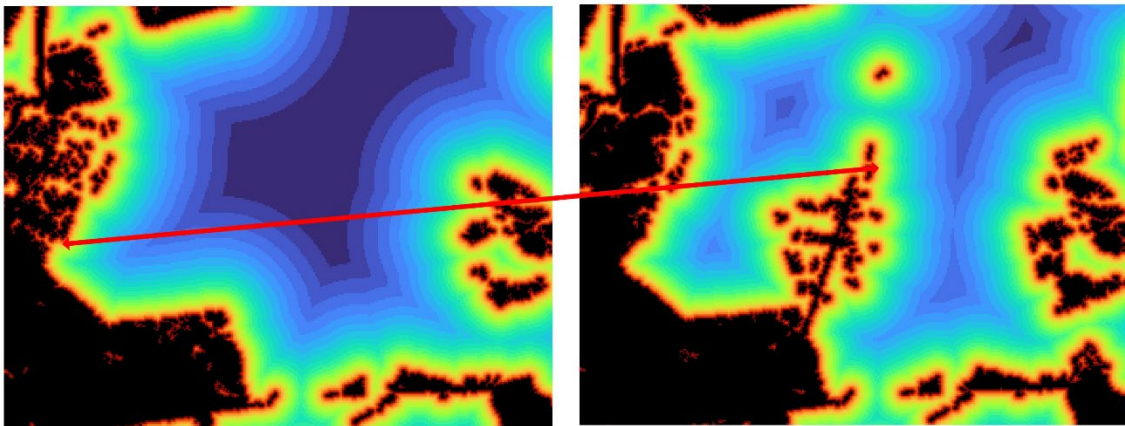
the prediction probability map. Finally, the prediction probability map is converted to densities by multiplying by the pixel areal resolution. These steps are described in detail below.

5.3.2.1   Step 1: Create the Prediction Vulnerability and Modeling Regions Maps

For the benchmark approach, the same process as was used for the fitting phase must be used for the prediction phase, with one important exception: the map of distance from non-forest should be based on non-forest at the start of the confirmation period (T2) in the testing stage and non-forest at the start of the BVP (T3) in the application stage. Otherwise, follow the same sequence as in Section 5.3.1.1 to get the prediction vulnerability map and Section 5.3.1.2 (using the prediction vulnerability map) to get the prediction modeling regions map.

Figure 7 shows an enlargement to illustrate how modeling regions may change position between the fitting and prediction phases.

Figure 7: An Enlargement of Corresponding Locations in the Fitting Modeling Regions in the Calibration Period (left) and the Prediction Modeling Regions in the Confirmation Period (right). The Arrow Points to Corresponding Modeling Regions 21008 – Vulnerability Zone 21 and Administrative Division 08.

5.3.2.2   Step 2: Assigning Prediction Probabilities and Densities Based on the Fitted Data

To produce a prediction, the relative frequencies of deforestation experienced in the fitting phase are assumed to persist into the prediction phase, although with a quantity adjustment based on the jurisdictional activity data estimate (see Section 5.3.2.3). Before the quantity adjustment, use the table of relative frequencies generated in the fitting phase to assign relative frequencies to the prediction modeling regions. GIS software systems generally refer to this as an "assign," "reclass by table," or "reclass by file" operation. Since this is a prediction, these relative frequencies are actually probabilities. However, the result is multiplied by the areal resolution of the map pixels to express the probabilities as densities. For example, with 30 m resolution images, the areal resolution is 0.09 ha. Multiplying the prediction probability map by 0.09 converts it to densities in ha/pixel.

5.3.2.3 Step 3: Applying the Quantity Adjustment

The final step in the prediction phase is to apply a quantity adjustment. In the testing stage, the prediction is used for comparative testing of different models, and the quantity must be adjusted to match the actual quantity of deforestation in the confirmation period (expressed in hectares). This adjustment is made to ensure that differences in the methods compared arise only from their spatial allocation of deforestation. In the application stage, the prediction is for the BVP, and the quantity must be adjusted for the projected amount of deforestation as determined from activity data (AD) sampling.

