Draft Report on Future Deforestation Modeling and Land Suitability Assessment for Oil palm

Agricultural Mapping Assessment in Papua New Guinea

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EXECUTIVE SUMMARY

Papua New Guinea's (PNG) forests are under pressure from several land uses such as small-scale agriculture and commercial agriculture, among others. These activities result in deforestation with diverse dynamics at the province level. It is therefore necessary to understand how drivers of deforestation influence the deforestation process and to predict what would be their future dynamics to identify where and when deforestation will take place. It is under this framework that UNDP, in close collaboration with PNGFA, decided to develop an agricultural mapping assessment in PNG.

This project to produce an agricultural mapping assessment had three objectives: i) identify five provinces to use as case studies to test our models; ii) develop a land suitability and a future deforestation models for oil palm expansion in PNG, and; iii) build capacity in PNGFA to develop and use of these models.

The five provinces we selected should be understood as provincial case studies; just provinces where we tested the functionality of our models. We divided the five selected provinces in two groups or Zones: Zone 1 (West Sepik, East Sepik and Madang) and Zone 2 (West New Britain and East New Britain). These five provincial case studies are not, and should not be considered as, pilot areas for REDD+ activities in PNG.

The overall process consisted of several steps starting from assessment and planning, data collection, identification of the five provincial case studies, development of a land suitability model and a future deforestation model, testing of the models in the provincial case studies, consultation workshop with key stakeholders, development of methodological guidelines for the generation and use of the models, and capacity building to GIS specialists at PNG's Forest Authority (PNGFA).

The main objective of the land suitability model was to identify areas suitable for oil palm growth based on a set of nine climatic and physical variables. The results of this model are maps showing suitable areas (with different degrees of suitability) and non-suitable areas for oil palm growth in PNG (Fig. A). These maps can be used to identify where oil palm can grow and also, by combining with other data such as location of grassland land, where sustainable oil palm can be developed.

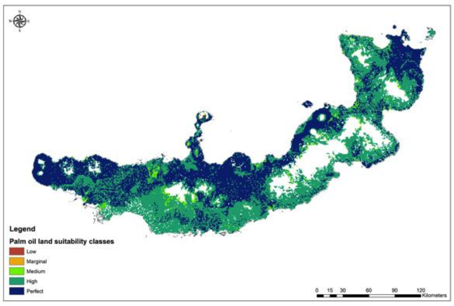

Fig. A: Maps resulting from a land suitability model

The objectives of the future deforestation model where three: i) estimate future deforestation under three scenarios: Business as Usual (BaU) that is a continuation of historical trends until the year 2024, Lax (40-50% higher annual deforestation rate than in BaU), and Conservation (same as BaU, but oil palm expansion shifts into suitable grassland areas); ii) to map the location of total future deforestation, and; iii) to map the location of deforestation from oil palm. Projected oil palm deforestation was considered as that larger than a 20 hectares size threshold. These resulting maps are useful for identifying areas with the highest risk of being deforested as well as for quantifying and locating potential future deforestation based on historical trends (Fig. B). We need to always have in mind that models are predictions of the future based on what we know happened in the past, thus models should not be taken as certain realities to occur in a determined future. For this reason, models must be improved and run again often to incorporate new and updated information about the behavior of the drivers of deforestation.

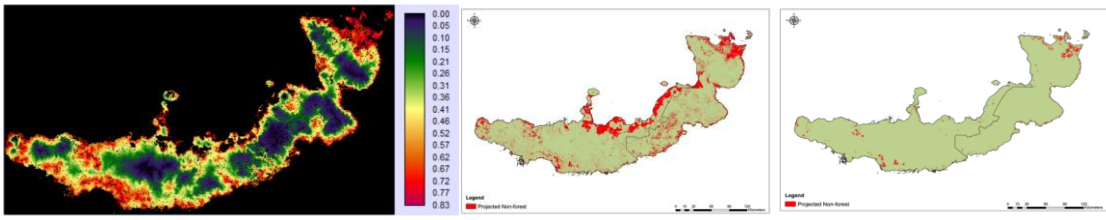

Figure B: Maps showing risk of deforestation (left), cumulative deforestation (center), and deforestation only from oil palm expansion (right)

Our findings from future deforestation modeling showed that Zone 1 (West Sepik, East Sepik and Madang) could lose about 96,000 ha under a BaU scenario and 144,000 ha under a Lax scenario until 2024; oil palm could be responsible for up to 87% of this deforestation. In the case of Zone 2 (West New Britain and East New Britain) this area could lose about 58,000 ha under a BaU scenario and 88,000 ha under a Lax scenario until 2024; oil palm could be responsible for up to 92% of this deforestation. We should mention that most of the projected deforestation took place within areas under the land-use “small-scale agriculture” and in the proximity of agricultural and forestry plantations. Furthermore, our findings from a quantitative-only assessment (with no mapping of deforestation) indicated that Zone 1 could lose around 312,000 ha and Zone 2 up to 254,000 ha of suitable forestland due to projected oil palm deforestation until the year 2050.

As for the Conservation scenario, our results indicated that Zone 1 has enough suitable grassland to absorb the expansion of oil palm in both the BaU and Lax scenarios; that was not the case in Zone 2. It must be highlighted these estimations do not took into account variables such as high carbon stocks and High Conservation Value of grassland areas.

These models are useful tools in the decision-making process of a national REDD+ strategy. Other countries such as Guyana and Colombia are using deforestation prediction models to understand the spatial distribution of deforestation, to identify which forest classes will be lost first in the future, and to help target REDD+ actions (UN-REDD 2015).

Following the presentation of these results in a workshop with key stakeholders in Port Moresby on November 2016, the next steps are to build capacity among GIS specialists with the collaboration of the PNGFA FAO/National Forest Inventory (NFI) team at PNGFA with the support of a national and international consultants during 2017.

1 BACKGROUND

As part of the REDD+ readiness development process Papua New Guinea (PNG) was considering a number of approaches to address the drivers of deforestation and forest degradation and strengthen land use management. Previous analyses of deforestation and forest degradation have highlighted the role of both agriculture and unsustainable logging as key drivers.

There has been a steady increase in deforestation in PNG in the period 2001-2014 with variations among provinces. Such variations mean that measuring deforestation at the provincial level is an important factor to be considered for PNG's REDD+ strategy (Cuthbert et al. 2016). Deforestation have occurred through the conversion of primary and degraded forestland into cropland by commercial companies and smallholders (many of which also contain cash crops).

Oil palm is an important crop for the economy of PNG. Oil palm is PNG's biggest agricultural export with nearly K1 billion per year. In PNG there are approximately 150,000 hectares of oil palm plantations (combination of large and small-scale producers) and about 200,000 more hectares are under development; the long-term goal of the Government of Papua New Guinea (Go-PNG) is to implement 1million hectares or oil palm (Bito and Petit 2016).

It becomes then necessary to develop spatio-temporal tools that allow for the estimation of the future dynamics of deforestation from agricultural activities, in particular, oil palm. For this reason UNDP, in close collaboration with PNGFA, decided to develop an agricultural mapping assessment in PNG.

2 OBJECTIVES OF THE STUDY

The objectives of this study are:

- Develop a land suitability model and a future deforestation model for oil palm expansion;
- Test both models in five selected provincial case studies, and;
- Provide capacity building to PNGFA on the development and application of such models.

The findings of this study will support Go-PNG through the PNG Forest Authority (PNGFA) to: i) create awareness on the usefulness of land suitability and future deforestation models as support tools for PNG's national REDD+ strategy; ii) build local capacity in the development and implementation of these models, and; iii) strengthen PNG's national REDD+ strategy and help targeting REDD+ actions.

3 METHODOLOGY

We collected primary data from interviews with key stakeholders in PNG and secondary data from literature review. Primary data was collected via semi-structured interviews held with 10 key stakeholders (from a total of 14 stakeholders who were invited to be interviewed) with a focus on the current and expected state of oil palm expansion. A complete list of the participating stakeholders can be found in Annex 1. As for secondary data, we identified available data from governmental institutions in PNG and from open available sources such as the Hansen dataset (Hansen et al. 2013). Our focus was in obtaining data on land-use, land-cover, and other essential spatial variables such as elevation, slope, roads, and main towns, among others.

Our methodological approach consisted on three steps: i) identification of provincial case studies; ii) development of a land suitability model, and; iii) development of a future deforestation model. Each of these three steps is presented below.

3.1 Provincial Case Studies

One of the objectives of this assignment on agricultural mapping assessment in PNG was to five provinces on which to test our land suitability and future deforestation models for oil palm expansion in PNG.

The five selected provinces in this assessment are not to be considered as the only pilot areas where oil palm expansion should/could be evaluated. These provincial case studies are merely provinces that we selected to test the two models.

Our analysis considered eight evaluation variables to identify the pilot provinces for future deforestation and suitability modeling. Each variable was assigned a weight and the selected variables were those three that scored the highest cumulative score.

Replicating the future deforestation model at the national level will take significantly more time. It can take five days to run the model for an individual province (including data preparation, processing time of the model, and analysis of the results). Many factors affect the total time to develop a deforestation model. For example, having all required data readily available in a consistent format and projections, running the model individually for each province or for the whole PNG at once, modeling period and intervals (i.e. a future projection of 40 years with 5-year intervals takes less than 1-year intervals). So, it can be assumed that only one operator working in one PC could complete the work in three to four weeks.

We identified nine evaluation variables to select the three pilot provinces for future deforestation and land suitability models (Table 1).

Table 1: Evaluation variables and source of information

ID	Variable	Sources of information			
1	Past land-cover change to oil palm 1999-2010	Gunarso et al. (2013)			
2	Above-ground carbon (AGC) stocks change by land-cover	Agus et al. (2013)			
3	Land-cover by province in 2013	PNGFA (2013)			
4	Population density and land suitability	PNG NSO	Bryan and Shearman	Pirker et al.	Gingold et al. (2012)

		(2011)	(2008)	(2015)	
5	Ongoing and potential oil palm developments	Nelson et al. (2014)	Bito and Petit (2016)	Interview with Dr. Gae (2016)	Information from BSI Group Singapore Ltd
6	Land-suitability and socio-legal barriers for potential oil palm developments	Trangmar et al. (1995) (as cited in Nelson et al., 2014) and Nelson et al. (2014)			
7	Changes to oil palm in previously logged areas in SABLs	Sherman and Mackey (2015)			
8	REDD+ demonstration activities	Babon and Gowae (2013)			

Source: Own elaboration

Each variable was assigned a weight of either 1 or 2. Variables with a weight of 1 represented biophysical and social criteria, past land-cover change (i.e. presence of forest, population density), and evidence of ongoing REDD+ demonstration initiatives. Variables with a weight of 2 represented evidence that suggested the development of oil palm plantations in PNG and their feasibility (Table 2).

Finally, a total weight was assigned to each province by adding up the weights of each individual variable.

Table 2: Weighting system for the evaluation variables

Weight = 1		**Weight = 2**	
Variables	**Criteria**	**Variables**	**Criteria**
Potential land-cover change: forest, grassland, and wetland	Top ten provinces by land-cover	Ongoing and potential oil palm developments	Provinces with identified existing and future oil palm plantations
Above-ground carbon (AGC) stocks change by land-cover	Top ten provinces by amount (Mg ha^{-1}) of AGC loss	Potential pilot areas according to Dr. Gae	Provinces identified based on his extensive professional experience
Population density (2011) in areas lower than 1,100 meters	Top five provinces with largest suitable areas (lower than 1,100 meters) with high population density (persons/km^2)	Land-suitability and socio-legal barriers for potential oil palm developments	Provinces with oil palm developments on suitable land and with low or none social and legal issues
Changes to oil palm in previously logged areas in SABLs	Provinces presenting changes from previously logged areas to oil palm plantations		
REDD+ demonstration activities	Provinces with REDD+ demonstration activities		

Source: Own elaboration

3.1.1 Land-use by province in 2013

We used the information on land-use in 2013 for each provinces from an official report from PNGFA (PNGFA 2013) (Table 3).

Table 3: Land-use areas (ha) by PNG province according to an assessment by PNGFA in 2013

ID	PROVINCE	LAND-USE CLASSES (HA)		
		FOREST	GRASSLAND	WETLAND
1	Western	8,575,619	571,576	433,132
2	West Sepik	3,377,845	64,225	30,106
3	East Sepik	3,294,725	418,568	314,922
4	Gulf	2,998,196	52,850	384,176
5	Central	2,523,384	174,427	63,957
6	Morobe	2,484,939	316,229	5,856
7	Madang	2,264,730	152,434	37,614
8	Oro (Northem)	1,850,196	104,728	42,667
9	West New Britain	1,808,312	6,109	4,073
10	East New Britain	1,304,550	17,603	1,956
11	Southern Highlands	1,279,215	122,522	26,996
12	Milne Bay	1,070,519	157,610	-
13	Hela	881,663	85,962	-
14	Enga	871,218	81,044	-
15	New Ireland	746,400	15,233	3,808
16	Eastern Highlands	674,262	220,207	-
17	Bougainville	589,306	11,865	13,843
18	Chimbu	416,757	29,488	-
19	Jiwaka	317,232	23,608	-
20	Western Highlands	207,138	32,543	3,616
21	Manus	152,903	3,130	3,130
22	NCD	1,329	-	-
TOTAL		**37,690,438**	**2,661,961**	**1,369,852**

Source: Own elaboration based on data from PNGFA (2013).

3.1.2 Land-cover change 1999-2010 and average aboveground carbon (AGC) stocks by land cover

We estimated potential future land-cover changes and potential average aboveground carbon (AGC) stocks losses in a 10-year period. We used PNGFA's land-cover from 2013 (see Section 2.1) and historical land-use activity of oil palm expansion (Gunarso et al. 2013) to estimate potential future land-cover change under a Business as Usual (BaU) scenario. Then, we calculated potential average AGC stock losses combining the projected land-cover changes with available average data on above-ground carbon (AGC) stocks (Agus et al. 2013) (Table 4).

It should be highlighted that our approach for estimating future land-cover change does not take into account the distribution of land-suitability among land-cover classes. We assumed that each forest class had the same probability of change because we did not have a future deforestation model at the time of developing this report. Also, we could access PNG's Baseline Map 2012 official files and we did not have data on the exact locations of future oil palm plantations. For this reason, results from the estimations of potential land-cover changes and potential average AGC losses should be taken as proxies for the potential of PNG provinces to generate GHG emissions, but not as predictions of future deforestation dynamics from oil palm expansion in PNG.

Table 4: Land cover change into oil palm plantation for PNG between 1990 and 2010 and average above ground carbon per land cover class

Land Cover Type	Description	Percentage of total land cover change into oil palm between 1999-2010	Average Above Ground Carbon (AGC) per land cover class (Mg ha^{-1})
Disturbed Upland Forest	Natural forest, highly diverse species, with significantly reduced based area due to logging. Evidence of logging, including logging roads and small clearings typical of logging platforms	46%	85 ± 43
Upland Shrub & Grasslands	Open woody vegetation, often as part of a mosaic including forest and grassland. Well-drained soils on a variety of landscapes impacted by fire and logging; previous temporal periods reveal forest (UDF) or disturbed forest (DIF). Open vegetation dominated by grasses (most often Imperata). Upland, well-drained soils often in association with shrub land.	34.8%	3 ± 1 (grassland) 30 ± 3 (shrubland)
Swamp Shrub & Grasslands	Open woody vegetation on poorly drained soils; less than 3-6 m in height. On landscapes impacted by fire and logging in areas subject to temporary or permanent inundation; previous temporal periods reveal swamp forest (USF) or disturbed swamp forest (DSF). Extensive cover of herbaceous plants with scattered shrubs or trees. Inundated floodplains or impacted peat domes. Comparison with previous temporal periods revealed forest habitat.	8.3%	2 (swamp grassland) 28 ± 6 (swamp grassland)
Undisturbed Upland Forest	Natural forest, highly diverse species and high basal area. Well-drained soils, often on hilly or mountainous terrain; absence of logging roads or settlements.	6%	154 ± 94
Intensive Agriculture	Open area characterized by herbaceous vegetation intensively managed for row crops or pasture. Associated with road networks and human settlements Open area characterized by herbaceous vegetation (rice paddy), with seasonal or permanent inundation. Reticular patterns of dikes and canals, usually in association with settlements.	5.2%	11 ± 2
Disturbed swamp forest	Natural forest with temporary or permanent inundation. Evidence of logging, regular network of canals and small-scale clearings. Associated with peat domes and meandering rivers in coastal areas; absence of logging canals.	0.2%	84 ± 42

Source: Own elaboration based on data on land cover change from Gunarso et al. (2013) and AGC for land covers from Agus et al. (2013).

3.1.3 Population density and land suitability

In PNG oil palm operations usually work with local smallholders under an arrangement known as "nucleus estate". Under this arrangement, an oil palm company supplies oil palm seedlings and plants to local people to establish small-scale oil palm plantations (2 ha on average and up to 5 ha) on community or village land. Then, the oil palm company purchases the harvest. Such schemes encourage local farmers to plant more oil palm on their lands for profits.

Population density is strongly correlated to deforestation, particularly for small-scale agriculture (Cuthbert et al. 2016; Babon and Gowae 2013); however, population density cannot be used as a stand-alone predictor of future oil palm expansion. For example, it can be the case of areas with high population density located in land non-suitable for growing oil palm (i.e. altitude higher than 1,100 meters and/or with slopes of more than 10 degrees and/or more than 4,000 mm of precipitation). Therefore, it is necessary to at least use another variable to put population density in context.

To complement data on population density, we used a first iteration of what will be one of our final deliverables: a land suitability map for oil palm in PNG. In this first iteration we used four variables[1] that limit the growth of oil palm beyond certain thresholds, namely: altitude, slope, rainfall, and minimum temperature.

Of course, the extension of suitable areas in each province will undergo changes once the remaining five variables are incorporated (particularly with inundation); however, non-suitable areas will remain the same or increase. Therefore, this initial map provides an idea of which provinces might have higher extensions of suitable land for oil palm.
Data for the population density analysis was gathered from the census conducted in 2011 in PNG (PNG NSO 2011) and data to develop the initial land suitability map for oil palm was collected from the Papua New Guinea Resource Information System (Bryan and Shearman 2008). In addition, information about appropriate thresholds for the development of oil palm under each variable was obtained from the Interim Report Global oil palm suitability assessment (Pirker et al. 2015).

3.1.4 Ongoing and potential oil palm developments

A study conducted by Nelson et al. (2014) identified 36 potential oil palm developments in SABL areas in 11 provinces in PNG (Table 5). Each project was then assessed for the its feasibility in terms of land suitability/availability (land suitability score), technical and financial capacity of the proponents of the developments (developer capacity score), and socio-legal constraints that might prevent the materialization of the developments (see Section 2.5) (Nelson et al. 2014).

[1] For the final version of the land suitability map we will employ nine variables. The additional variables will be: soil (erodability, depth, texture, and drainage) and inundation areas.

Table 5: Oil palm developments identified in PNG as described by Nelson et at. (2014)

ID	Name	Province	Lease length (years)	Lease area (ha)	Oil palm area planned (ha)	Forest Clearing Authority issued (ha)	Land suitability score (A)	Developer capacity score (B)	*Overall capacity score (A*B)*	Socio-legal constraints score (C)
1	Aramia	Central	99	115000	ns		1	0	*0*	1
2	Baina Agroforestry Project	Central	40	42100	4500		0	0	*0*	2
3	Mekeo Hinterland Integrated Agroforestry Project	Central	99	116420	40000	116427	2	1	*2*	2
4	Ome Oil Palm Project	Central	99	11700	10530	11700	2	1	*2*	2
5	Ania-Melkoi Integrated (Rural) Development Project	East New Britain	ns	68300	30000		1	0	*0*	0
6	Gar-Marai Agroforestry Project	East New Britain	99	11800	3500		1	0	*0*	0
7	Illi-Wawas Integrated Rural Development Project	East New Britain	99	38500	3200	38500	1	0	*0*	0
8	Immerr-Kiligia Agroforestry Project	East New Britain	99	33500	17500		1	0	*0*	0
9	Inland Lassul Baining Integrated Agriculture Develop. (2 SABLs)	East New Britain	ns	53480	ns	30830	0	0	*0*	2
10	Kairak	East New Britain	99	11800	ns		0	0	*0*	0
11	Lote Kamlang (part of Illi-Wawas?)	East New Britain	99	4736	ns		1	0	*0*	0
12	Sigite-Mukus Integrated Agriculture Develop. Project (4 SABLs)	East New Britain	60	55400	20000		1	1	*1*	2
13	Angoram (Marienberg) Integrated Agriculture Project	East Sepik	99	25600	ns	25600	1	0	*0*	2
14	Nungwaia-Bongos Integrated Large-Scale Agriculture	East Sepik	99	109580	89000		1	1	*1*	2
15	Wewak Turubu Integrated Agriculture Project	East Sepik	99	116840	90000	121000	1	1	*1*	1
16	Arowa	Gulf	ns	12340	ns		0	0	*0*	2
17	East Waii Oil Palm Ltd	Gulf	ns	21110	ns		0	0	*0*	1
18	Kerema-Meporo Integrated Agroforestry Project	Gulf	99	59460	20000	89000	2	0	*0*	2
19	Vailala Agroforestry Project	Gulf	99	11800	ns		1	1	*1*	2
20	Wowobo	Gulf	ns	23180	ns		2	0	*0*	1
21	Urasir Agroforestry Oil Palm Development	Madang	66	112400	75520		2	0	*0*	2
22	Markham Valley Oil Palm Project	Morobe	ns	ns	7000		2	0	*0*	0
23	Central New Hanover Integrated Agroforestry Project	New Ireland	40	56592	16000	56592	1	1	*1*	2
24	Tabut Mamirum & Umbukul Integrated Agriculture	New Ireland	40	36970	ns	11864	2	1	*2*	2
25	Musa-Pongani Integrated Agroforestry Project	Oro	99	320060	100000	350000	1	0	*0*	2
26	Wanigela Integrated Agriculture (2 SABLs)	Oro	99	38350	ns	38350	2	1	*2*	2
27	Akami Oil Palm Estate (2 SABLs)	West New Britain	ns	577	ns		2	1	*2*	2
28	Lolokoru Estates Ltd.	West New Britain	45	17500	ns		2	1	*2*	1
29	Pulie-Anu Oil Palm Project (5 SABLs)	West New Britain	ns	41230	32000		2	1	*2*	1
30	Ainbai-Elis Integrated Rural Development Project	West Sepik	99	22850	18000		1	0	*0*	2
31	Aitape East Integrated Development (3 SABLs)	West Sepik	ns	20793	ns	29205	2	0	*0*	0
32	Aitape West Integrated Development	West Sepik	99	47626	20000	47626	1	0	*0*	1
33	Bewani Oil Palm Development Project	West Sepik	99	139090	26000	139910	1	1	*1*	1
34	Nuku Integrated Agroforestry Project	West Sepik	99	239810	25000		1	0	*0*	2
35	Wammy Rural Development Project	West Sepik	60	105200	58000		0	1	*0*	2
36	Wawoi Guavi Oil Palm Project (4 SABLs)	Western	70	62663	ns		1	1	*1*	0

Source: Own elaboration based on data from Nelson et al. (2014)

Bito and Petit (2016) gathered information on potential oil palm plantation developments in PNG as a consequence of the government's national strategy to increase production of this commodity. The authors relied on secondary information as well as on interviews with representatives of companies planning on developing oil palm plantations in SABL areas. The study indicated the province where potential developments will take place as well as the estimated extension of each one (Bito and Petit 2016).

Another source of information on existing oil palm activities was an Annual Report developed by New Britain Palm Oil Limited (NBOPL) (NBPOL 2010).

Finally, from our interviews with Dr. Gae Gowae it was possible to identify five provinces that would be adequate pilot areas for our modeling work. The identification of such provinces was based on Dr. Gae Gowae's experience in oil palm expansion in PNG and the results from his study (only the executive summary was available at the time of this assessment).