To make the adjustment, use the following process:

a) Determine the expected deforestation (*ED*) for the period being modeled. In the testing stage, determine the total deforestation (in hectares) during the confirmation period. In the application stage, use the amount of deforestation (in hectares) as determined from the activity data estimation. Where the activity data amount is specified as an annual rate, multiply by the duration of the BVP to derive the total expected activity over the BVP. Converting the rate to total expected deforestation ensures that the adjustment does not allocate more deforestation to any pixel than is possible given its areal resolution. The final step in the adjustment process converts the result back to a per annum rate.

b) Sum the pixels in the prediction density map. This is the modeled deforestation (*MD*).

c) Calculate an adjustment ratio, *AR*, using the following formula:

$$AR = ED / MD \tag{3}$$

d) Apply the adjustment ratio by multiplying *AR* by the prediction density map:

$$Adjusted\_Prediction\_Density\_Map = AR \times Prediction\_Density\_Map \tag{4}$$

e) Check whether any pixels in the adjusted map exceed their maximum density. The maximum density is equal to the areal resolution of map pixels (e.g., 0.09 ha for 30 m data). It is very unlikely that the maximum density will be exceeded. However, if the density of deforestation exceeds the maximum for any pixels in the adjusted map, reclassify all pixels greater than the maximum (e.g., >0.09) to be the maximum, and repeat stages b) and c) above. Then, when *AR* ≤ 1.00001 (six significant figures), treat this as the final adjusted prediction density map. Otherwise, treat the result as the new prediction density map and repeat stages d) through e) as many times as necessary to obtain *AR* ≤ 1.00001.

f) As a final step, convert the result back to an annual rate by dividing by the number of years in the BVP.

Figure 8 shows the final prediction for the BVP in the example jurisdiction, expressed in densities (ha/pixel). The adjustment ratio is 1.079. After adjustment, there were no pixels that exceeded the maximum density, so no iterative adjustment is needed.

Figure 8: Final Prediction for the Example Jurisdiction in the BVP, After the Quantity Adjustment (ha/pixel/yr)
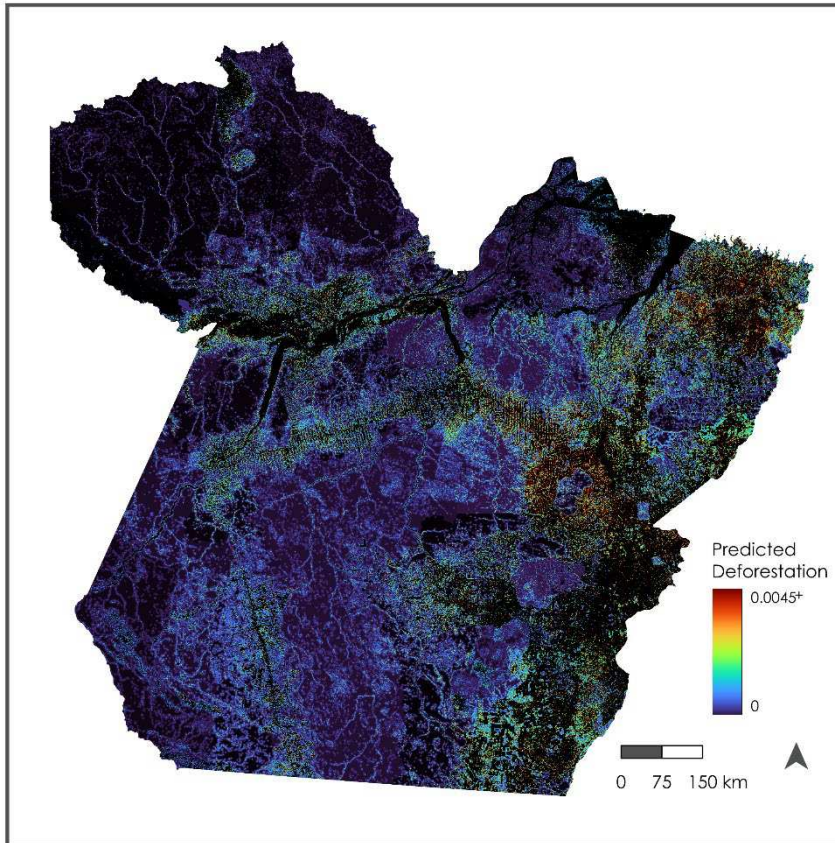
5.4   Alternative Risk Mapping

The benchmark method is a standard against which alternative deforestation risk models may be compared. At least two alternative models must be tested with the goal of developing a more skillful model. However, an alternative model must pass two tests as described in Section 5.5 before being accepted for use.

5.4.1   Creating a 30-class Alternative Vulnerability Map

Alternative vulnerability maps to be evaluated should also have vulnerability scaled from 1 to 30, with 0 denoting excluded and non-forested areas.

Typically, empirical models of the relationship between deforestation and a set of explanatory variables yield a map scaled continuously on a [0.0,1.0] range. Any classification scheme may be considered as long as it scales vulnerability from 1 to 30, with 1 denoting the lowest risk

class and 30 the highest, with excluded and non-forested areas represented as 0. However, a geometric classification similar to that used by the benchmark, which assigns narrow zones to the areas with highest vulnerability and progressively wider zones for areas of lower vulnerability, is recommended. To replicate the geometric classification used for the benchmark on data scaled continuously on a [0.0,1.0] range:

1) The continuous empirical vulnerability map should be rescaled to a [1.0,2.0] range. This step distinguishes between areas modeled to have a very low risk – which will be assigned to class 1 – and exclusions, including areas outside the jurisdiction. It also ensures that the geometric series equation will solve properly because a lower limit of 0 is not admissible for such a series.

2) Apply any exclusions (such as planned deforestation areas, non-forest areas and areas outside the jurisdiction) such that they become 0.

3) Use a geometric series classification to rescale the values from 1.0–2.0 to 30 classes from 1–30, where 1 is the lowest and widest vulnerability class and 30 is the highest and narrowest vulnerability class.

### 5.4.2 Fitting an Alternative Risk Model

Apply Steps 2 through 4 of Section 5.3.1 and all of the steps in Section 5.3.2, using the 30-class alternative vulnerability map created in Section 5.4.1 instead of the benchmark vulnerability map created in Step 1 of Section 5.3.1.

5.5 Testing and Model Selection

When considering an alternative model, tests must be conducted to discern whether the alternative is superior to the benchmark for both the fitting and prediction phases, using data from the calibration and confirmation periods respectively.

For both tests, a coarse grid is established with a resolution equal to the median size of REDD projects within the jurisdiction (where this is unknown, a value of 100 000 ha may be used). This may be done by creating a regular grid of sample points within the jurisdiction to create Theissen polygons. The number of sample points is the nearest integer to the size of the jurisdiction area divided by the median size of the REDD projects within the jurisdiction. Polygons at the edges tend to be irregular and vary in size and are thus removed. Removing polygons at the edges can be achieved using the GIS operation "select by location" and selecting features from the Theissen polygon grid found inside the binary mask of the jurisdiction using "are within" as the spatial relationship predicate. An example coarse grid is shown in Figure 9.