3.1.5 Feasibility assessment of potential oil palm developments

We adopted two feasibility criteria for oil palm developments presented by Nelson et al. (2014): land suitability and socio-legal constraints. The first criteria, land suitability, refer to the presence of sufficient suitable land for oil palm in PNG. Nelson et al. (2014) used as a reference an oil palm suitability map for PNG developed by Trangmar et al. (1995) (Fig. 1). Based on this information and the proposed location of the developments, Nelson et al. (2014) determined if there was sufficient available land not only accounting for the size of the oil palm developments, but also considering the required land for complementary infrastructure (i.e. mills). As a result, developments received a score of 0 (insufficient land), 1 (marginal or unknown), or 2 (sufficient) for land suitability.

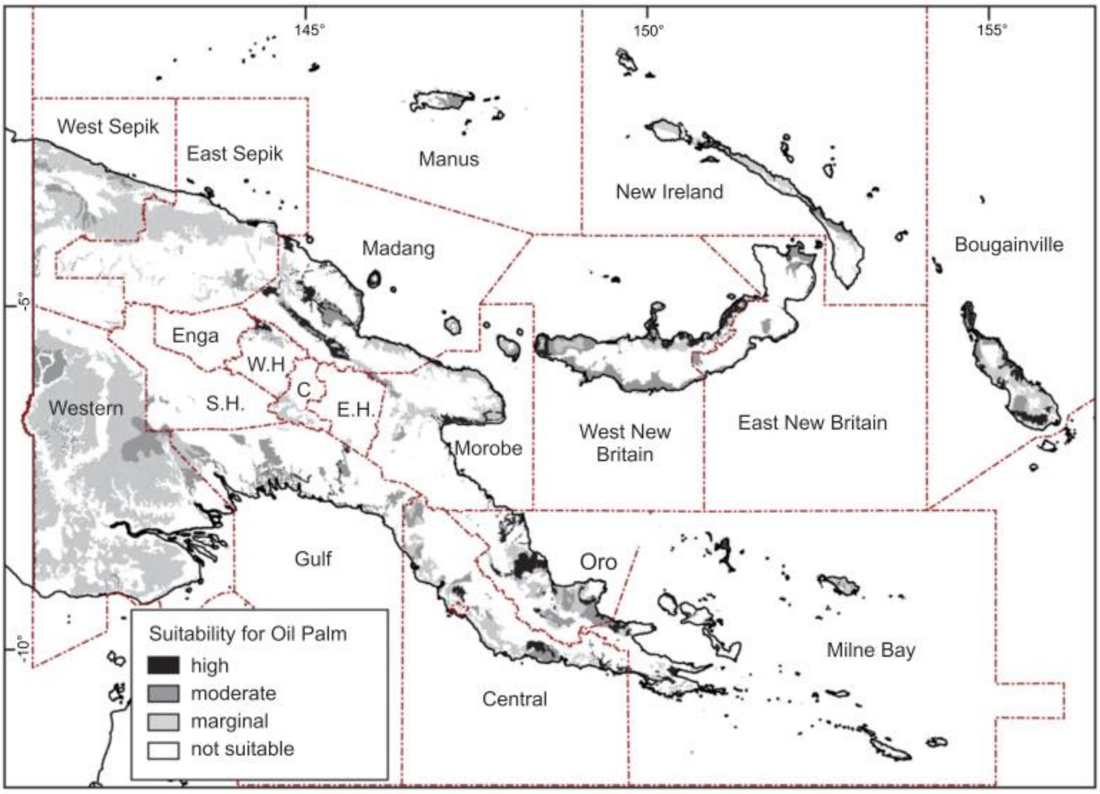

Figure 1: Map of PNG showing provinces and suitability for oil palm cultivation. Province acronyms are: C, Chimbu; E.H., Eastern Highlands; S.H., Southern Highlands; W.H., Western Highlands

Source: Trangmar et al. (1995) (as cited in Nelson et al., 2014)

The second criteria, socio-legal constraints, referred to disputes with landowners and legality of the proposed project activities, receiving a score between 0 (no known constraints) to 2 (major issues) (Nelson et al. 2014).

Finally, we mapped the developments according to their land suitability and socio-legal constraints scores (see Section 3.3). Our selection included only developments with land suitability scores of 1 or 2 and socio-legal scores of 0 or 1, this to rule out the least feasible developments.

3.1.6 Changes to oil palm in previously logged areas in SABLs

A study conducted by Shearman and Mackey (2015) assessed land-use and land-cover changes from 2002 to 2014 in the 52 largest Special Agriculture and Business Leases (SABLs) that in total covered 90% of the total SABL area. They evaluated the subsequent conversion into oil palm plantations of previously deforested areas by logging activities in each of the 52 SABL areas. Results showed that only 7% of the total deforested areas in SABLs were converted into oil palm plantations; however, there were substantial differences among individual leases. There were two SABL areas in the West Sepik and East New Britain provinces respectively, that saw a 20% conversion of previously degraded areas by logging into oil palm plantations. The study concludes that these two provinces are "focal areas for expansion of the oil palm industry" (Shearman and Mackey 2015).

3.1.7 REDD+ demonstration provinces

We collected information from the Babon and Gowae (2013) report on "The Context of REDD+ in Papua New Guinea".

3.2 Land Suitability

As part of this assignment our team conducted a land suitability assessment for oil palm growth in PNG. The objective was to use available physical and climatic variables to identify the spatial distribution of the suitable areas for oil palm growth in the selected provincial case studies.

A detailed methodological approach on how to develop a land suitability model was prepared as a stand-alone document. In this section we present a short summary of the steps involved in generating the suitability maps were:

1. Identification of variables and value thresholds that limit oil palm productivity based on national (Bryan and Shearman 2008) and international literature (Pirker et al. 2015):
    - Elevation
    - Slope
    - Minimum temperature
    - Precipitation
    - Soil erodability
    - Soil depth
    - Soil drainage
    - Soil texture
    - Soil Inundation
2. Creation of raster files for each variable replacing the characteristics of each variable with suitability classes from 1 (lowest) to 6 (highest) according to the adopted threshold values
3. Development of a model using the tool Model Builder in ArcGIS that combined suitability classes for all variables at a pixel level using the "Weighted Sum" tool. The result from this step is a new raster
4. Assessment of the range of values generated from the weighted sum tool for each Zone[2]. Then, the range of values was re-grouped into five suitability categories (low, marginal, medium, high, and perfect suitability) by evenly distributing the range of values from resulting from the weighted sum tool. In the case an even distribution was not possible, then a conservative approach was taken and fewer values were assigned to the highest suitability classes.

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[2] In theory the minimum value could be 9 (each of the nine variables scoring "1" for any given pixel) and the maximum value could be 54 (each of the nine variables scoring "6" for any given pixel).

It should be highlighted that our land suitability model only takes into account variables that limit the productivity of oil palm. However, there are other important factors that could be considered such as (but not limited to) (Gingold et al. 2012):

- Carbon content in different land-covers
- Biodiversity richness and presence of high-conservation values (HCV)
- Presence of conservation areas
- Presence of concessions (i.e. mining)
- Land tenure
- Land accessibility

3.3 Future Deforestation Model

Future deforestation modeling was performed using IDRISI Selva's Land Change Modeler (LCM) and ArcGIS 10.1 software. A detailed methodological approach on how to develop a land suitability model was prepared as a stand-alone document. In this section we present a short summary of the steps involved in generating a future deforestation model.

The first step to project deforestation into the future is to have remote sensing data on land-cover for at least two points in time encompassing an assessment period: an initial and final forest cover. In our case we used the publicly and freely available Hansen dataset (Hansen et al. 2013) because at the time of this study there was not official available data on land-cover change.

From the Hansen dataset we used the following data:

i) Forest cover in the year 2000 (tcover): This data refers to a land-cover classification of two classes: tree cover and tree-cover loss[3]

ii) Annual tree-cover loss for each year between 2000 and 2014 (lossyear): this data refers to the tree-cover that has been lost in each of the 14 years between 2000 and 2014

iii) A data mask layer (dmask): this data presents information about features that are neither tree cover nor tree-cover loss; thus, they are rivers.

iv) A data layer of tree-cover gain between 2000 and 2014 (gain): this data refers to tree-cover that has been regenerated between 2000 and 2014. However, it should be taken into account that in the case of PNG such gain or "regeneration" is the result of farming cycles; areas that appeared as regenerated tree-cover in 2014 were plantations already present in 2000 that grew their crops. Therefore, it is important to consider this layer to avoid overestimating baseline deforestation.

The objective was to first generate forest and non-forest classified images for the years 2000 (initial forest cover) and 2014 (final forest cover). These were the two images encompassing the assessment period 200-2014.

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[3] Tree-cover loss is not the same as deforestation. What a forest is depends on the definition adopted by each country whereas the Hansen dataset identifies tree-cover loss as a stand-replacement disturbance, or a change from a forest to non-forest state, during the period 2000–2014

Besides the data aforementioned, we also used a layer with official data on agricultural and forestry plantations in PNG (Qa,Qf), which was provided by PNGFA. This data layer is key because it allowed us to identify which areas were already plantations (and thus assumed as non-forest) in the year 2000.

For the future deforestation models in both zones we used the same set of eight (8) variables. Of course, these variables were selected for the purposes of testing the model, but other combinations of variables can be tried depending on the provinces and of the land-use change being assessed. The variables we selected were:

- Digital Elevation Model (DEM) of 30 meters
- Distance to existing non-forest in the year 2000
- Distance to primary roads (roads shapefile from Bryan and Shearman (2008))
- Distance to secondary roads (walkable paths shapefile from Bryan and Shearman (2008))
- Distance to rivers
- Distance to main towns
- Distance to census 2011 points
- Distance to Special Agricultural Business Leases (SABL) areas

We used data on agricultural and forestry plantations extracted from the Forest Base Map 2012 (JICA and PNGFA 2016) provided by PNGFA in the form of shapefile. Data on small-scale agricultural areas and grassland areas were generated via coarse digitalization of the publicly available land-covers from the Forest Base Map 2012 (JICA and PNGFA 2016) available at http://png-nfms.org/portal/ (FAO et al. 2016).

We used the following terminology when referring to projected non-forest:

- Total cumulative non-forest: represents the total non-forest resulting from the deforestation model for a scenario. This includes all non-forest including that of the baseline year 2014, thus is a cumulative non-forest result:

> Cumulative non-forest: baseline non-forest + projected non-forest

- Total net non-forest > 20ha: represents only the non-forest areas covering an area of more than 20 hectares. This represents only the projected areas of non-forest without the non-forest of the baseline year 2014 (therefore it is not cumulative but rather net deforestation):

> Net non-forest of more than 20ha = (projected non-forest>20ha) – (baseline non-forest>20ha)

- Net oil palm projection: represents only non-forest areas covering an area of more than 20 hectares that fall within suitable areas for the growth of oil palm:

> Net oil palm projection → within areas suitable for oil palm (land suitability map)

Future deforestation was modeled taking into account three development scenarios in PNG:

- Business as Usual (BaU) scenario: an extrapolation of historical deforestation based on available satellite data between the years 2000 and 2014 obtained from the Hansen dataset (Hansen et al. 2013)
- Lax scenario: a faster expansion of oil palm resulting from a higher annual deforestation rate between 40-50% than that of the BaU scenario
- Conservation scenario: assumes an expansion of oil palm under a BaU scenario with the difference that such expansion does not take place in forested land, but on suitable grassland areas.

For the BaU scenario the approach to estimate deforestation from oil palm was:

- Project total deforestation from 2014 to 2024 on five years intervals (cumulative non-forest)
- Calculate net non-forest of more than 20ha. It was assumed that areas larger than 20ha could represent oil palm plantations for two reasons: i) small-scale farmers own farms of xxx or less, and; ii) oil palm developments require areas of at least 5,000 – 10,000 to support a mill above the actual area with oil palm plantations. Although the 20ha estimate might be high and not applicable to all oil palm developments in PNG, it was adopted to generate conservative results on projected deforestation (i.e. as the threshold is set higher then fewer areas would go beyond it and the less projected future deforestation would be attributed to oil palm).
- Calculate net oil palm projection

For the Lax scenario we needed first to identify an expected amount of non-forest and then search for a point in time that yielded such amount (40-50% higher annual deforestation rate than BaU scenario). Therefore, we followed the same steps as for the BaU scenario, but projecting future deforestation up to the year 2029 and then assessing in which year the model predicted the expected amount of deforestation. The justification for this approach is that the software we used generates projections based on historical data; it cannot be asked to generate a projection based on an expected amount of deforestation.

Annual rates of change in forest cover were calculated using Puyravaud (Puyravaud 2003) and FAO (FAO 1995) formulas for both BaU and Lax scenarios:

Equation 1: FAO (1995) formula for annual rate of forest change

$$q = \left(\frac{A_2}{A_1}\right)^{1/(t_2-t_1)} - 1$$

Equation 2: Puyravaud (2003) formula for annual rate of forest change

$$r = \frac{1}{t_2 - t_1} \ln \frac{A_2}{A_1}$$

Where A_1 and A_2 are the forest cover at time t_1 and t_2, respectively.

Then, we used the annual rates of change in forest cove to generate quantitative projections of deforestation (with no spatial distribution of deforestation) until 2050 (40 years from our

2014 baseline year). Because we did not have access to land-use change activity data, projections of oil palm deforestation until 2050 were estimated as the loss of forest cover in suitable land for oil palm growth.

For the conservation scenario our approach was to test whether there was enough suitable grassland area (grassland of more than 20ha falling in suitable land for oil palm growth) to absorb the expansion of oil palm under a BaU scenario or not. We took this approach under the assumption that even under a conservation scenario oil palm expansion wouldn't slow down, particularly because of the current expansion and the long-term expansion of Go-PNG for oil palm (Bito and Petit 2016).

To identify suitable grassland areas for the expansion of oil palm we considered all available grassland in the selected provinces. To do this, a layer of grassland land-cover was generated via a coarse digitalization of all grassland classes in the Forest Base Map 2012 (JICA and PNGFA 2016), which is publicly available at PNG's REDD+ and forest monitoring web-portal (FAO et al. 2016). Once we had the grassland layer we identified suitable grassland areas based on two criteria (Gingold et al. 2012):

- Crop productivity: based on the climate, topography, and soil conditions suitable for oil palm cultivation (map of land suitability for palm)
- Size availability: only grassland areas of more than 20 hectares were considered

It should be highlighted that we considered grassland areas as an option for the expansion of sustainable oil palm based on literature (Gingold et al. 2012) only taking into account that our Conservation scenario focused on keeping oil palm expansion while avoiding deforestation. However, this approach does not consider the fact that some grassland classes have significant carbon stock as soil carbon, thus a conversion from grassland to oil palm could result in important levels of GHG emissions.

4 RESULTS

4.1 Provincial Case Studies

4.1.1 Land-cover change and potential aboveground carbon (AGC) stock losses

Results from our land-cover change analysis for the next 10 years indicate that the provinces showing the largest percentage of change of the total land-cover classes in PNG are Western, West Sepik, East Sepik, Madang, Gulf, Oro (Northern), and Central provinces (Table 6).

Results from our assessment of AGC carbon stock losses show that the top five provinces in descending order are: East Sepik, Cental Jiwaka, New Ireland, and Chimbu (Table 7) (full results are presented in Annex 1).

Table 6: Potential perceptual change of total land-cover in PNG assessed by provinces for the next 10 years

ID	Province	Percentage of total land-cover class in PNG that could change by province		
		Forest	Grassland	Wetlands
1	Western	12%	7%	3%
2	West Sepik	5%	1%	0%
3	East Sepik	5%	5%	2%
4	Gulf	4%	1%	2%
5	Oro (Northern)	3%	1%	0%
6	Central	3%	2%	0%
7	Madang	3%	2%	0%
8	Morobe	3%	4%	0%
9	East New Britain	2%	0%	0%
10	West New Britain	2%	0%	0%
11	Southern Highlands	2%	2%	0%
12	Bougainville	1%	0%	0%
13	Chimbu	1%	0%	0%
14	New Ireland	1%	0%	0%
15	Enga	1%	1%	0%
16	Hela	1%	1%	0%
17	Milne Bay	1%	2%	0%
18	Eastern Highlands	1%	3%	0%
19	Jiwaka	0%	0%	0%
20	Manus	0%	0%	0%
21	NCD	0%	0%	0%
22	Western Highlands	0%	0%	0%

Source: Own calculations

Table 7: Potential average above-ground carbon (AGC) losses from land-cover change into oil palm plantation by land-cover in all PNG provinces

ID	Province	Potential above-ground carbon (AGC) loss from land-cover change to oil palm plantation (Mg ha^{-1})			
		Forest	Grassland	Wetlands	TOTAL
1	East Sepik	-624,305	-2,360,658	-76,762	-2,985,331
2	Enga	-245,907	-261,981	-5,336	-507,913
3	Central	-239,856	-1,728,323	-55,812	-1,968,447
4	Bougainville	-218,269	-278,970	-68,086	-497,566
5	Chimbu	-183,702	-708,366	-11,335	-892,123
6	Jiwaka	-180,904	-126,4821	-1,038	-1,445,729
7	Eastern Highlands	-164,872	-615,826	-6,666	-780,731
8	East New Britain	-134,694	-426,064	-7,562	-560,794
9	Madang	-131,645	-25,133	-722	-156,781
10	NCD	-94,971	-70,694	-347	-165,667
11	Gulf	-93,127	-494,412	-4,784	-587,562
12	Oro (Northern)	-77,934	-629,878	0	-707,811
13	Southern Highlands	-64,185	-343,541	0	-407,726
14	West New Britain	-63,425	-323,887	0	-387,312
15	Manus	-54,338	-61,549	-675	-115,890
16	New Ireland	-49,086	-880,042	0	-929,129
17	Hela	-42,901	-49,859	-2,453	-92,772
18	West Sepik	-30,340	-117,847	0	-148,187
19	Western	-23,094	-94,348	0	-117,442
20	Milne Bay	-15,080	-130,694	-641	-145,776
21	Morobe	-11,131	-13,061	-555	-24,195
22	Western Highlands	-97	0	0	-97

Source: Own elaboration based on data on land-cover from PNGFA (2013), historical land-cover change to oil palm from Gunarso et al. (2013) and AGC for land covers from Agus et al. (2013).

4.1.2 Population density in 2011

Results indicate that the provinces with high population density on suitable land for oil palm are West Sepik, East Sepik, Madang, Oro (Northern), Gulf, West New Britain, East New Britain, and New Ireland (Fig. 2).

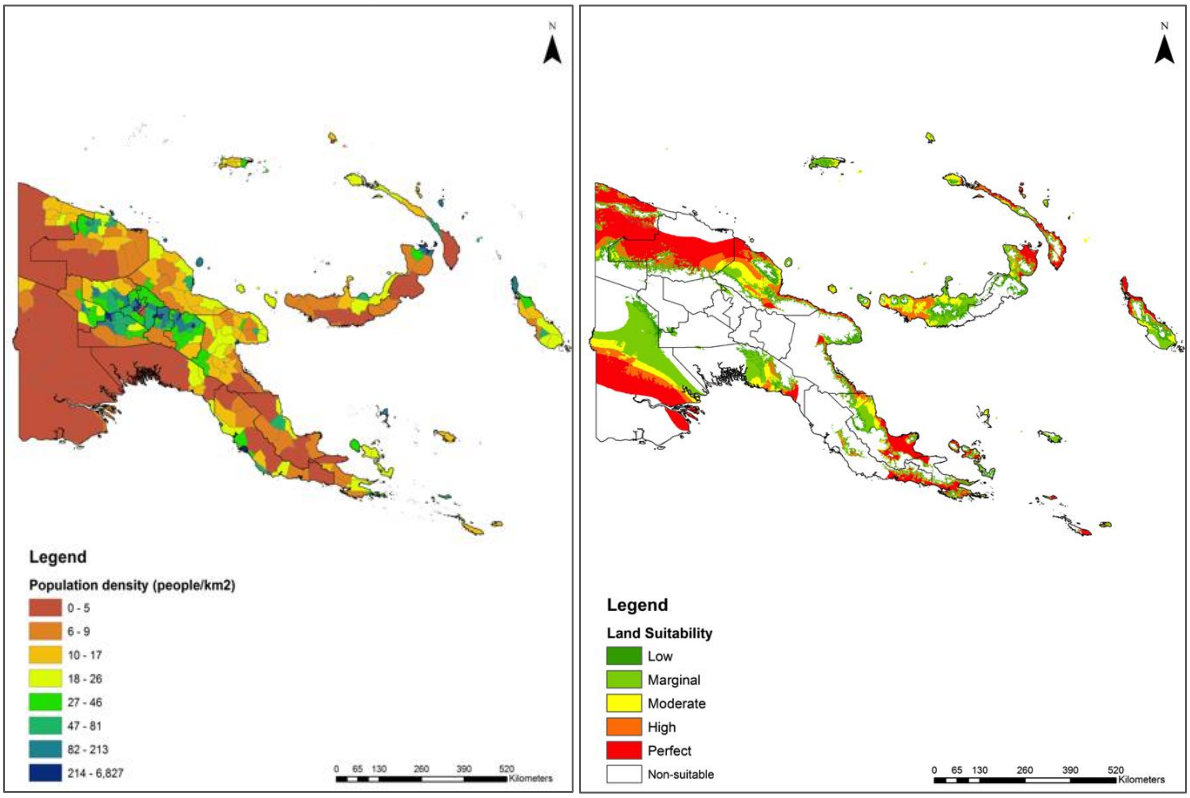

Figure 2: Population density by locality in PNG (left) and suitability map based on altitude, slope, rainfall, and minimum temperature (right)

Source: Own elaboration based on altitude data and population data from PINGRIS (2008) and PNG NSO (2011)

4.1.3 Potential oil palm developments by province

Information from Bito and Petit (2016) allowed us to identify West New Britain, East New Britain, West Sepik, East Sepik, and New Ireland as provinces with potential oil palm plantations development (Table 8)

Table 8: Oil palm plantations to be developed in PNG according to Bito and Petit (2016)

Developer	Oil palm Plantation (ha)	Province
Wewak Agriculture Development Corporation	90,000	West/East Sepik
The Kaoagil Oil palm Project	85,000	New Ireland
Kuala Lumpur Keponk (KLK)	37,000	West/East Sepik
Rimbunan Hijau Group	31,000	East New Britain

Hargy Oil Palms[4]	29,000	West New Britain
Bewani Oil Palm Development	26,000	West/East Sepik
Tzen Plantation Ltd / Tzen Nuigini	20,000	East New Britain
Tzen Plantation Ltd / Tzen Nuigini	10,000	East New Britain

Source: Own elaboration based on data from Bito and Petit (2016)

Information extracted from Nelson et al. (2014) allowed us to identify as feasible developments those expected to take place in West Sepik, East Sepik, West New Britain, East New Britain, Morobe, Western, and Central provinces (Fig 3).

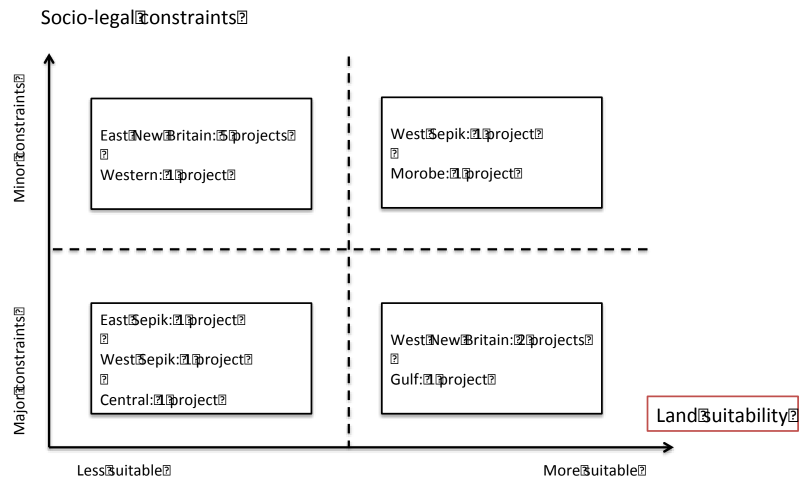

Figure 3: Provinces were potential oil palm developments could be implemented according to land suitability and socio-legal constraints

Source: Own elaboration based on data from Nelson et al. (2014)

Information from NBOPL (2010) indicated that there are ongoing oil palm operations in Madang, Milne Bay, West New Britain, and New Ireland.