Figure 9: Coarse Grid for the Example Jurisdiction Using the Theissen Polygon Method: Grid Resolution Equals the Median Area of REDD Projects in the State, which is 95,296 ha
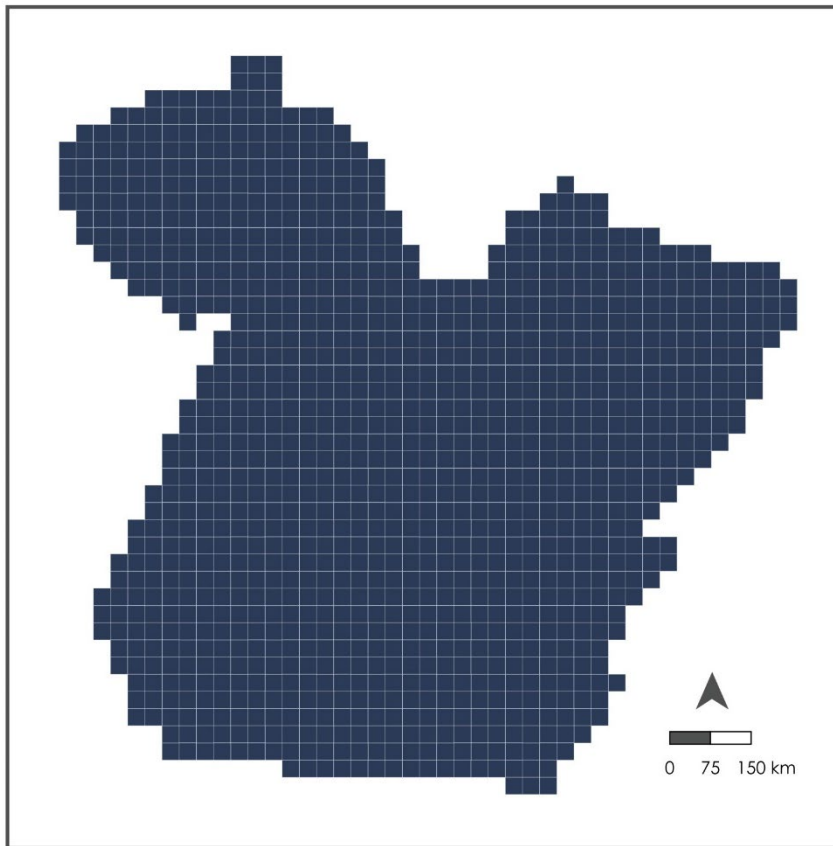
5.5.1 The Fit Test

To assess the goodness of fit, the relative frequency maps are first multiplied by the areal resolution of the pixels. For example, a map with pixels that measure 30 m × 30 m has an areal resolution of 0.09 hectares. Thus, a pixel where the relative frequency is 0.20 would be converted to a density of 0.018 ha/pixel. The resulting maps are the fitting confirmation period density maps. These maps must be produced for the benchmark and each of the alternative models being considered.

Tabulate the amount of deforestation (in hectares) that was observed in the calibration period (T1 to T2) within each grid cell. Use this on the *x*-axis for a scatter plot where the *y*-axis is the sum of pixels within the grid polygons from the fitting confirmation period density maps (benchmark and alternative). Show the 1:1 line that indicates perfect agreement between actual deforestation (*x*) and fitted deforestation (*y*). Figure 10 shows such a graph for the benchmark fit test.

Given these data, compute the median absolute error (MedAE) as the median of the absolute differences between actual and fitted deforestation. In Figure 10, each dot represents one of the coarse grid cells. The absolute value of the distance between any dot and the 1:1 line

represents the error associated with that grid polygon. The median across all grid polygons yields the MedAE in hectares.

In the example jurisdiction, where the grid cells were set to be 95 296 ha, the MedAE for the fit is 315.88 ha, which represents 0.3 percent of the median size of a REDD project.