Finally, from our interview with Dr. Gae Yansom it was possible to identify five provinces: West Sepik, East Sepik, West New Britain, East New Britain, and Gulf.

4.1.4 Changes into oil palm in previously logged areas in SABLs

The provinces with conversion of logged forest to oil palm plantation are West Sepik (WSK), East New Britain (ENB), East Sepik (ESK), and Central (CEN) (Table 9).

[4] Updated information indicated that this project is already under development.

Table 9: State of forest areas in SABL areas by province in 2014

Provinces	Total land SABL (km2)	Total Forest	Unlogged area	Logged area	Plantation
WES	28%	32%	34%	15%	0%
WSK, ESK, MAD	18%	16%	14%	32%	62%
GUL	11%	10%	10%	11%	0%
CHI	7%	6%	7%	3%	0%
ORO	6%	5%	6%	0%	0%
ENB/WNB	5%	5%	3%	20%	37%
CEN	4%	5%	5%	6%	1%
ENB	3%	3%	3%	8%	37%
NIR	3%	2%	1%	13%	0%
WNB	2%	1%	0%	13%	0%

WSK (West Sepik), ESK (East Sepik), MAD (Madang), WES (Western), GUL (Gulf), CEN (Central), ENB (East New Britain), WNB (West New Britain), ORO (Oro (Northern)), NIR (New Ireland), CHI (Chimbu)
Source: Own elaboration based on data from Shearman and Mackey (2015)

4.1.5 REDD+ demonstration provinces

According to Babon and Gowae (2013) PNGFA identified four provinces for REDD+ demonstration developments based on sustainable forest management:

- Milne Bay
- Sandaun (West Sepik)
- Eastern Highlands
- West New Britain

Similarly, DEC identified three provinces for REDD+ demonstration activities:

- Milne Bay
- Eastern Highlands
- West New Britain

Also, the April Salumei FMA developments in East Sepik was identified by PNGFA as one of PNG REDD+ pilot projects (Babon and Gowae 2013).

Our results suggested developing a future deforestation and suitability models in five provinces, divided in two Zones:

- Zone 1: West Sepik, East Sepik, and Madang
- Zone 2: West New Britain and East New Britain

These five provinces ranked highest in their total scores (Table 9).

Table 10: Summary table of scores by evaluation variables

Rank	Provinces	Potential forest cover change	Potential grassland cover change	Potential wetland cover change	Potential total AGC loss	Population density in suitable areas (4 variables analysis)	Changes to oil palm in previously logged areas in SABLs	REDD+ demonstration provinces	Ongoing and potential oil palm developments per province	Potential pilot areas according to Dr. Gae	Land-suitability and socio-legal barriers for identified developments	TOTAL SCORE
1	West Sepik	1		1	1	1	1	1	2	2	2	12
2	East Sepik	1	1	1	1	1	1		2	2	2	12
3	Madang	1	1	1	1	1	1		2		2	10
4	West New Britain	1				1	1	1	2	2	2	10
5	East New Britain	1				1	1		3	2	2	10
6	Gulf	1		1		1	1		2	2	2	10
7	Western	1	1	1	1		1		2		2	9
8	Morobe	1	1	1	1				2		2	8
9	Oro (Northem)	1	1	1	1	1						5
10	Central	1	1	1	1							4
11	Eastern Highlands		1		1			1				3
12	Milne Bay		1		1			1				3
13	Southern Highlands		1	1	1							3
14	New Ireland					1	1					2
15	Bougainville			1								1
16	Hela		1									1
17	Chimbu											0
18	Enga											0
19	Jiwaka											0
20	Manus											0
21	NCD											0
22	Western Highlands											0

Source: Own elaboration

4.2 Land suitability assessment for oil palm

Results for Zone 1 indicate that 6,376,096 ha (58% of total land area) are suitable land for oil palm[5] meaning areas of more than 20ha that are within the thresholds of the selected physical and climatic variable (Fig. 4).

Results for Zone 2 indicate that 2,781,238 ha (76% of total land area) are suitable land for oil palm[6] meaning areas of more than 20ha that are within the thresholds of the selected physical and climatic variables (Fig 5).

It should be indicated that our results for suitable land for oil palm expansion include different land cover classes such as forest, grassland, shrubland, and others. Therefore, suitability criteria are based on where oil palm could grow, but without considering criteria such as where it would be "environmentally sustainable" to grow oil palm.

[5] This is the total net area of suitable land for oil palm without considering the suitable land that is already used for agricultural/forestry plantations as per the Forest Base Map 2012.

[6] IDEM.

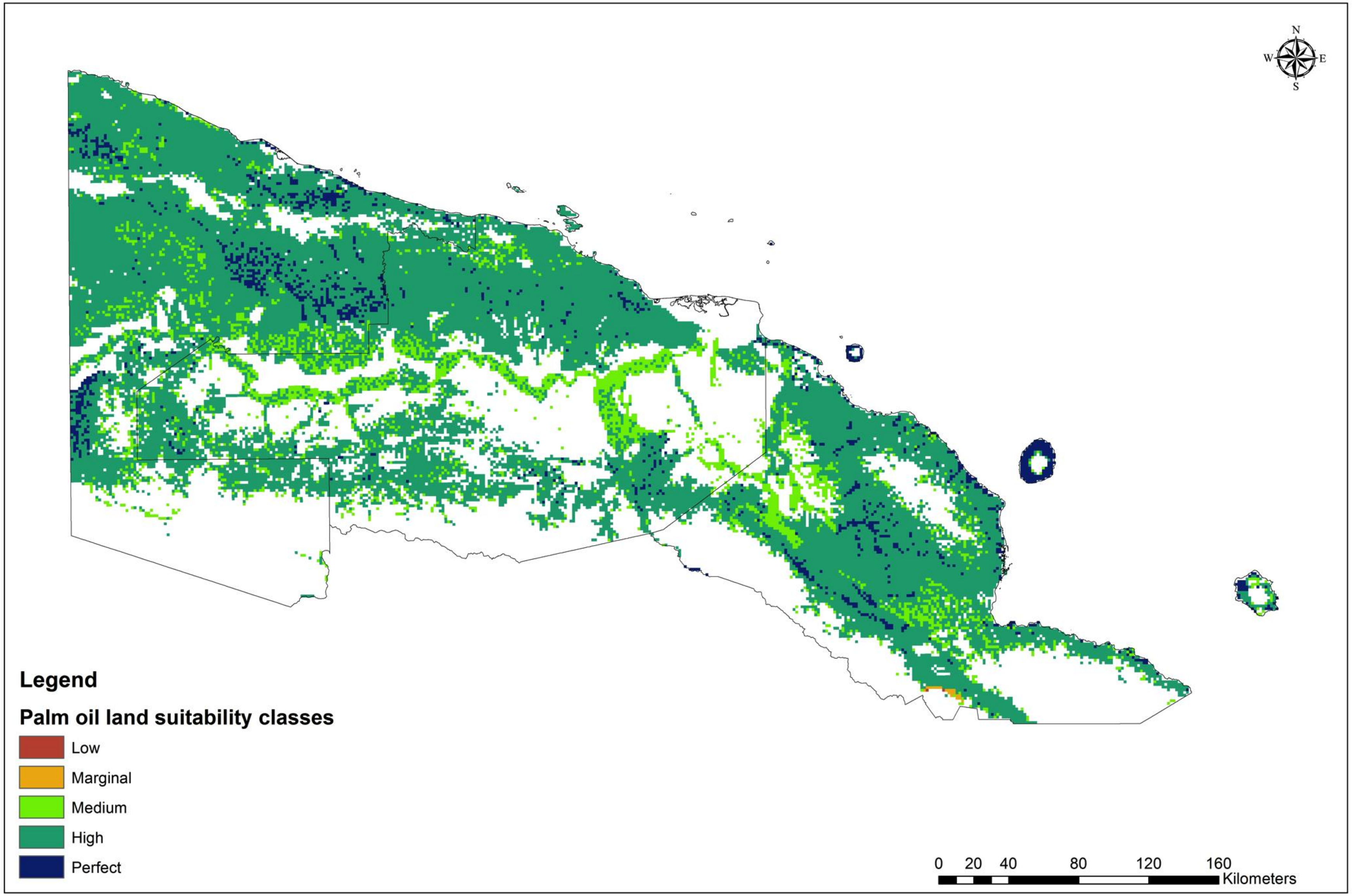

Figure 4: Suitability map for Zone 1 -West Sepik, East Sepik, and Madang (white areas represent totally unsuitable areas for oil palm growth)

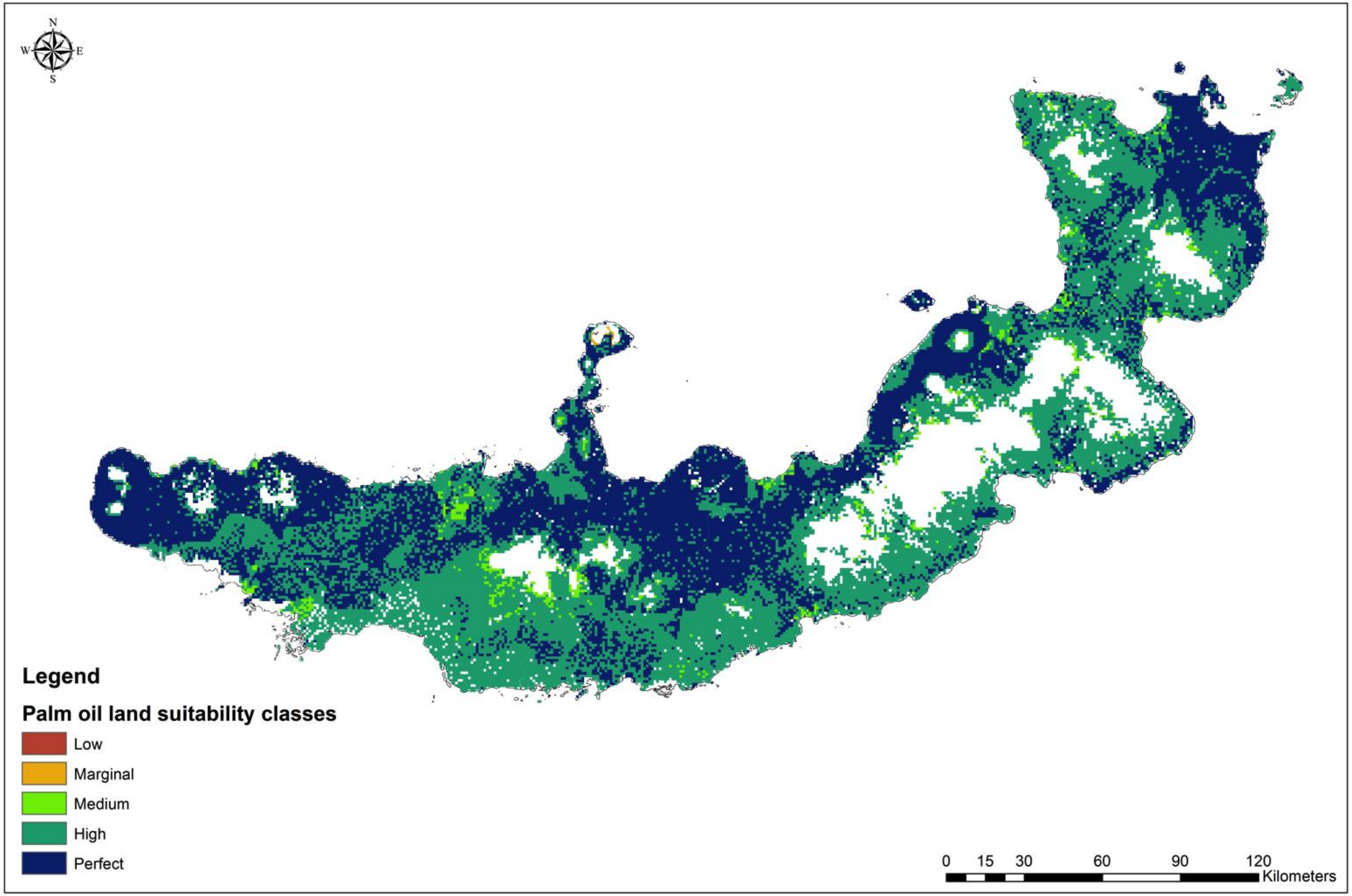

Figure 5: Suitability map for Zone 2 – West New Britain and East New Britain (white areas represent totally unsuitable areas for oil palm growth)

4.3 Future Deforestation Model

4.3.1 Zone 1

Results for Zone 1 showed that the three variables that correlate the highest to the expansion of non-forest in the assessment period (2000-2014) were elevation (DEM 30m), distance to previously existing non-forest, and distance to primary roads (Table 11).

Table 11: Cramer's V results for the prediction variables in Zone 1

Variable	Cramer's V
DEM 30 meters	0.3847
Distance to non-forest 2000	0.343
Distance to primary roads	0.1958
Distance to rivers	0.1848
Distance to SABL areas	0.1747
Distance to 2011 census points	0.1595
Distance to major towns	0.1325
Distance to secondary roads	0.0972

In assessing the sub-model for the prediction of future deforestation, the variables with the highest relevance weight were: DEM 30m, distance to primary roads, distance to 2011 census points, and distance to non-forest in 2000 (Fig. 6).

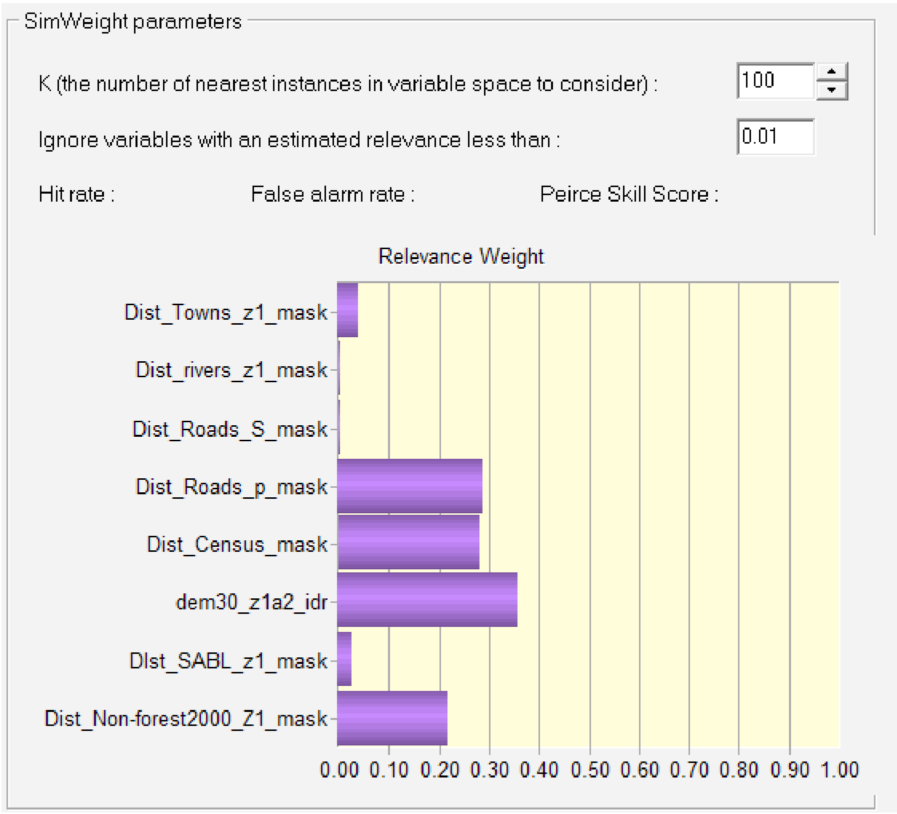

Figure 6: Relevance weight results for the prediction variables in Zone 1

The calculated annual rates of change of forest loss for the BaU and Lax scenarios were -0.11% and -0.16%, respectively (Table 12). The estimated quantitative-only deforestation scenarios until the year 2050 indicate a total deforestation of 344,714 ha and 510,356 in the BaU and Lax scenarios, respectively (Table 13). Similarly, we projected the extent of deforestation accounting only for forest cover on suitable land for oil palm growth resulting in 211,042 ha for the BaU scenario and 312,452 for the Lax scenario (Table 14).

Table 12: Annual forest loss rate for Business as Usual and Lax scenarios in Zone 1

Annual rate of change	Scenarios	
	BaU	Lax
Puyravaud (2003)	-0.11%	-0.16%
FAO	-0.11%	-0.16%

Table 13: Projected total deforestation by 2050

Scenarios	Baseline forest in 2014 (ha)	Projected forest cover loss (%)	Forest cover loss (ha)
BaU	8,953,606	3.85%	344,714
Lax	8,953,606	5.7%	510,356

Table 14: Projected deforestation of forest cover on suitable land by 2050

Scenarios	Baseline forest in 2014 (ha)	Expected forest cover loss (%)	Forest cover loss (ha)
BaU	5,481,609	3.85%	211,042
Lax	5,481,609	5.7%	312,452

The total projected non-forest for the Business as Usual (BaU) scenario is 1,875,407 ha and for the Lax scenario is 1,923,433 ha (Table 15). These values represent the total cumulative non-forest (non-forest in the baseline year 2014 plus the projected future non-forest).

Table 15: Overall results for the Business as Usual and Lax scenarios for Zone 1

Land-cover	Areas (ha)		
	Baseline year	Scenarios	
	2014	BaU	Lax
Forest	8,953,606	8,857,554	8,809,528
Non-forest	1,779,355	1,875,407	1,923,433
Rivers/water	117,209	117,209	117,209
TOTAL	**10,850,170**	**10,850,170**	**10,850,170**

Disaggregated results by province indicate that East Sepik has the highest percentage of cumulative projected deforestation in both scenarios in Zone 1 (Table 16). However, Madang represents the highest proportion of areas larger than 20 hectares and of projected areas of oil palm expansion (Table 17).

Table 16: Overall results for the Business as Usual and Lax scenarios by province in Zone 1

Provinces	BaU Scenario		Lax Scenario	
	Cumulative Non-forest (ha)	% of total non-forest	Cumulative Non-forest (ha)	% of total non-forest
Madang	520,382	28%	544,481	28%
East Sepik	1,086,195	58%	1,099,475	57%
West Sepik	268,317	14%	278,963	15%

Table 17: Total extension of non-forest areas larger than 20 hectares ("Total net non-forest>20ha) and total extension of non-forest areas larger than 20 hectares that fall within suitable land for oil palm growth ("Total net non-forest > 20ha)

Province	Areas (ha)			
	BaU Scenario		Lax Scenario	
	Total net non-forest > 20ha	Net oil palm projection	Total net non-forest > 20ha	Net oil palm projection
Madang	57,411	55,915	74,606	72,206
East Sepik	16,687	15,888	26,378	24,877
West Sepik	12,354	11,926	21,940	20,904
TOTAL	**86,453**	**83,728**	**122,924**	**117,986**

Results for the Conservation scenario indicate that there are enough suitable grassland areas in Zone 1 to locate projected oil palm expansion in both the BaU and Lax scenarios (Table 18).

Table 18: Estimated suitable grassland area to absorb the expansion of oil palm in both BaU and Lax scenarios

Study Area	Extension of grassland areas of more than 20 ha (estimated)	Extension of oil palm in BaU scenario	Extension of oil palm in Lax scenario
Zone 1	600,000	**83,728**	**117,986**

The soft-prediction or "risk of deforestation" map is presented in Fig. 7. Baseline non-forest in 2014 is presented in Fig. 8. Model results for future cumulative non-forest and oil palm deforestation under BaU scenario are presented in Fig. 9 and Fig. 10, respectively. Model results for future cumulative non-forest and oil palm deforestation under Lax scenario are presented in Fig. 9 and Fig. 10, respectively.

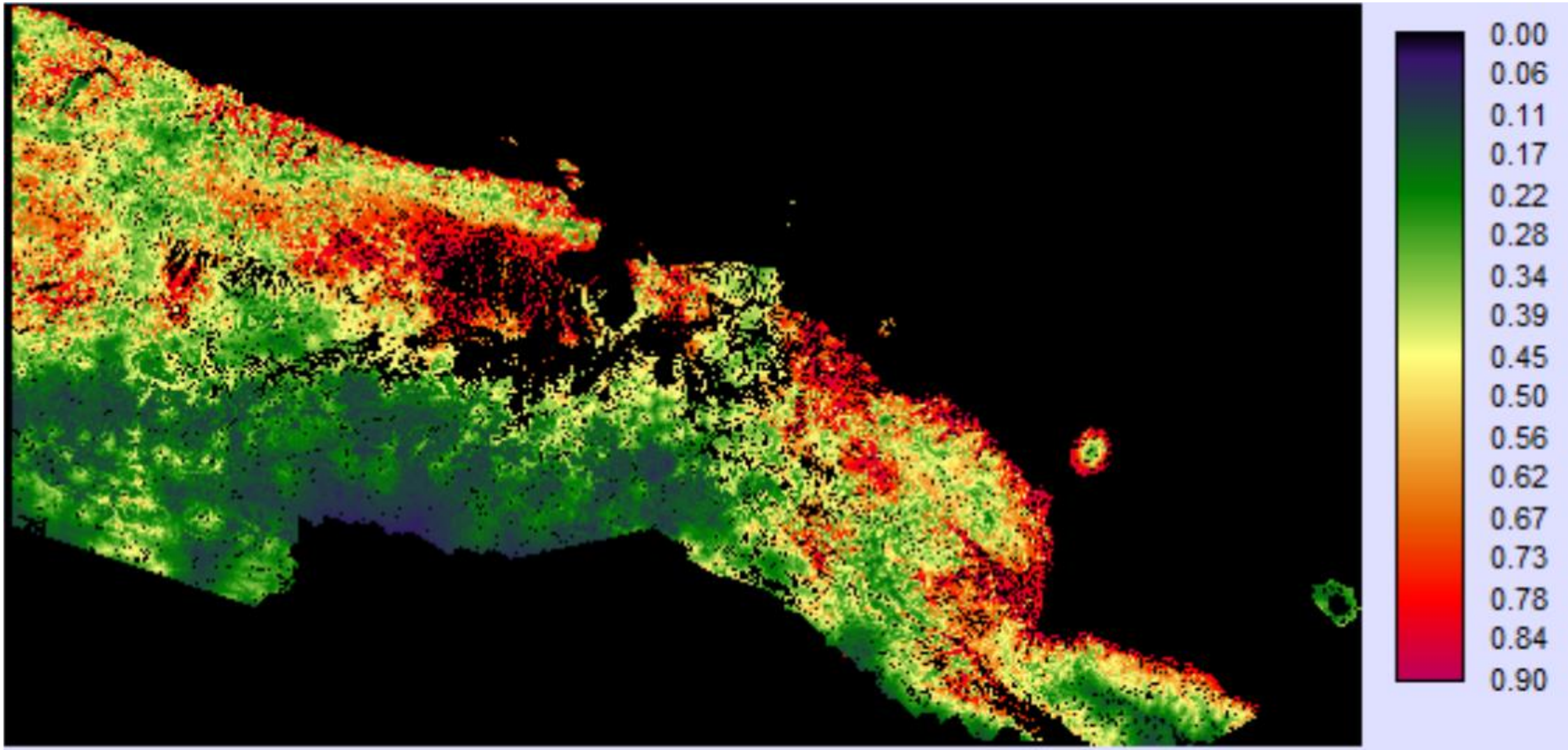

Figure 7: Soft-prediction or "deforestation risk" for Zone 1 (higher values represent higher deforestation risk)