Figure 10: A Scatterplot of the Fit Test Results for the Example Jurisdiction Using the Benchmark Model
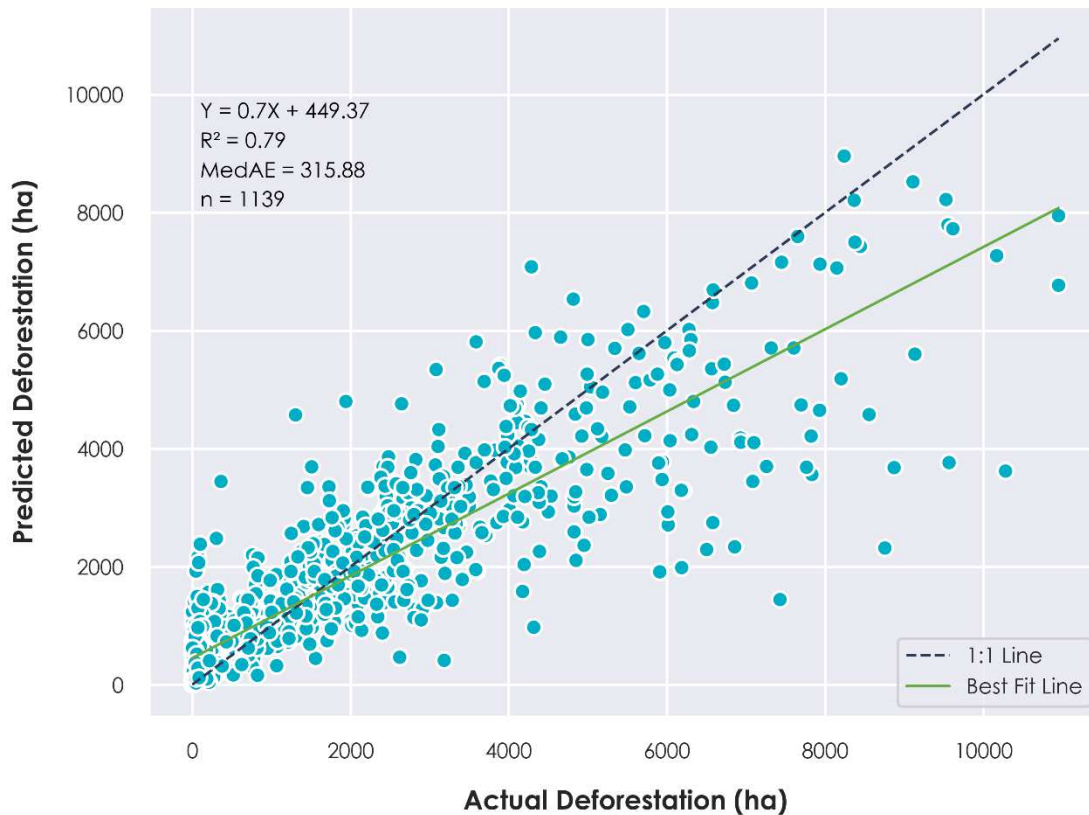
5.5.2 The Prediction Test

For the prediction test, use the actual deforestation during the confirmation period (T2 to T3) as *x* (in hectares) and the sum of densities on the adjusted prediction density maps (adjusted for the quantity of deforestation during the confirmation period) as *y*, for the benchmark and alternative model(s). Again, create an *x* versus *y* scatter plot and compute the MedAE as in Section 5.5.1.

5.5.3 Validation and Model Selection

The fit and prediction tests must be completed for both the benchmark model and each of the alternative models being considered. An alternative model that exhibits a lower MedAE than the benchmark, for both the it test and the prediction test, qualifies for use in the final analysis.

5.6 Using the Allocated Risk Map

The final prediction map for the BVP (the adjusted prediction density map) is now the allocated risk map. Vulnerability represents susceptibility to a threat (deforestation in this case). Risk is quantified vulnerability. Risk projects the expected forest loss during the timeframe considered (a single year in the BVP).

5.6.1 Estimating Unplanned Deforestation Activity Data

Allocated risk is expressed in per annum densities of expected deforestation (ha/pixel/year). For any polygonal area of interest, such as a REDD project area or an associated leakage belt, sum the values for all the pixels within the polygon. The result is the projected deforestation during the projected year.

5.6.2 Estimating Unplanned Deforestation Emissions

To obtain an estimate of emissions, first create a map of forest strata for the jurisdiction and assign to each stratum the emissions factor in t CO_2e/ha. Then multiply this map by the allocated risk (adjusted prediction density) map. The result is an expected emissions map in t CO_2e/pixel. For any polygonal area of interest, such as a REDD project area or an associated leakage belt, sum the values for all the pixels within the polygon. The result is the expected emissions from that polygon for the time period of focus.