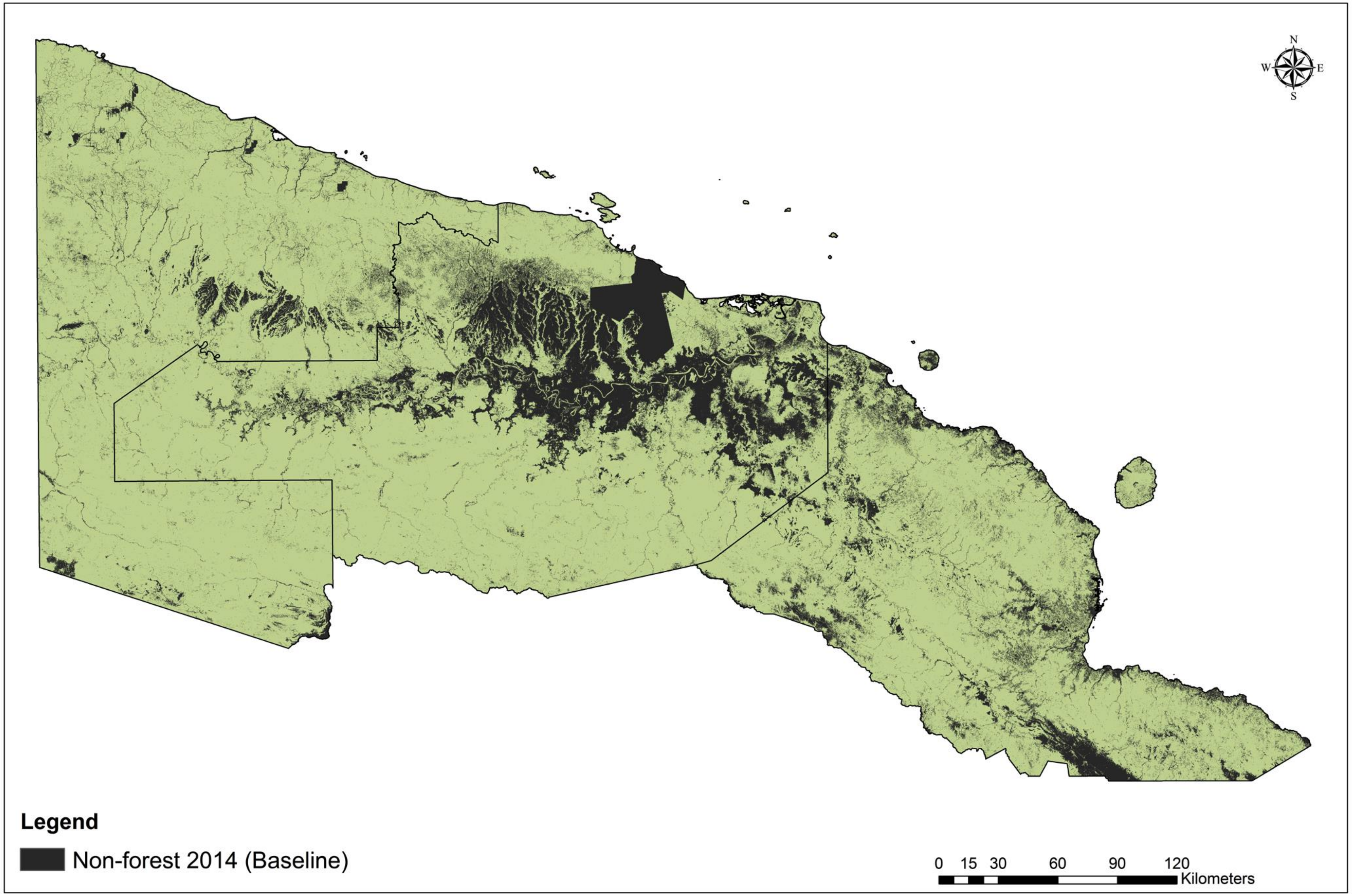

Figure 8: Baseline non-forest in the year 2014 for Zone 1

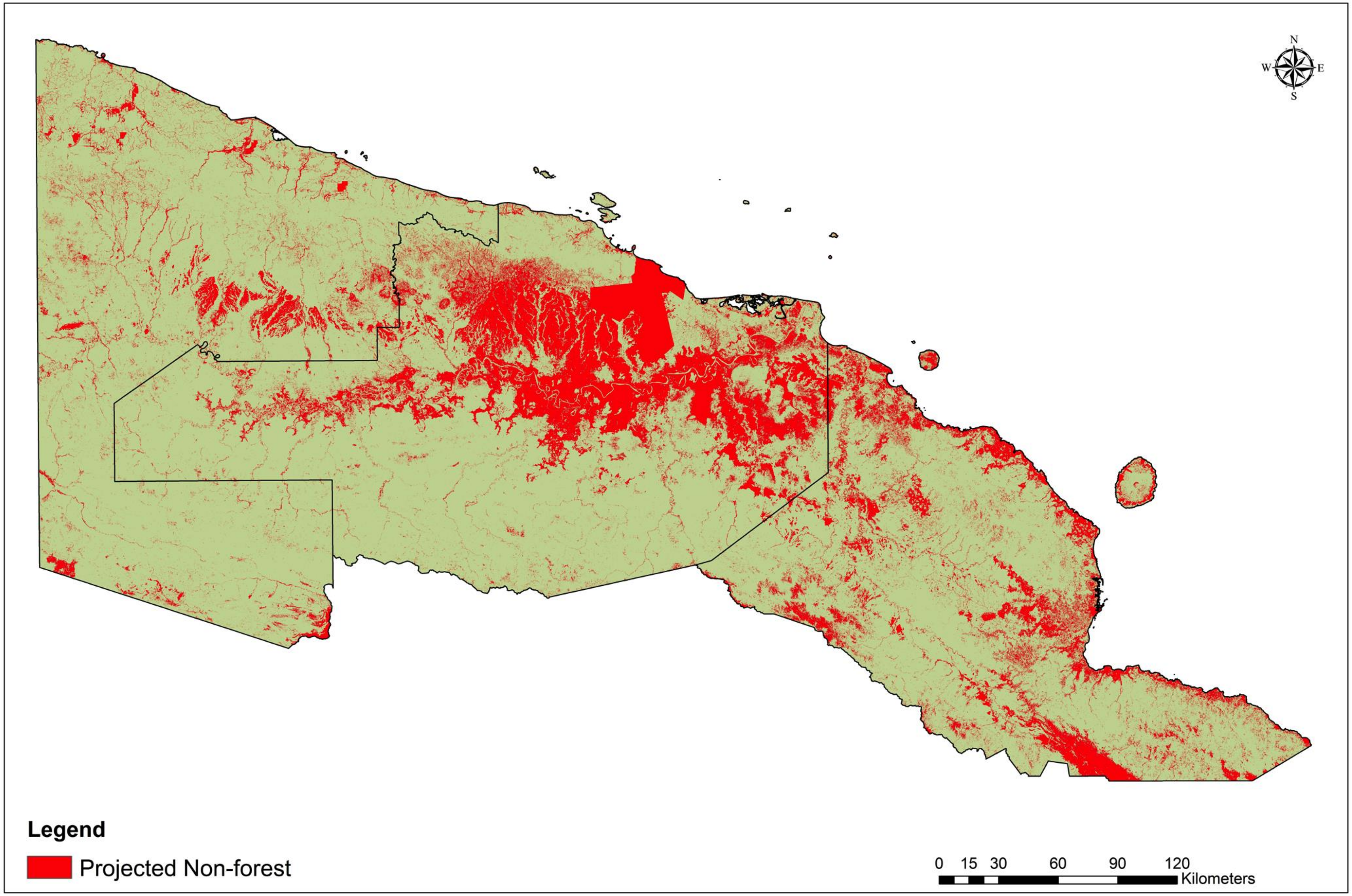

Figure 9: Projected non-forest for the Business as Usual scenario for Zone 1

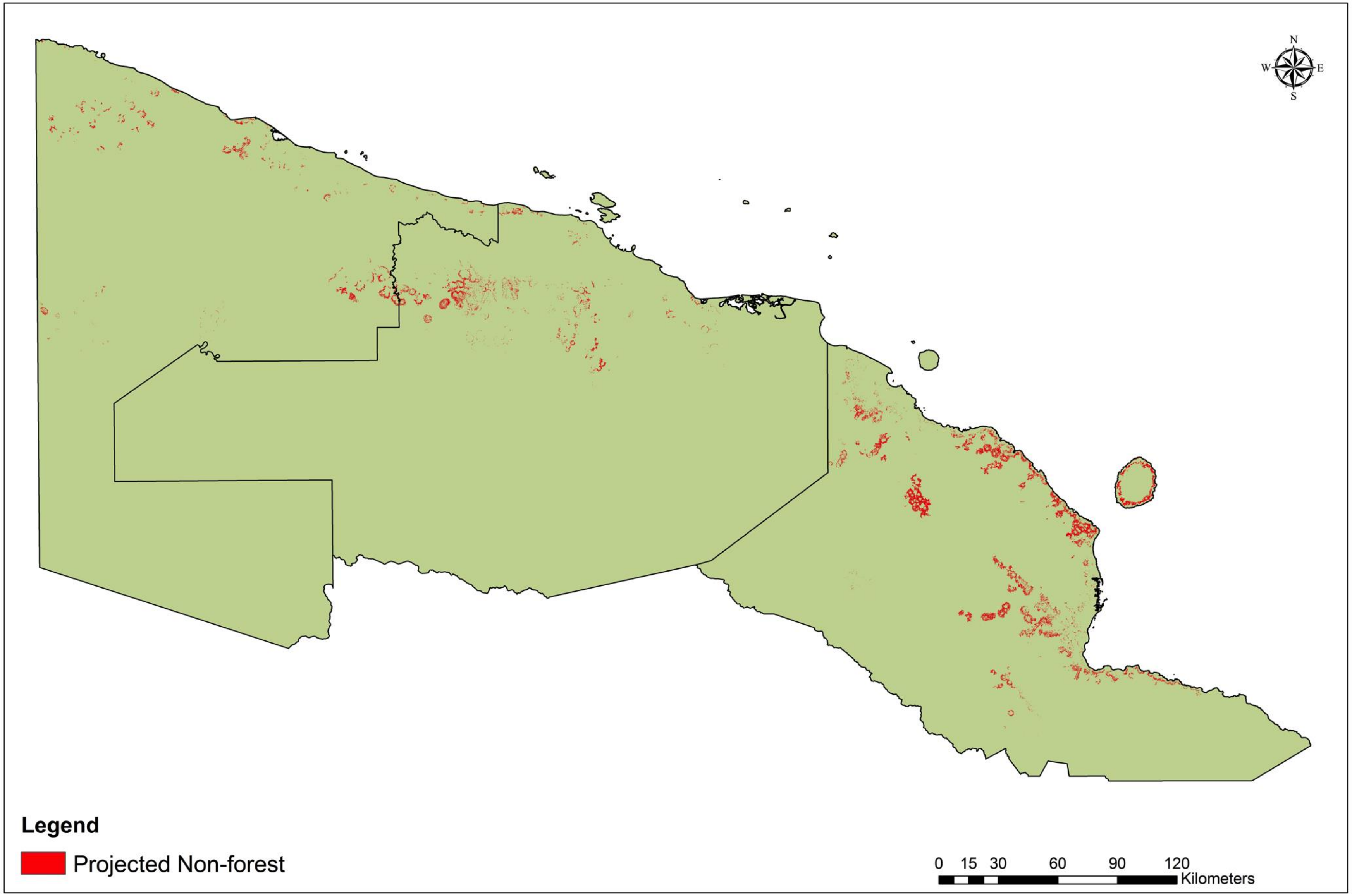

Figure 10: Projected non-forest for the Business as Usual scenario for Zone 1

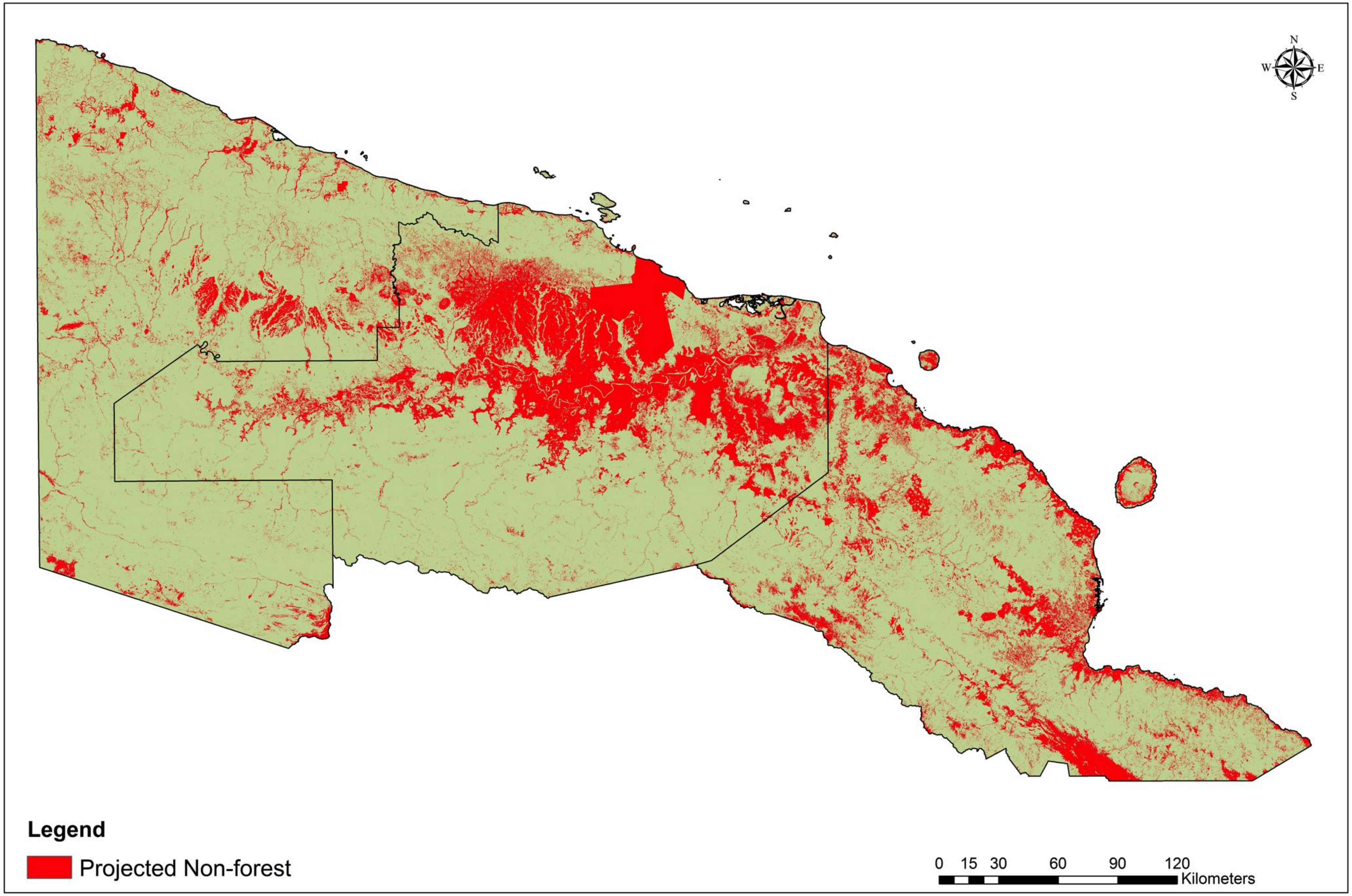

Figure 11: Projected non-forest for the Lax scenario for Zone 1

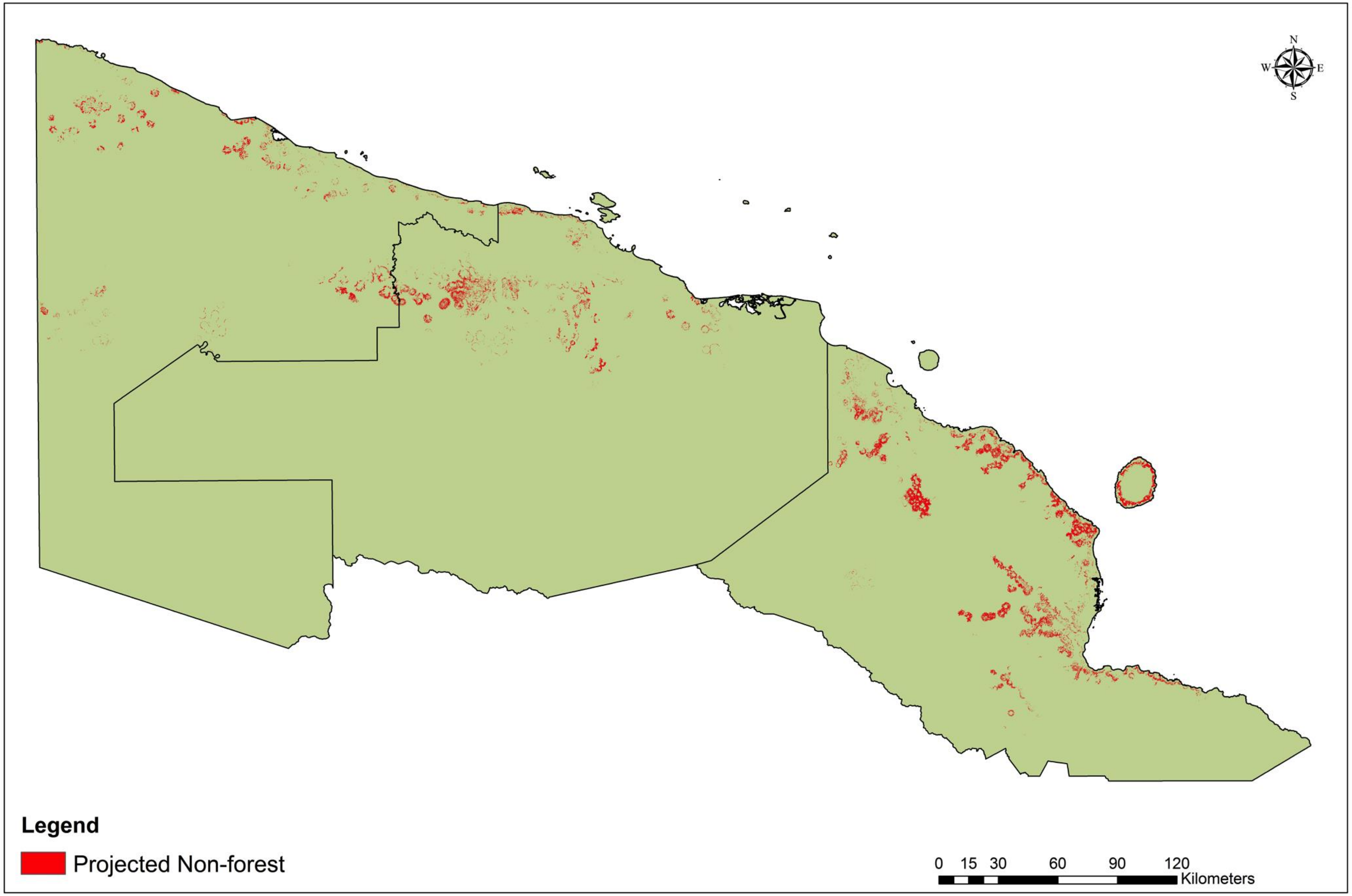

Figure 12: Projected non-forest areas due to Oil palm expansion (areas> 20ha) in the Lax scenario for Zone

Results for Zone 1 also show that most[7] of the projected deforestation from oil palm would take place within areas designated as small-scale farming areas, which is the land-cover “Bare areas” presented in the Forest Base Map 2012 (JICA and PNGFA 2016).
Also, there appears to be a relation between proximity to forestry and agricultural plantation areas and projected deforestation (Fig. 13).

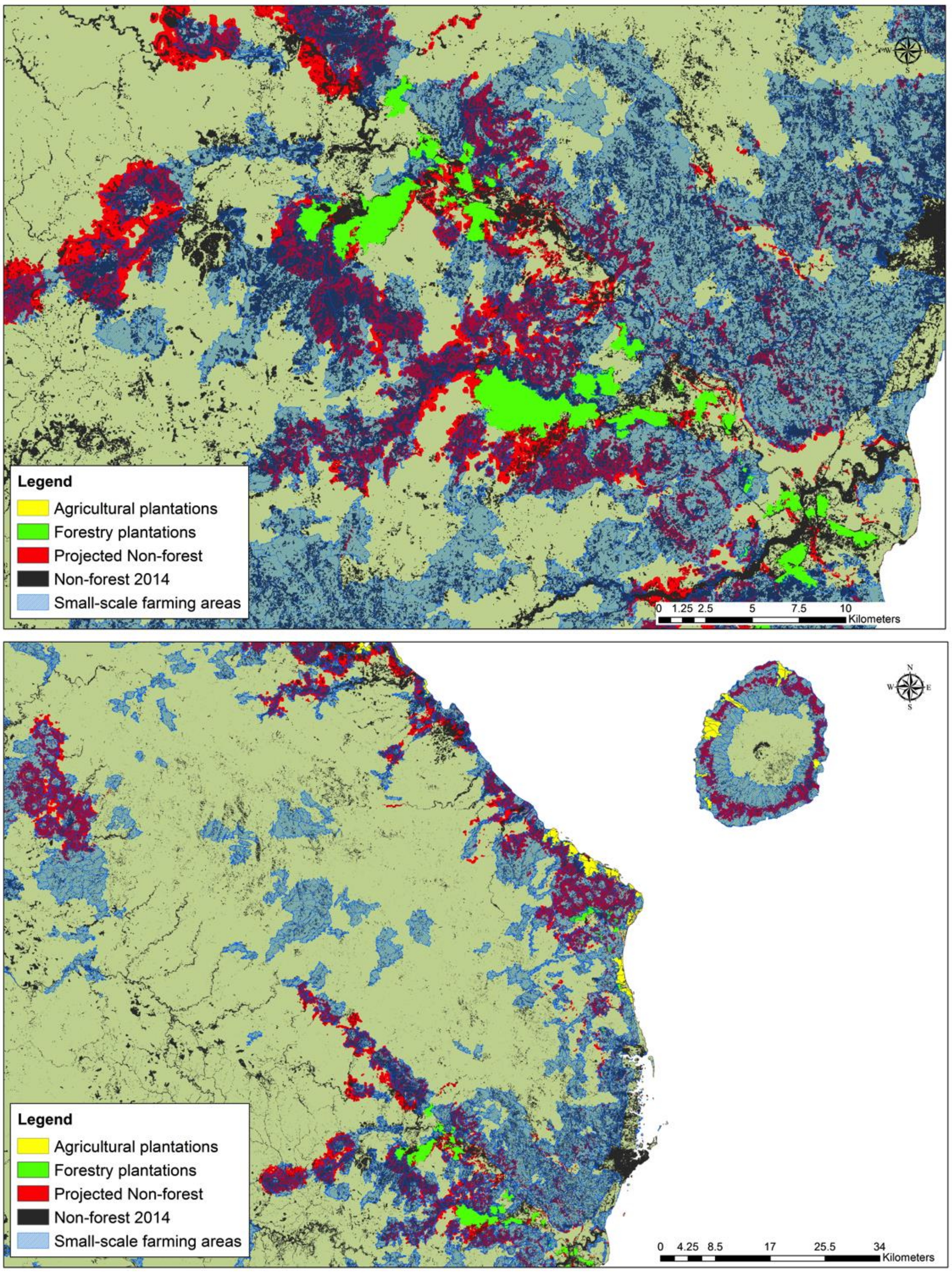

Figure 13: Extract from Madang province showing projected non-forest (oil palm deforestation), forestry plantations, and agricultural plantations

[7] We did not calculate the proportion of projected deforestation within small-scale agricultural areas because we didn’t have access to the official shapefile of this land-cover class; we worked only with a very coarse digitalization based on the data available on the web (FAO et al. 2016).

4.3.2. Zone 2

Results for Zone 1 showed that the three variables that correlate the highest to the expansion of non-forest in the assessment period (2000-2014) were: distance to previously existing non-forest, distance to primary roads, and elevation (DEM 30m) (Table 19).

Table 19: Cramer's V results for the prediction variables in Zone 2

Variable	Cramer's V
stance to non-forest 2000	0.8881
stance to primary roads	0.3312
EM 30 meters	0.3192
stance to 2011 census points	0.3155
stance to major towns	0.2766
stance to rivers	0.1751
stance to SABL areas	0.1373
stance to secondary roads	0.1162

In assessing the sub-model for the prediction of future deforestation, the variables with the highest relevance weight were: DEM 30m, distance to 2011 census points, distance to primary roads, distance to non-forest in 2000, and distance to rivers (Fig. 14).

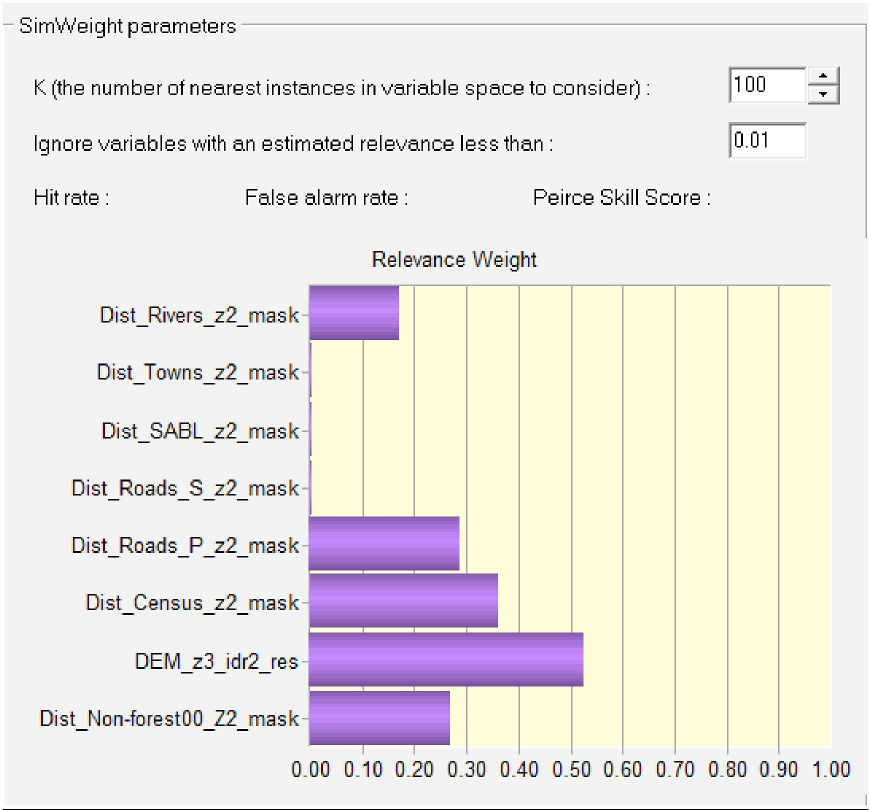

Figure 14: Relevance weight results for the prediction variables in Zone 2

The calculated annual rates of change of forest loss for the BaU and Lax scenarios were -0.38% and -0.58%, respectively (Table 20). The estimated quantitative-only deforestation scenarios until the year 2050 indicate a total deforestation of 203,990 ha and 309,075 in the BaU and Lax scenarios, respectively (Table 21). Similarly, we projected the extent of deforestation accounting only for forest cover on suitable land for oil palm growth resulting in 168,099 ha for the BaU scenario and 254,695 for the Lax scenario (Table 22).

Table 20: Annual forest loss rate for Business as Usual and Lax scenarios in Zone 2

Annual rate of change	Scenarios	
	BaU	Lax
Puyravaud (2003)	-0.19%	-0.29%
FAO	-0.19%	-0.29%

Table 21: Projected total deforestation by 2050

Scenarios	Baseline forest in 2014 (ha)	Projected forest cover loss (%)	Forest cover loss (ha)
BaU	3,090,754	6.6%	203,990
Lax	3,090,754	10%	309,075

Table 22: Projected deforestation of forest cover on suitable land by 2050

Scenarios	Baseline forest in 2014 (ha)	Projected forest cover loss (%)	Forest cover loss (ha)
BaU	2,546,951	6.6%	168,099
Lax	2,546,951	10%	254,695

The total projected non-forest for the Business as Usual (BaU) scenario is 527,411 ha and for the Lax scenario is 556,758 ha (Table 23). These values represent the total cumulative non-forest (non-forest in the baseline year 2014 plus the projected future non-forest).

Table 23: Overall results for the Business as Usual and Lax scenarios for Zone 2

Land-cover	Areas (ha)		
	Baseline year	Scenarios	
	2014	BaU	Lax
Forest	3,090,754	3,032,059	3,002,711
Non-forest	468,716	527,411	556,758
Rivers/water	12,016	12,016	12,016
TOTAL	3,571,486	3,571,486	3,571,486

Disaggregated results by province indicate that West New Britain represents the highest percentage of cumulative projected non-forest in both scenarios in Zone 2 (Table 24) as well as the highest proportion of areas larger than 20 hectares and of projected areas of oil palm expansion (Table 25).

Table 24: Overall results for the Business as Usual and Lax scenarios by province in Zone 2

Provinces	BaU Scenario		Lax Scenario	
	Cumulative Non-forest (ha)	% of total non-forest	Cumulative Non-forest (ha)	% of total non-forest
West New Britain	302,914	57%	316,999	57%
East New Britain	223,924	43%	239,187	43%

Table 25: Total extension of non-forest areas larger than 20 hectares ("Total net non-forest>20ha) and total extension of non-forest areas larger than 20 hectares that fall within suitable land for oil palm growth ("Total net non-forest > 20ha)

Province	Areas (ha)			
	BaU Scenario		Lax Scenario	
	Total net non-forest > 20ha	Net oil palm projection	Total net non-forest > 20ha	Net oil palm projection
West New Britain	32,016	30,915	47,602	45,558
East New Britain	23,698	22,630	37,839	35,876
TOTAL	**55,714**	**53,545**	**85,441**	**81,435**

Results for the Conservation scenario indicate that there are not enough suitable grassland areas in Zone 2 to locate projected oil palm expansion in neither the BaU nor the Lax scenario (Table 26).

Table 26: Estimated suitable grassland area to absorb the expansion of oil palm in both BaU and Lax scenarios

Study Area	Extension of grassland areas of more than 20 ha (estimated)	Extension of oil palm in BaU scenario	Extension of oil palm in Lax scenario
Zone 2	20,000	**53,545**	**81,435**

The soft-prediction or "risk of deforestation" map is presented in Fig. 15. Baseline non-forest in 2014 is presented in Fig. 16. Model results for future cumulative non-forest and oil palm deforestation under BaU scenario are presented in Fig. 17 and Fig. 18, respectively. Model results for future cumulative non-forest and oil palm deforestation under Lax scenario are presented in Fig. 19 and Fig. 20, respectively.

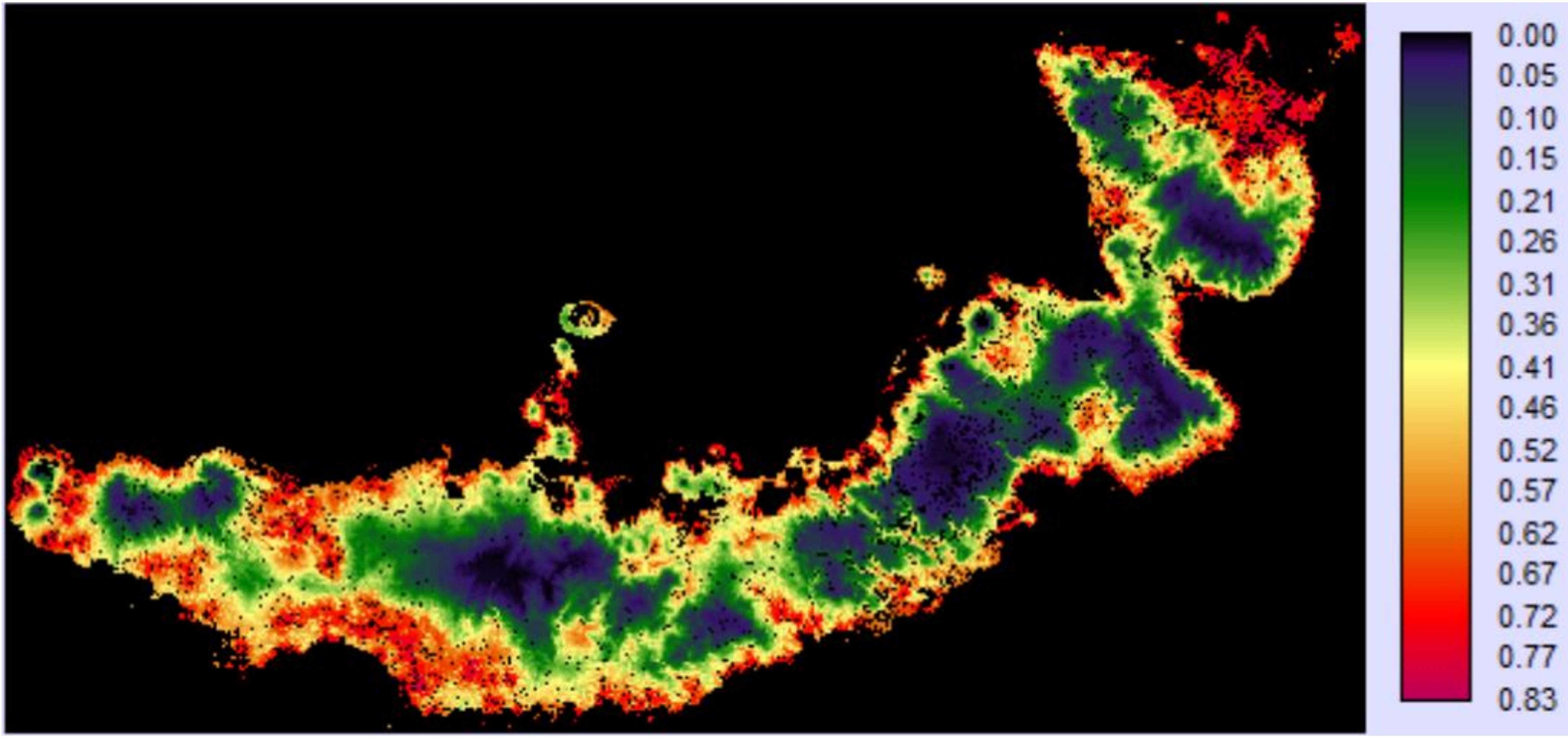

Figure 15: Soft-prediction or “deforestation risk” for Zone 2 (higher values represent higher deforestation risk)

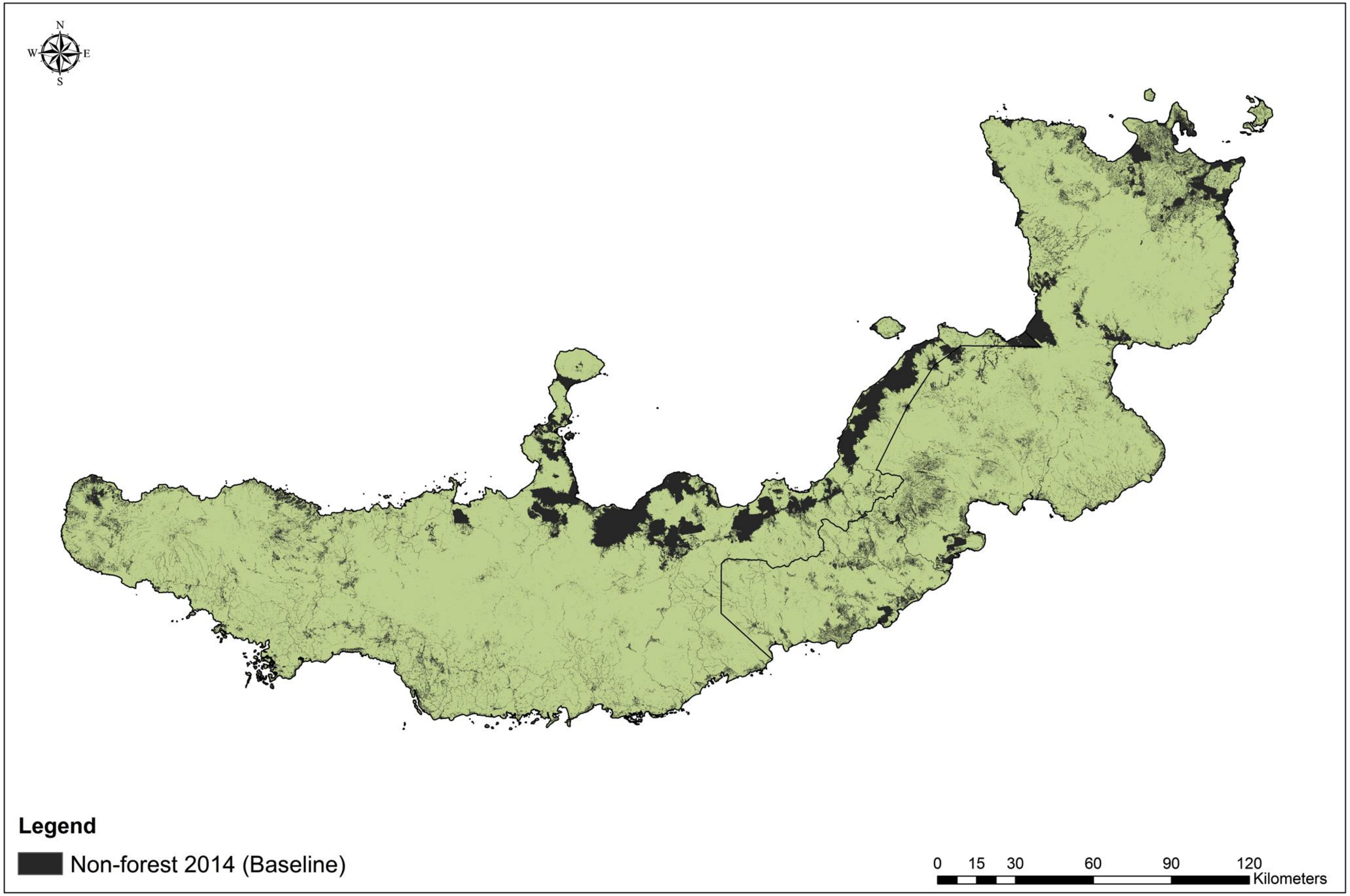

Figure 16: Baseline non-forest in the year 2014 for Zone 2

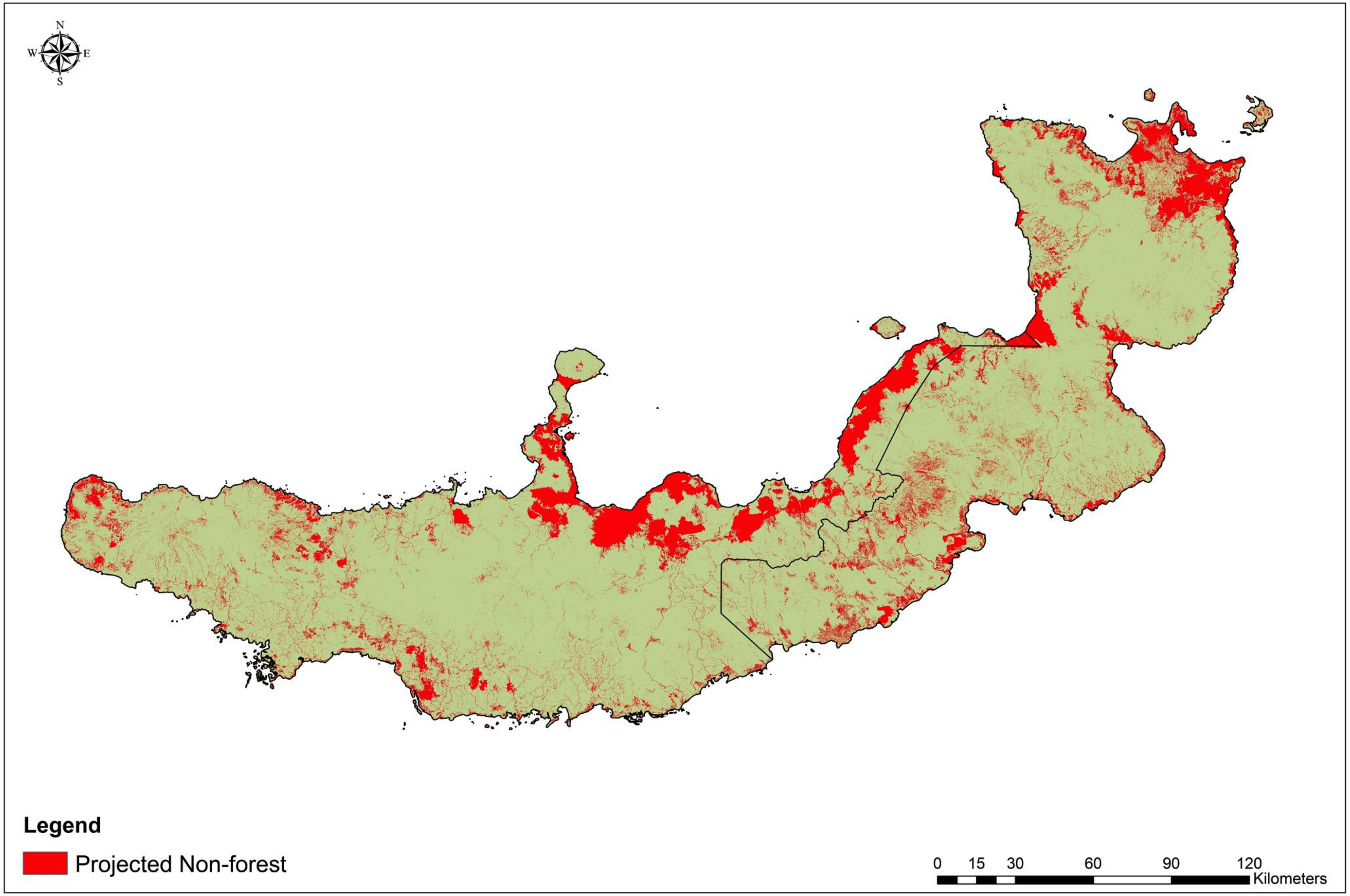

Figure 17: Projected non-forest for the Business as Usual scenario for Zone 2

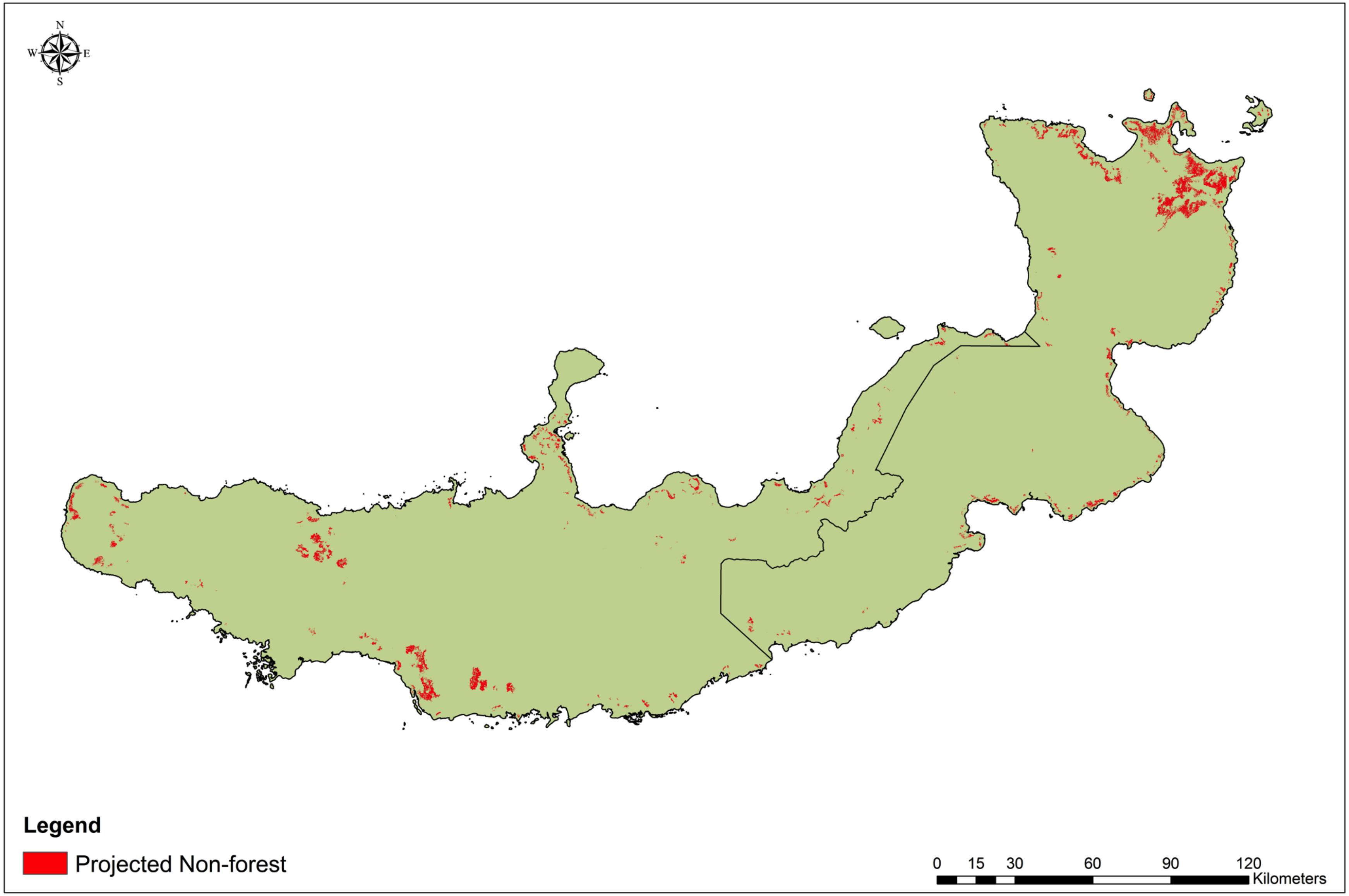

Figure 18: Projected non-forest areas due to Oil palm expansion (areas> 20ha) in the Business as Usual scenario