6 DATA AND PARAMETERS

Data/Parameter	FCBM
Data unit	unitless categorical map
Description	A wall-to-wall forest cover benchmark map covering the entire jurisdiction that delineates forest transitions during the HRP
Equations/Section	Section 5.2, items 2-9
Source of data	Verra (see Appendix A1.4.3, step 1 of *VMD0055*)
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	The map must meet the specifications given in Section A1.4.3, step 1 of *VMD0055*.
Purpose of data	Calculation of project and leakage emissions
Comments	None

Data/Parameter	Administrative divisions map
Data unit	unitless categorical map
Description	Map of administrative divisions one level below the jurisdictional level
Equations/Section	Section 5.3.1.2, Step 2
Source of data	Verra (see VMD0055 Appendix 1, Section A1.4.3 and Appendix 3, Section A3.3)
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	Administrative divisions are typically scaled inversely to population density, are easily accessed and provide additional local context when creating modeling regions that are situationally similar.
Purpose of data	Calculation of project and leakage emissions
Comments	None

Data/Parameter	LLmin
Data unit	meters
Description	Lower limit of the lowest vulnerability class
Equations	(1), (2)
Source of data	Calculated in GIS or common statistics software
Value applied	NRT
Justification of choice of data or description of measurement methods and procedures applied	All values greater than or equal to the NRT are assigned to the lowest risk class; therefore, the lower limit of the lowest vulnerability class is the NRT. The same value is also the upper limit to the geometric classification used to bin continuous distance to forest edge data into vulnerability classes.
Purpose of data	Calculation of project and leakage emissions
Comments	

Data/Parameter	LLmax
Data unit	meters
Description	Lower limit of highest vulnerability class
Equation	(1)
Source of data	Calculated in GIS

Value applied	Spatial resolution of FCBM and derived layers
Justification of choice of data or description of measurement methods and procedures applied	The highest vulnerability class is comprised of distance values nearest to the forest edge. The minimum distance possible when calculating Euclidean distance from forest edge on a raster map is equal to the spatial resolution of the input map.
Purpose of data	Calculation of project and leakage emissions
Comments	Value is used as the minimum distance to forest edge when creating histogram of distance to forest edge, as shorter distances would not be represented in the data.
	Value may be used as class width for histogram of distance to forest edge.

Data/Parameter	*NRT*
Data unit	meters
Description	Negligible risk threshold – the distance from non-forest at which 99.5 percent of deforestation has occurred
Equations	(1), (2)
Source of data	Calculated in GIS or common statistics software
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	1) Create a map of distance from non-forest at beginning of the HRP.
	2) Construct cumulative histogram frequency of this map, considering only areas deforested during the HRP, and with minimum distance for calculation set equal to resolution of map data.
	3) Examine histogram and determine distance at which cumulative total equals or just surpasses 99.5 percent.
Purpose of data	Calculation of project and leakage emissions
Comments	None

Data/Parameter	*ED*
Data unit	hectares
Description	Number of hectares of unplanned deforestation in the jurisdiction during a given period
Equation	(5)
Source of data	In the testing stage, calculated from the FCBM using GIS software.

	In the application stage, use the amount of deforestation (in hectares) as determined from the activity data produced by Verra as described in Appendix 1, Section A1.4.1 of *VMD0055*.
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	For the testing stage, sum the map of deforestation during the confirmation period and multiply by the areal resolution (in ha) of the map to determine the total deforestation in hectares.
	For the application stage, produce according to Appendix 1, Section A1.4.1 of *VMD0055*
Purpose of data	Calculation of project and leakage emissions
Comments	None

7 REFERENCES

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Fischer, R., Taubert, F., Müller, M. S., Groeneveld, J., Lehmann, S., Wiegand, T., & Huth, A. (2021). Accelerated forest fragmentation leads to critical increase in tropical forest edge area. *Science Advances*, *7*(37). https://doi.org/10.1126/sciadv.abg7012

Linkie, M., Rood, E., & Smith, R. J. (2010). Modelling the effectiveness of enforcement strategies for avoiding tropical deforestation in Kerinci Seblat National Park, Sumatra. *Biodiversity and Conservation*, *19*(4). https://doi.org/10.1007/s10531-009-9754-8

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APPENDIX 1: DOCUMENT HISTORY

Version	Date	Comment
v1.0	21 Feb 2024	Initial version