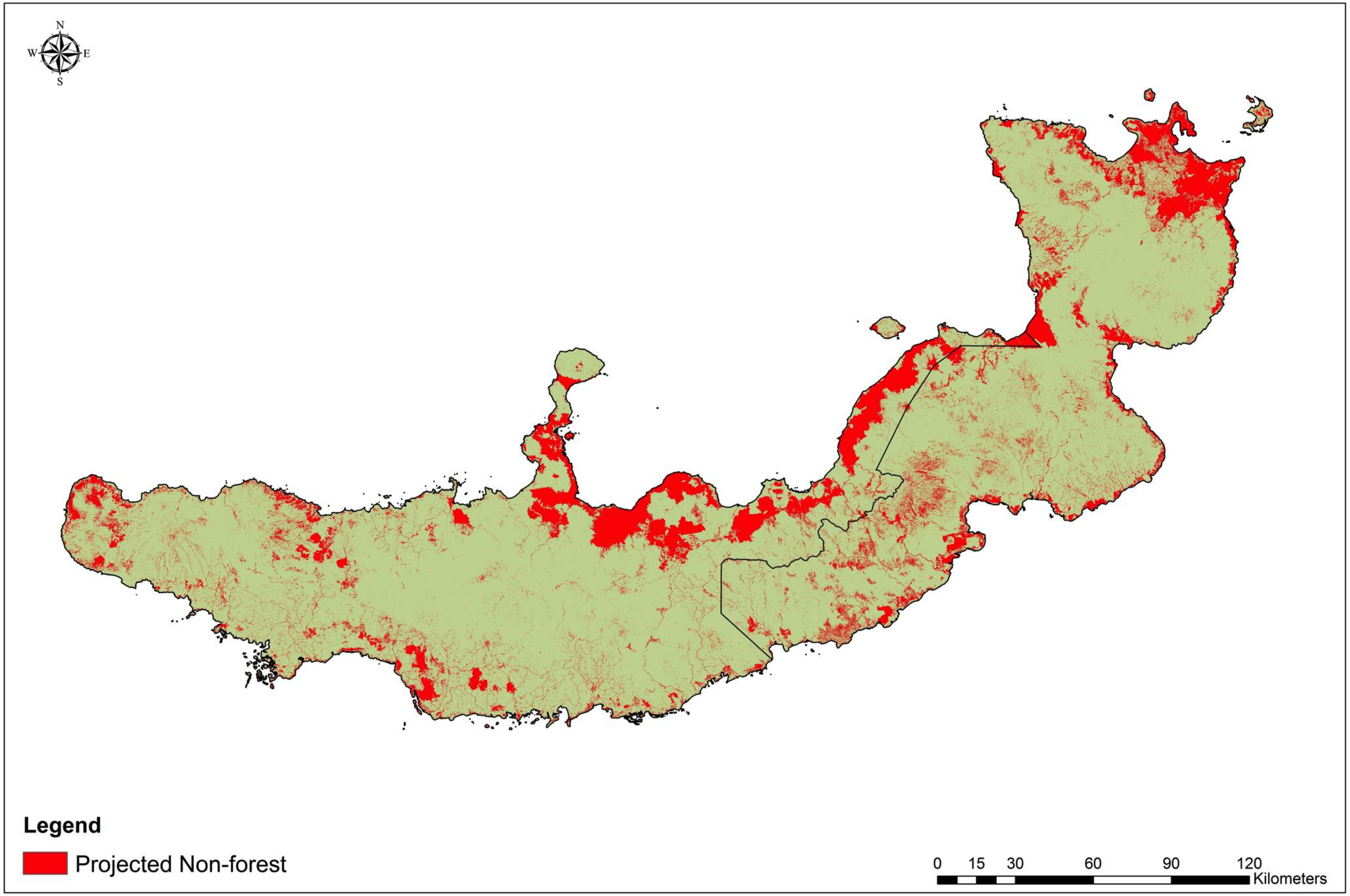

Figure 19: Projected non-forest for the Lax scenario for Zone 2

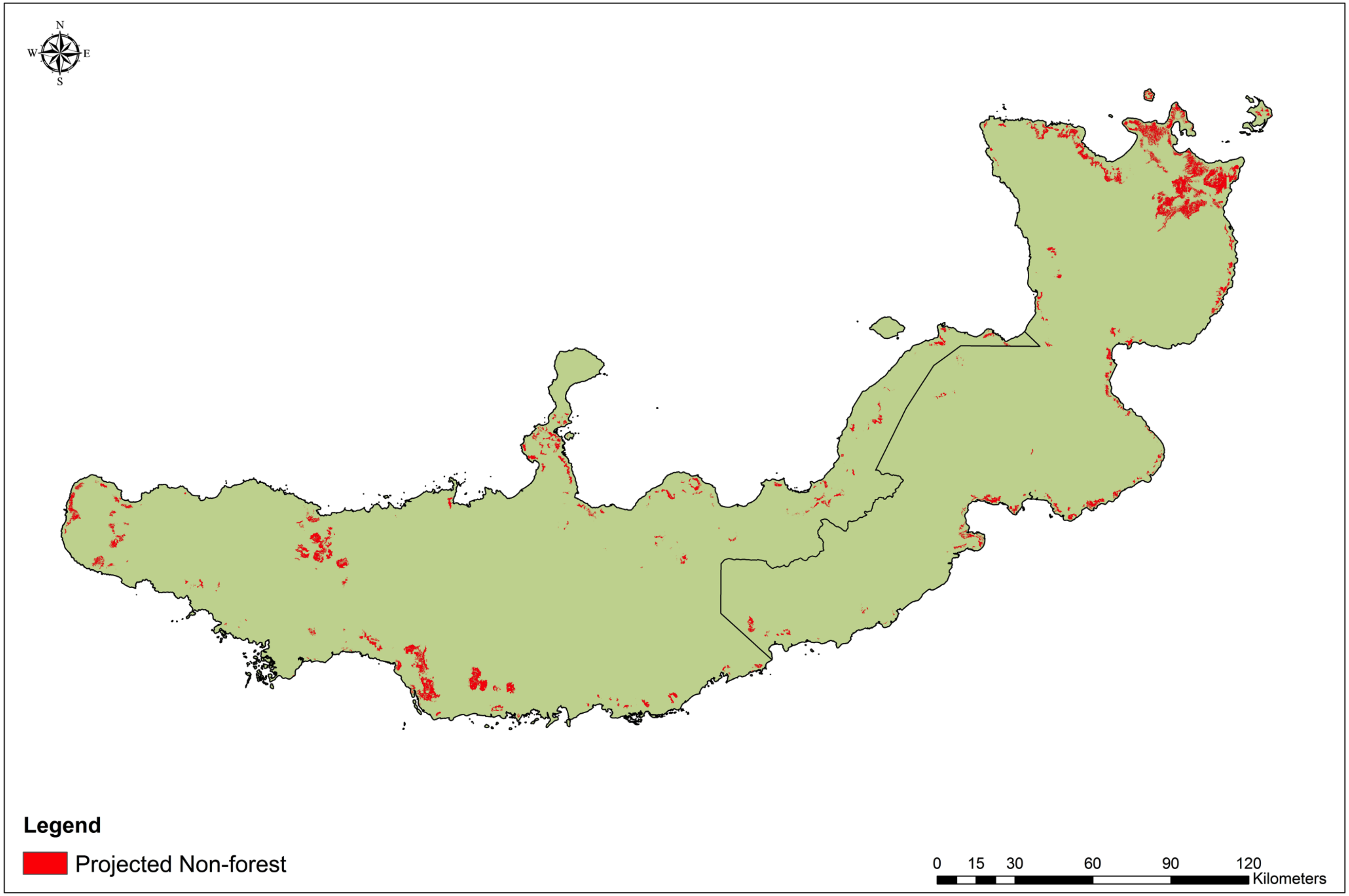

Figure 20: Projected non-forest areas due to Oil palm expansion (areas> 20ha) in the Lax scenario for Zone

Results for Zone 2 also show that a significant proportion of the projected deforestation from oil palm would take place within areas designated as small-scale farming areas (Fig. 21 and Fig. 22); however, this trend appear to less pronounced than in the provinces in Zone 1.

Also, there appears to be a relation between projected deforestation from oil palm and proximity to agricultural plantation areas in both West New Britain (Fig. 20) and East New Britain (Fig. 23).

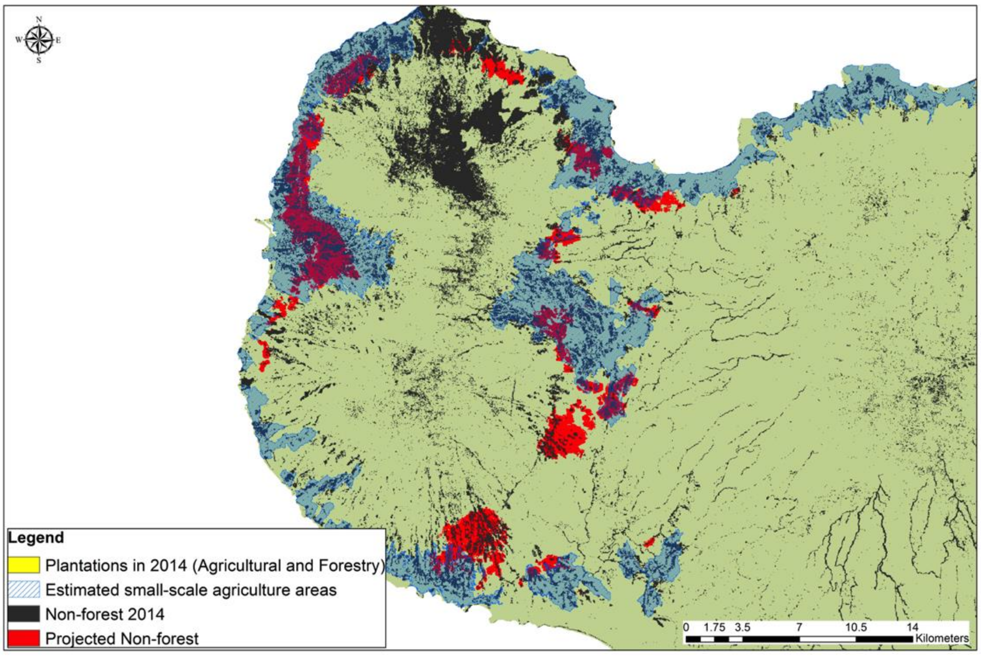

Figure 21: Extract from West New Britain province showing projected non-forest (oil palm deforestation) within and outside small-scale agricultural areas

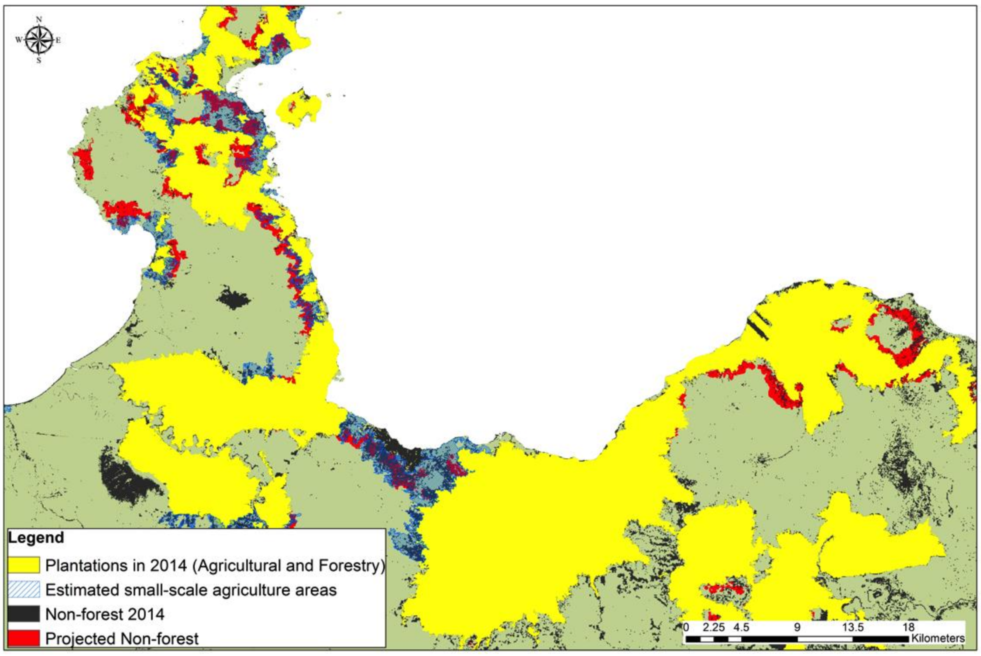

Figure 22: Extract from West New Britain province showing projected non-forest (oil palm deforestation) and agricultural plantation areas

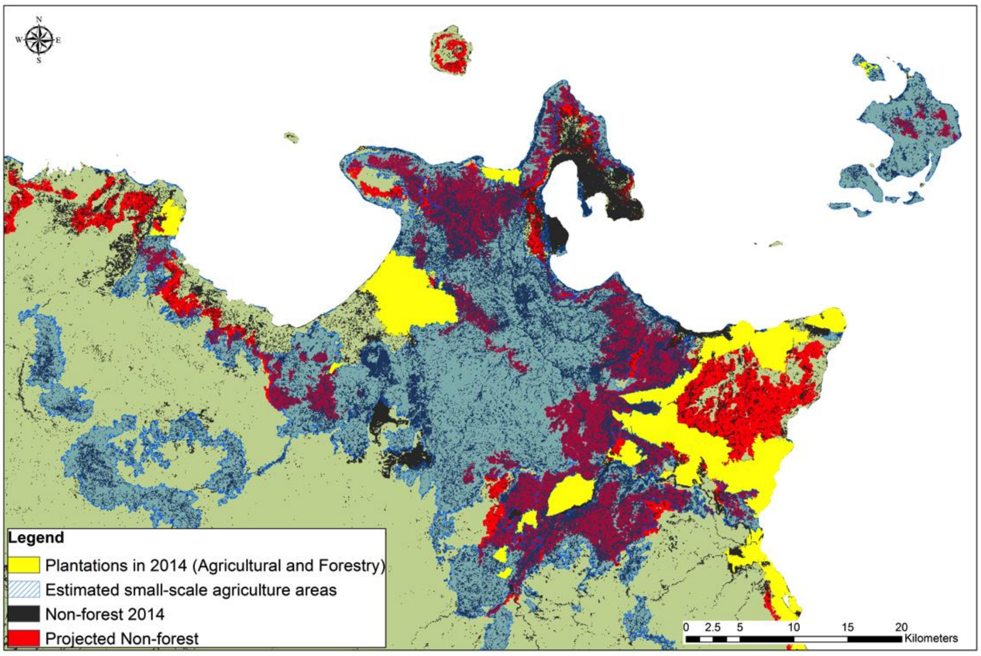

Figure 23: Extract from East New Britain province showing projected non-forest (oil palm deforestation) and agricultural plantation areas

5 DISCUSSION

Our results from the land suitability model suggested that there were large extensions of suitable areas for oil palm growth in both Zones, some more suitable than others. Differences in land suitability were a result of the combination of suitability values that represent the characteristics of the selected assessment variables in any given location. For example, Zone 2 presents a larger extension of "perfectly suitable" land for oil palm growth as a result of such larger extensions of land falling within what it was considered the highest achievable ranking for all selected variables. Land suitability categories should be understood in light of the analytical approach taken. In a general sense, these suitability maps were a first effort to identify suitable areas (regions with very high to very low suitability values, but suitable nevertheless) and non-suitable areas (regions with values beyond the limiting thresholds of the selected variables). The number of suitability classes and the threshold values selected for each class were adapted from international accepted values for the selected assessment variables (Pirker et al. 2015), which raises two issues. First, land suitability categories and their threshold values can be adapted according to the particularities of each province. Second, although it is expected for oil palm plantations in PNG to develop in areas that have some degree of land suitability, it does not necessarily mean that oil palm will grow only in areas of high suitability categories. It is possible for oil palm to grow low land suitability areas depending on management practices applied (i.e. improvement of soil texture, soil drainage, erosion control practices, others). Therefore, results from a land suitability model should be validated with ground-level data to assess the accuracy of the results on a site-by-site basis (Gingold et al. 2012).

Regarding future deforestation, our findings indicated a continuous expansion of total projected deforestation and projected deforestation from oil palm expansion (non-forest areas of more than 20 hectares) in Zone 1 and Zone 2 under both BaU and Lax scenarios. Also, our findings indicated that total projected deforestation and projected deforestation from oil palm expansion was located mostly within small-scale agriculture areas. This fact is in line with the results from the study conducted by Cuthbert et al. (2016) on direct and indirect drivers of deforestation in PNG (Cuthbert et al. 2016) that indicate that population density has a strong relevance in predicting future deforestation. Finally, our results indicate that under a Conservation scenario (all projected deforestation under BaU scenario is shifted into suitable grassland areas) there could be sufficient suitable grassland to shift the expansion of oil palm under a BaU and Lax scenarios projection in Zone 1; however, this is not the case for Zone 2.

In the case of the Conservation scenario our findings showed that Zone 2, although it had most of its area classified as perfect/high suitability for oil palm expansion, it did not have enough areas for the expansion of sustainable oil palm. On the other hand, Zone 1 had most of its area classified as high/medium suitability for oil palm, but it had enough areas for the expansion of sustainable oil palm in both BaU and Lax scenarios. Therefore, the most suitable areas are not always the best option for the expansion of sustainable oil palm and less suitable areas could be a feasible option if adequate management measures are put in place. It should be highlighted that, our methodology assumed that all grassland on suitable land could be converted into oil palm plantations with the aim of assessing the maximum capacity of each Zone to absorb oil palm expansion under a sustainability approach. This "best scenario" assumption does not account for grassland classes with high carbon content and/or High Conservation Value (HCV) (such data was available to our team during the study). So, at this point, our results should not be taken as a recommendation for where to direct oil palm expansion, but rather as a first step in a series of iterations that will eventually result in tools to support sustainable oil palm expansion in PNG. Therefore, further iterations of the land suitability model should incorporate geo-referenced variables such as, but not limited to, carbon stocks in grasslands, HCV, land tenure regimes, accessibility, and others that support a more precise estimation of the available suitable grassland areas for sustainable oil palm developments.

Based on our findings, drivers of deforestation (i.e. proximity to SABL areas, roads, rivers, others) appeared to have different relevance in the prediction of future deforestation in each Zone. Cuthbert et al. (2016) found similar results in their study on future deforestation in PNG where the prediction weight of drivers of deforestation was not the same among provinces in PNG. Also, an assessment conducted by Shearman and Mackey (2015) on land-use change in PNG identified that the development of oil palm plantations in previously logged SABL areas differed among provinces (Shearman and Mackey 2015). Therefore, it is important to evaluate future deforestation at the province level (or at an aggregated level of provinces sharing similar deforestation dynamics) to avoid misinterpreting deforestation dynamics.

The size threshold we adopted to detect projected oil palm deforestation (deforestation of more than 20 hectares) was an important factor with significant implications. First, the application of a size threshold involved the possibility that a deforested area of more than 20 hectares could be in reality the result of an aggregation of many farms sharing borders and growing crops other than oil palm; such farms would have been classified as oil palm plantation only because they were on suitable land and were larger than the size threshold. Second, the total available area for oil palm expansion (sustainable and uncertified) depended on the minimum size for an oil palm development to take place not only accounting for the plantation itself, but also for the area required for processing facilities. Third, the size threshold meant that in reality some areas might undergo significant oil palm deforestation (i.e. 15 -19 hectares), but without being accounted as oil palm because they do not go over the threshold limit. Therefore, results for projected oil palm deforestation must be validated on the ground and the selection of a size threshold for projected oil palm deforestation must be carefully determined by assessing the minimum area requirements for a potential oil palm development to be feasible (i.e. accessibility, vicinity to palm oil processing facilities, planned large-scale oil palm developments, among others). Furthermore, it should be taken into account that the size of plantations might not be the same in all provinces and that there even might be variations within a province depending on how suitable the land is (i.e. plantations in low-suitability areas might need larger extensions to produce the same as plantations in areas with better growing conditions). For the reasons presented above, it is recommended the use of land-use activity data in the prediction of future deforestation from oil palm (and other land-uses) in order to reduce as much as possible the uncertainty incorporated by the application of a size threshold.

Our findings indicated that the quantity of available suitable forestland was not always a good predictor of contribution of an area to the total deforestation from oil palm expansion in PNG. A study conducted by Harris et at. (2013) on predictive models of oil palm deforestation in PNG estimated that by 2050 around 3.5 million hectares in PNG would be occupied by oil palm development out of which almost 2 million hectares (57%) would be implemented at the expense of forest cover loss (Harris et al. 2013). Using this projection as a benchmark, our estimations for 2050 indicate that Zone 2, an area encompassing 7% of the forest cover in PNG, would generate 13% of the projected oil palm deforestation. In contrast, Zone 1 would represent 15% of the projected oil palm deforestation albeit encompassing 15% of the forest cover in PNG, which is more than double that of Zone 2.

The quantitative and spatial distribution of projected deforestation should be understood as possible futures based on what occurred in the past; such results are not to be accepted as definitive certainties. One of the reasons to explain this is that there is significant uncertainty related to the future dynamics of oil palm expansion in PNG. For example, a study conducted by Harries et al. (2013) on future scenarios of oil palm expansion in PNG suggested that it is possible for large oil palm plantations to be implemented in a short timeframe, thus complicating the prediction of future expansion dynamics (Harris et al. 2013). Moreover, it appears that no consensus exists on future trajectories for oil palm expansion in PNG (Bito and Petit 2016), with some authors expecting for a slow expansion whereas others predict even higher deforestation rates than that observed in the historical period up to 2010 (Harris et al. 2013).For this reason, we recommend updating projected deforestation results at least every five years.

There are some limitations in this study and recommendations that should be taken into account when replicating and scaling-up these models to other provinces in PNG. First, we did not have access to historical land-use change activity data, thus our projections of future deforestation only produced two classes: forest and non-forest (deforestation). For this reason, it was only possible to use the annual rates of change of forest cover to make quantitative estimations for total deforestation, but not for projected oil palm deforestation. So, to give an approximate estimate of oil palm deforestation up to 2050 we project deforestation on forest cover on suitable land for oil palm growth. We recommend incorporating land-use change activity data in future iterations of the deforestation model in order to accurately discriminate deforestation cause by oil palm expansion from other drivers of deforestation. Second, our results are based on a model that relied on historical deforestation trends, but without accounting for any planned deforestation developments (i.e. infrastructure, plantations) because such data was not available to our team. Thus, our resulting projected deforestation results are based on the expansion of previously existing deforestation (frontier deforestation), but without accounting for patches of deforestation that appear in areas without previous deforestation in their vicinity (planned deforestation). This means that future deforestation, by oil palm or other deforestation agent, could be larger than indicated in our results, so we recommend that further application of our model should account for planned deforestation in order to achieve results that reflect more closely the expected dynamics of forest cover loss.

6 CONCLUSIONS

The aim of this project was to develop two spatial models, a land suitability and a future deforestation models for oil palm expansion in PNG. We tested the future deforestation model under three development scenarios: Business as Usual (BaU), Lax (annual deforestation rate 40-50% higher than in BaU), and Conservation scenarios (potential to shift BaU deforestation into suitable grassland land). Both models were tested in five provinces in PNG that served as case studies, which we grouped in two working zones: Zone 1 (West Sepik, East Sepik, and Madang) and Zone 2 (West New Britain and East New Britain). Finally, we assessed total deforestation and deforestation from oil palm expansion (only deforested areas of more than 20 hectares) in each Zone.

Our future deforestation projection results indicate that deforestation continues to expand under a BaU and Lax scenarios. It should be highlighted that provinces with the highest total deforestation are not always those with the highest deforestation from oil palm. Also, our results showed that the majority of projected total deforestation and deforestation from oil palm took place under "small-scale agriculture" land-use. This fact is in line with previous studies that highlight the relation between population density and expansion of deforestation frontier.

Regarding the Conservation scenario, our findings indicated that the provinces with the highest suitable lands for oil palm expansion might not be the best option in a future were such expansion follows sustainability criteria, such as expansion into non-forest areas.

Land suitability and future deforestation models are useful tools to better understand future dynamics of deforestation and to assess possibilities of sustainable expansion of crops. Although such models have limitations and their accuracy depend on the quality of available data, they still provide valuable inputs useful as complementary data in a national REDD+ strategy. We aim for these models to become support tools in the decision-making decision making process of institutions involved in PNG's national REDD+ strategy.

7 NEXT STEPS

It is envisioned for a national expert on GIS to assemble a team of local GIS specialists to build national capabilities on the development, use, and scale-up of the land suitability and future deforestation models to other provinces in PNG and eventually to the whole country. It is envisioned that PNGFA staff will be able to significantly improve the results we obtained by making use of additional government-developed data that was not available/completed at the of this study such as the complete land-use classes from the Forest Base Map 2012 and geo-referenced data on planned infrastructure projects and agricultural and extractive developments.

To improve accuracy in modeling future deforestation not only for oil palm, but also for other agents of deforestation (i.e other crops, mining, others) we would recommend developing land-use change activity data and use it to generate change sub-models specific for each agent (i.e. forest to oil palm, forest to cacao, forest to mining, etc). This would be useful for several reasons: i) projection of deforestation from oil palm would not have to rely solely on a size threshold for its identification; ii) more accurate quantification of the contribution of each agent to future deforestation; iii) better understanding of past and future dynamics of deforestation as well as identification of the location of risk of deforestation by agent; iv) finally, there is the possibility to assess other land-cover and land-use changes beyond deforestation, but with the potential to generate significant carbon emissions and other environmental impacts (i.e. peatland to oil palm, HCV grassland to oil palm, timber concession to oil palm, etc).

Additionally, an international consultant would participate in the project to provide capacity building and guidance. This would be done under a close collaboration with the PNGFA FAO/National Forest Inventory (NFI) team at PNGFA, who are currently working in the development of a historical land-use assessment. to PNGFA team working on the models.

As a tentative timeline, it is expected for the capacity building sessions to start early 2017 producing the first mapping results by the first half of the year.

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9 ANNEXES

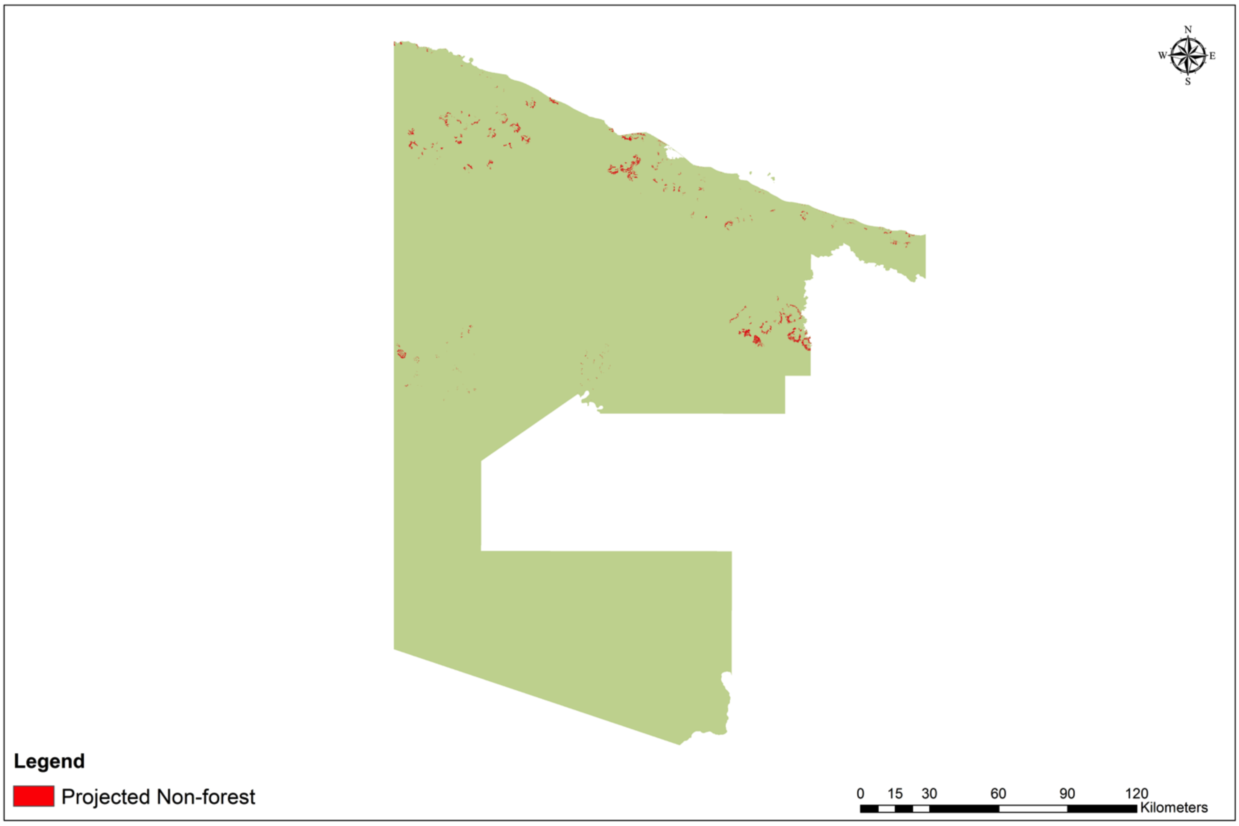
9.1 Annex 1

#	Name	Title	Email/Phone#	Appointment Time Time & Date
GOVERNMENT OF PAPUA NEW GUINEA				
Office of the Prime Minister/NEC				
1.	Mr. Kwaipo Vali	a/ Director - Renewable Resources	Email:kwaipov@gmail.com/kvali@pmnec.gov.pg Telephone: 76539012	2:30pm, Monday 18th July
Climate Change and Development Authority				
2.	Mr. Joe Pokana	Acting Managing Director	Email: jnpokana@gmail.com Telephone: 709 10 300/713 54721	8:30am, Tuesday 19th July
3.	Mr. Terence Barambi	Acting Manager REDD+	Email: larsonwavi@gmail.com Telephone: 725 23 692	10am, Friday 22nd July
PNG Forest Authority				
4.	Mr. Goodwill Amos	Acting Managing Director	Email: gamos@pngfa.gov.pg Telephone:	9:30am, Friday 22nd July
5.	Dr. Ruth Turia	Director-Forest Policy and Planning	Email: RTuria@pngfa.gov.pg	10am, Wednesday 30th July
Conservation and Protection Authority (CEPA)				
6.	Mr. James Sabi	Manager, Biodiversity	Email: james.sabi.roaming@gmail.com/jsabi@dec.gov.pg Telephone:	10am, Tuesday 19th July
Department of Treasury				
7.	Mr. Larry Asigau	Budget Officer, Budget Policy Unit, Budget Co-ordination and Analysis Division	Email: Larry_Asigau@treasury.gov.pg Telephone: 72103264	10am, Thursday 21st July
Department of Lands and Physical Planning (DLPP)				
8.	Mr. Gibson Pitz	Planner – Policy Land Use in Physical Planning Division	Email: pitzg@lands.gov.pg Telephone: (+675) 301 3205 / 7170 7757	Did not reply
Institute of National Affairs/CIMC (INA/CIMC)				
9.	Ms. Wallis Yakam	Executive Officer	Email : Wallis.Yakam@cimcpng.org Telephone:	Did not reply

#	Name	Title	Email/Phone#	Appointment Time Time & Date
ACADEMIA				
10.	Dr. Justin Ondopa	Senior Research Fellow, National Research Institute	Email: ondopa@gmail.com Telephone:	3pm, Monday 18th July
DEVELOPMENT PARTNERS				
11.	Mr. Masamichi Haraguchi	FAO/JICA	Email: masamichi_haraguchi@kk-grp.jp	10:30pm, M Monday 18th July (Skype)
12.	Mr. Tatsuya Watanabe	JICA/ PNGFA Project	Email: TWatanabe@pngfa.gov.pg Telephone:	2pm, Wednesday 20th July
NON-GOVERNMENTAL ORGANIZATIONS				
13.	Mr. Senson Mark	Eco-forestry Forum	Email: smark@ecoforestry.org.pg/sensonhornbymark@gmail.com	Did not reply
14.	Ian Orrell	New Britain Palm Oil Limited – Head of Sustainability	Email: ian.orrell@nbpol.com.pg Telephone: 72117777	Did not reply

9.2 Annex 2: model results by province in Zone 1

Oil palm projection: Business as Usual (BaU) Scenario



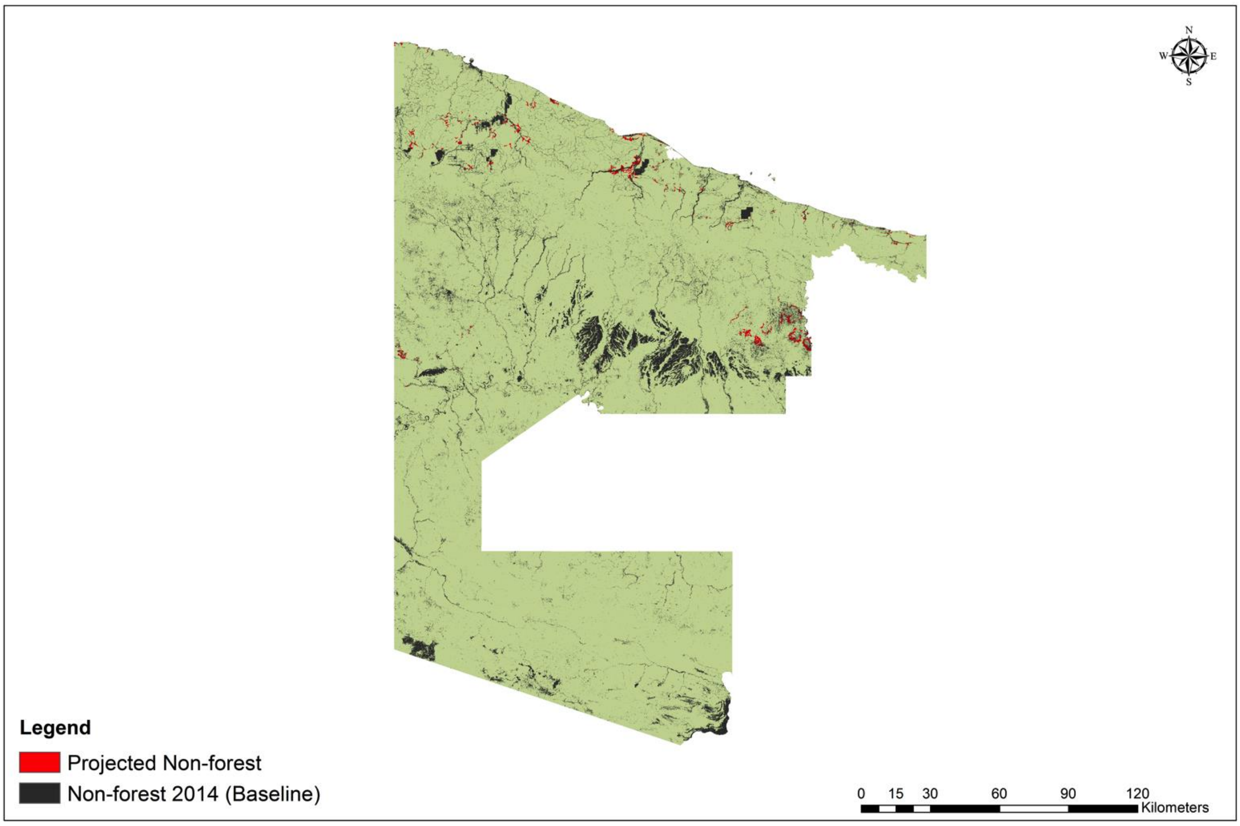
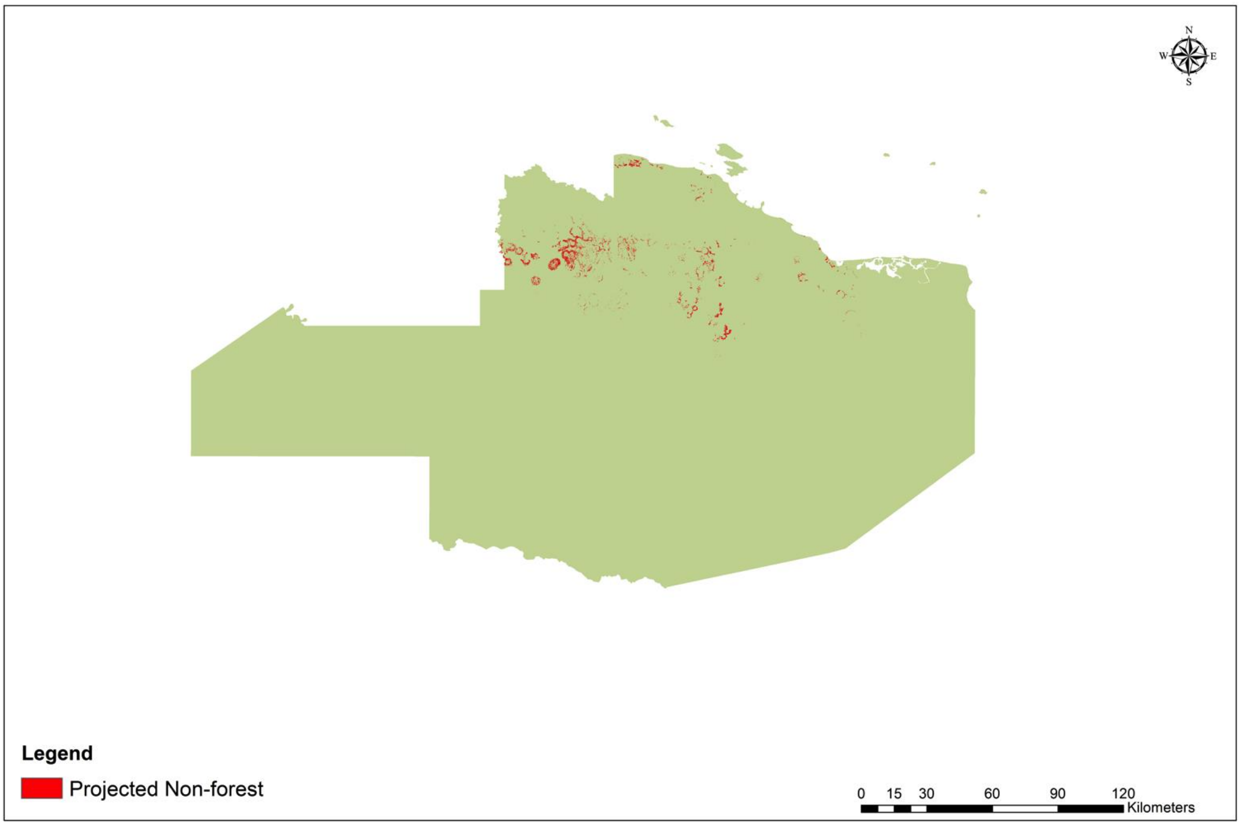


Figure 24: Projected non-forest resulting from oil palm expansion in the Business as Usual scenario in West Sepik



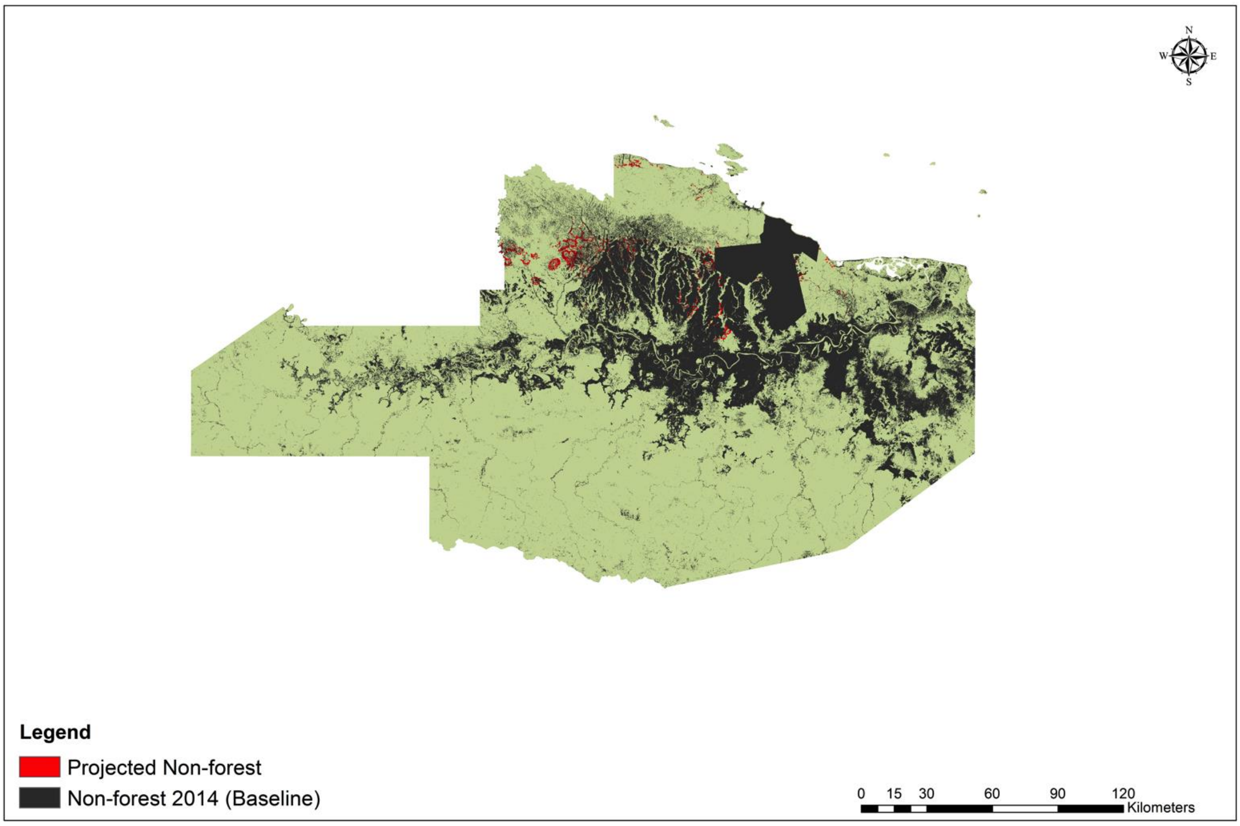
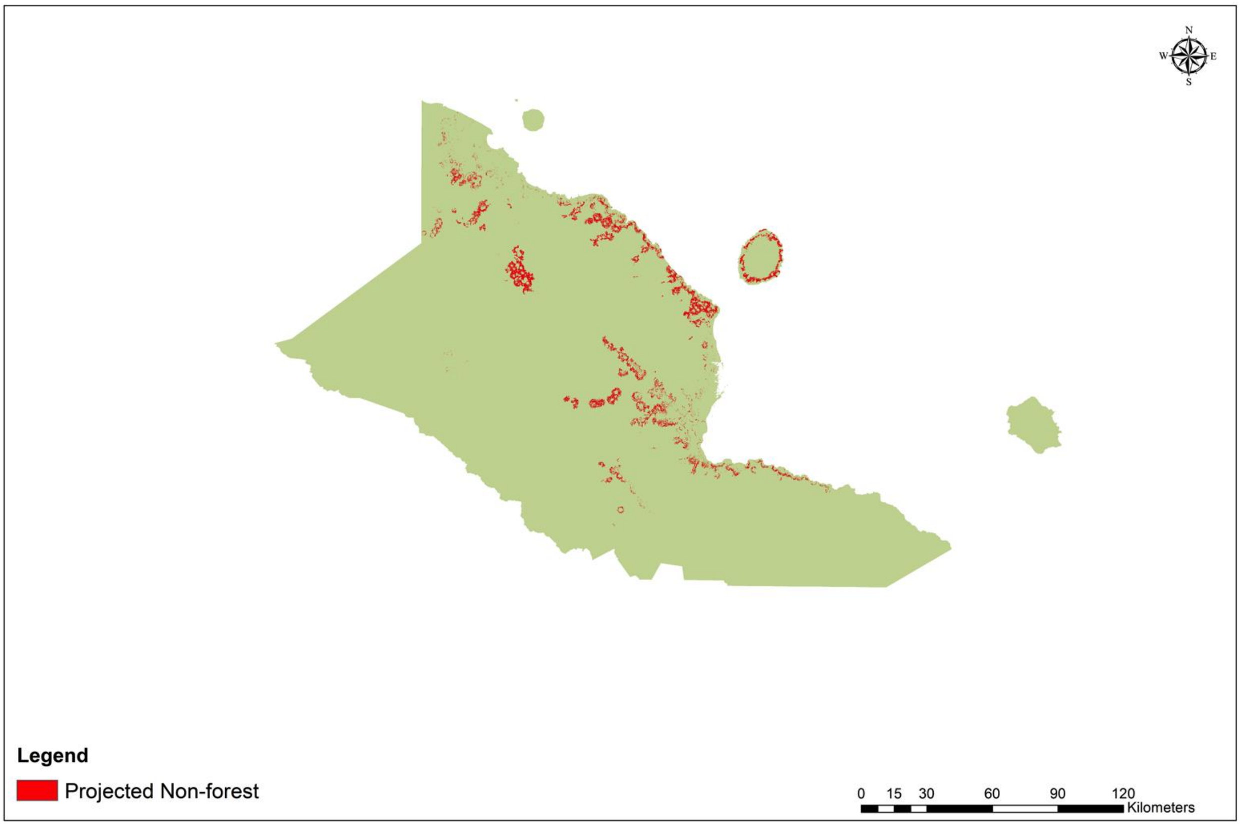


Figure 25: Projected non-forest resulting from oil palm expansion in the Business as Usual scenario in East Sepik



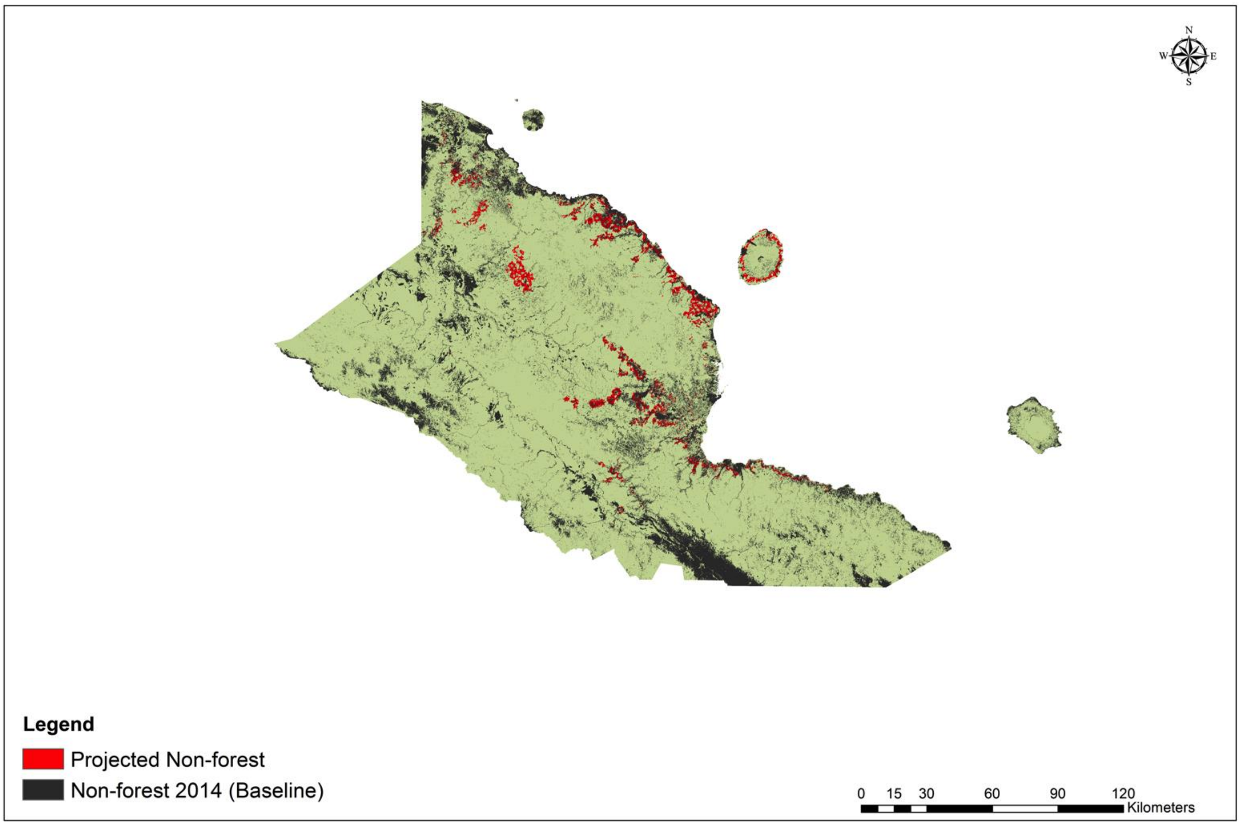


Figure 26: Projected non-forest resulting from oil palm expansion in the Business as Usual scenario in Madang

Oil palm projection: Lax Scenario

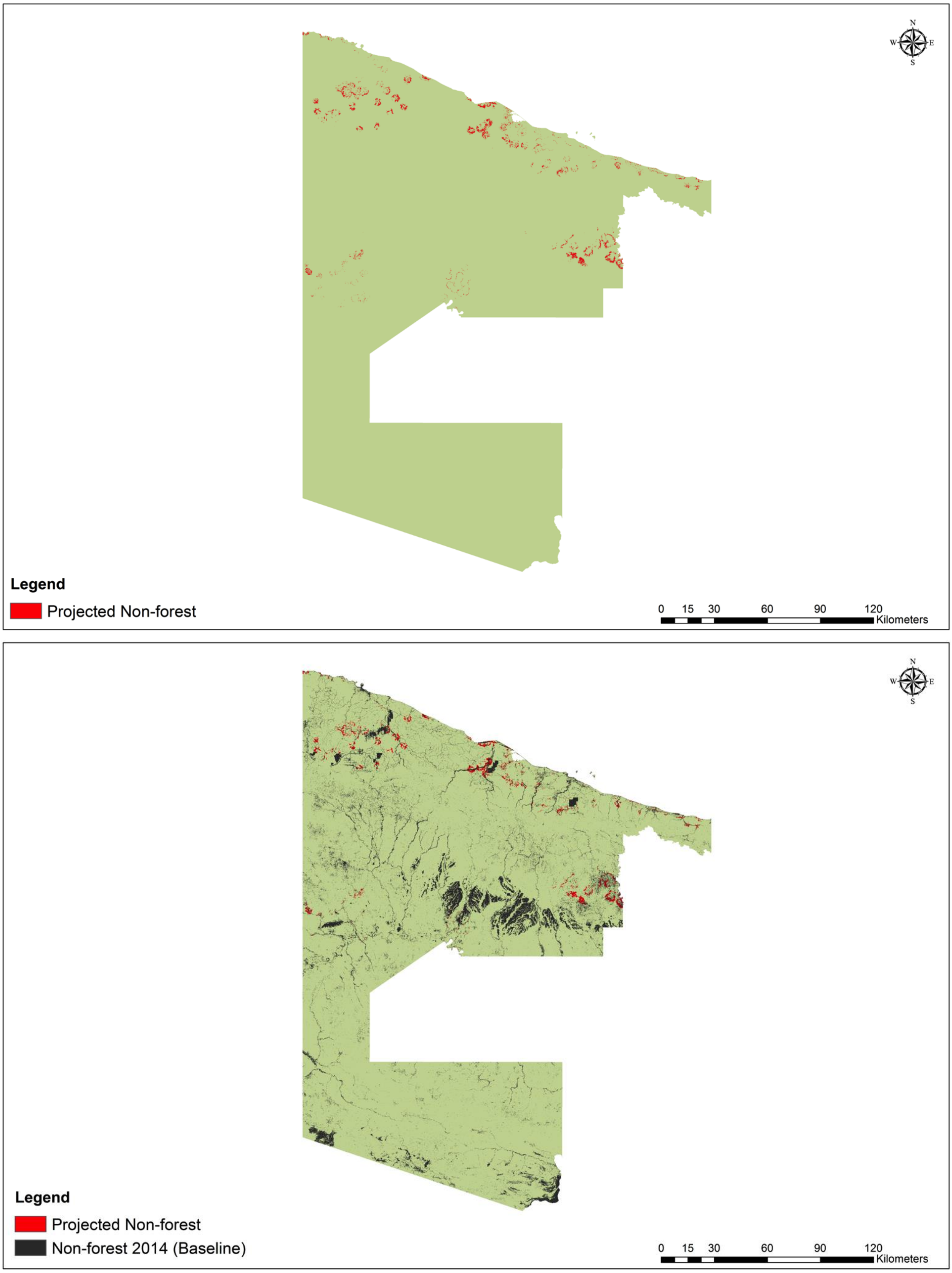


Figure 27: Projected non-forest resulting from oil palm expansion in the Lax scenario in West Sepik

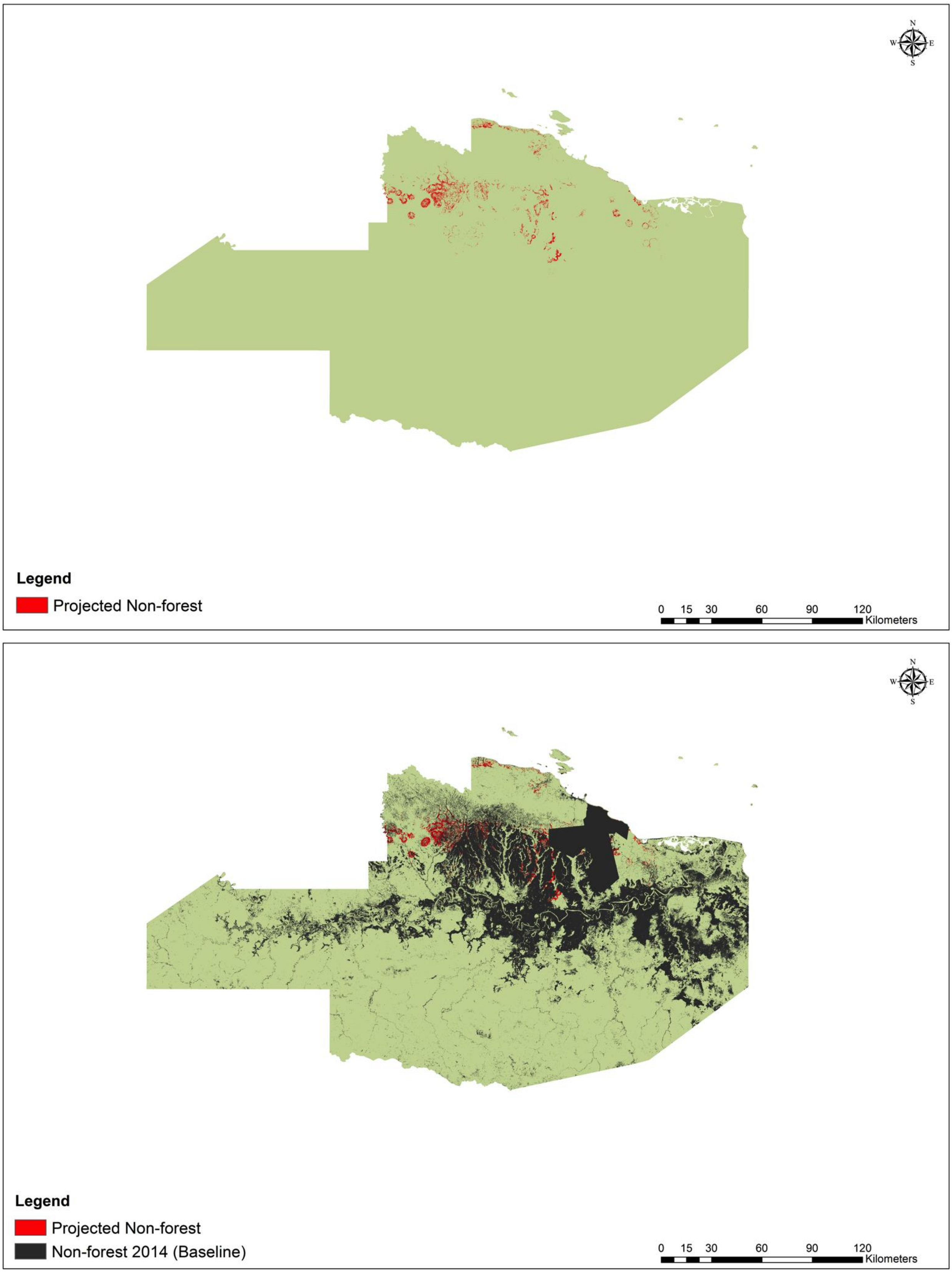
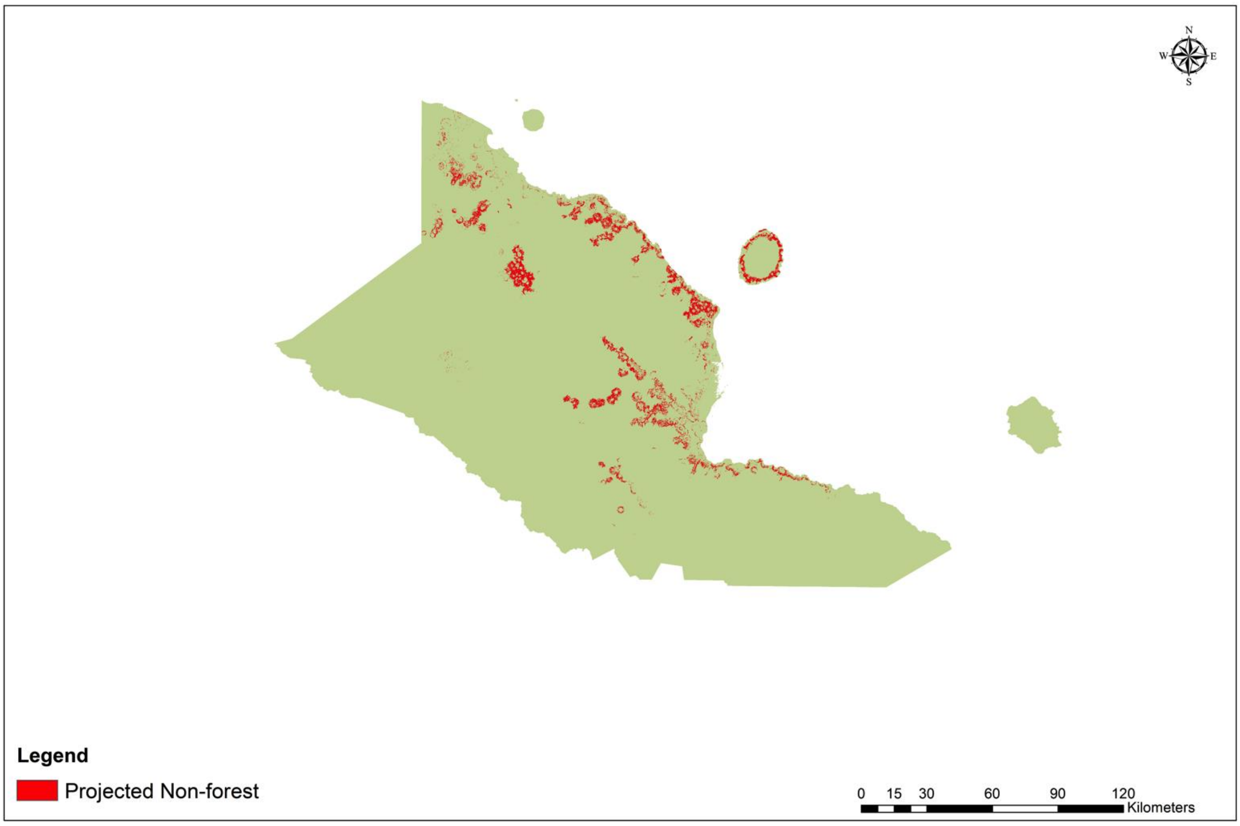


Figure 28: Projected non-forest resulting from oil palm expansion in the Lax scenario in East Sepik



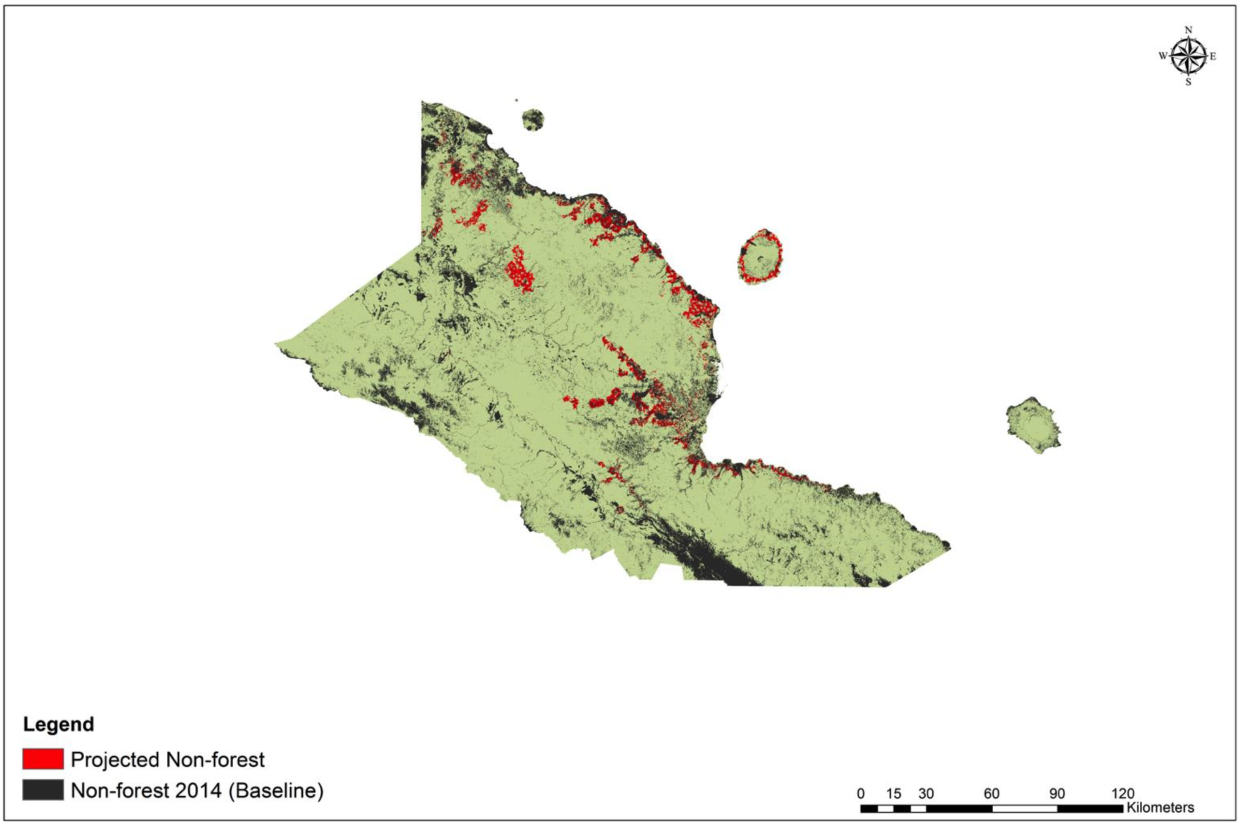
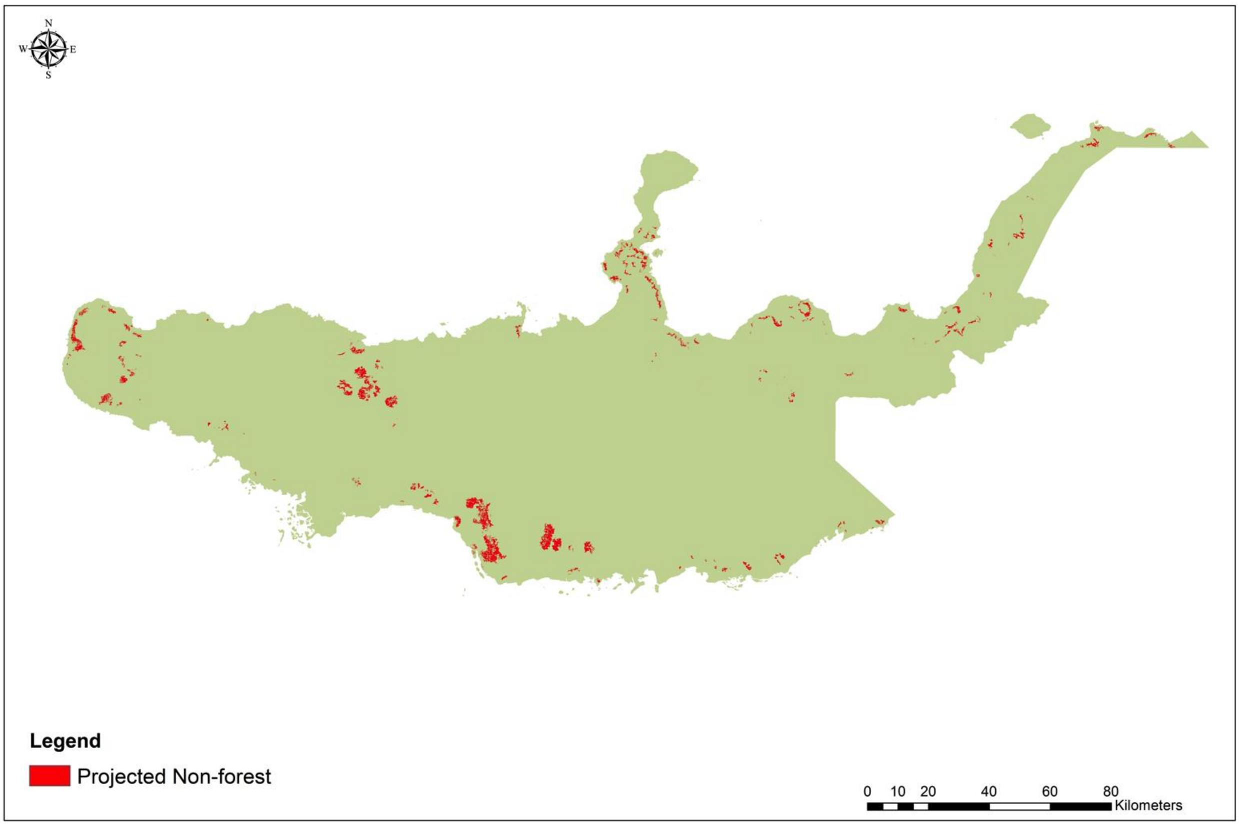


Figure 29: Projected non-forest resulting from oil palm expansion in the Lax scenario in Madang

9.3 Annex 3: model results by province in Zone 2

Oil palm projection: Business as Usual (BaU) Scenario



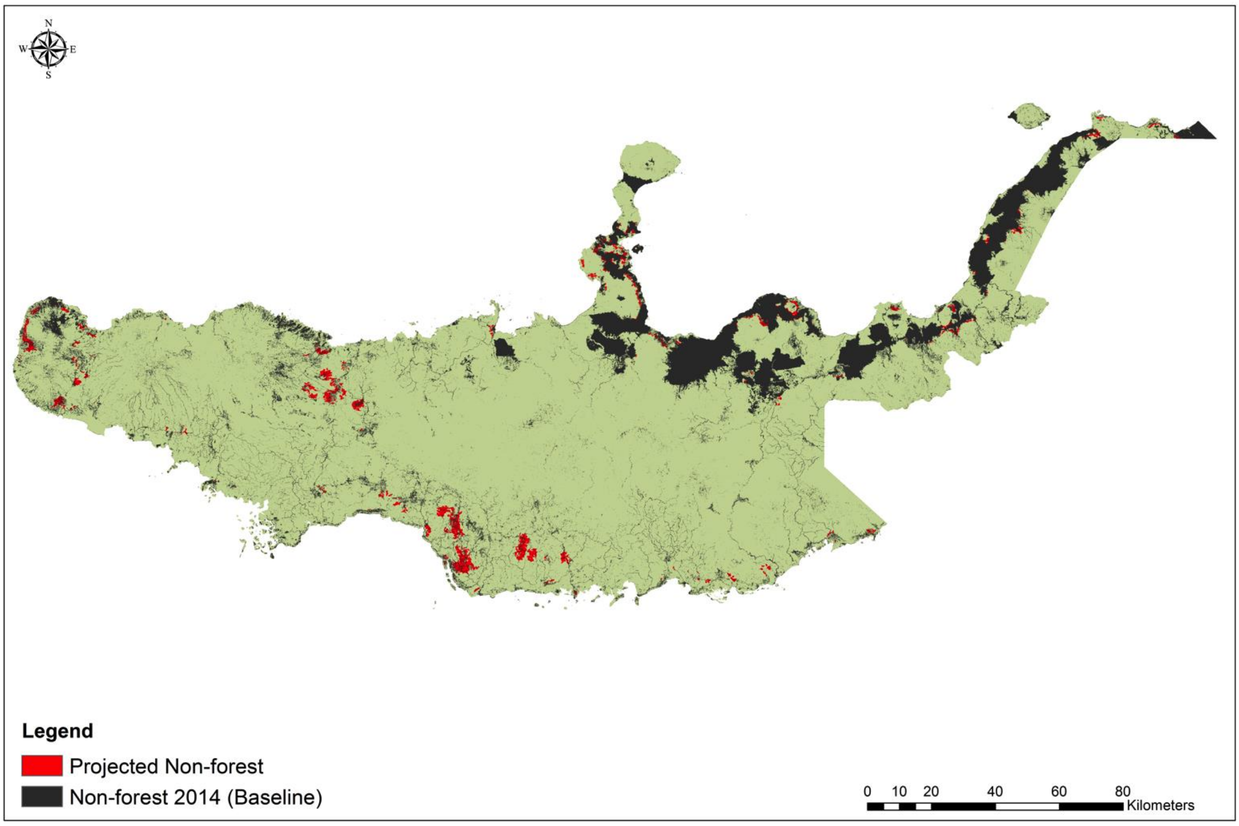


Figure 30: Projected non-forest resulting from oil palm expansion in the Business as Usual scenario in West New Britain

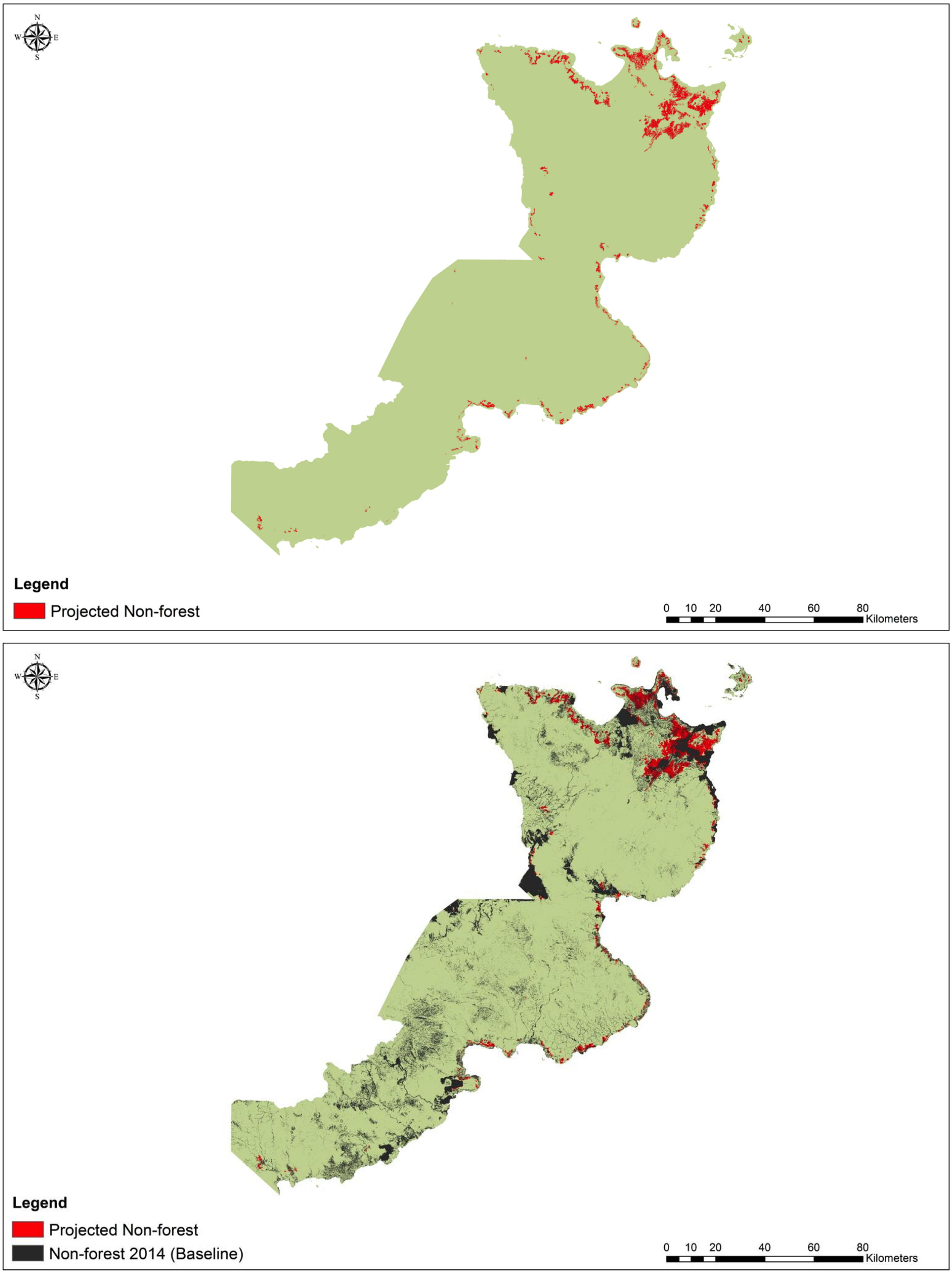


Figure 31: Projected non-forest resulting from oil palm expansion in the Business as Usual scenario in East New Britain

Oil palm projection: Lax Scenario

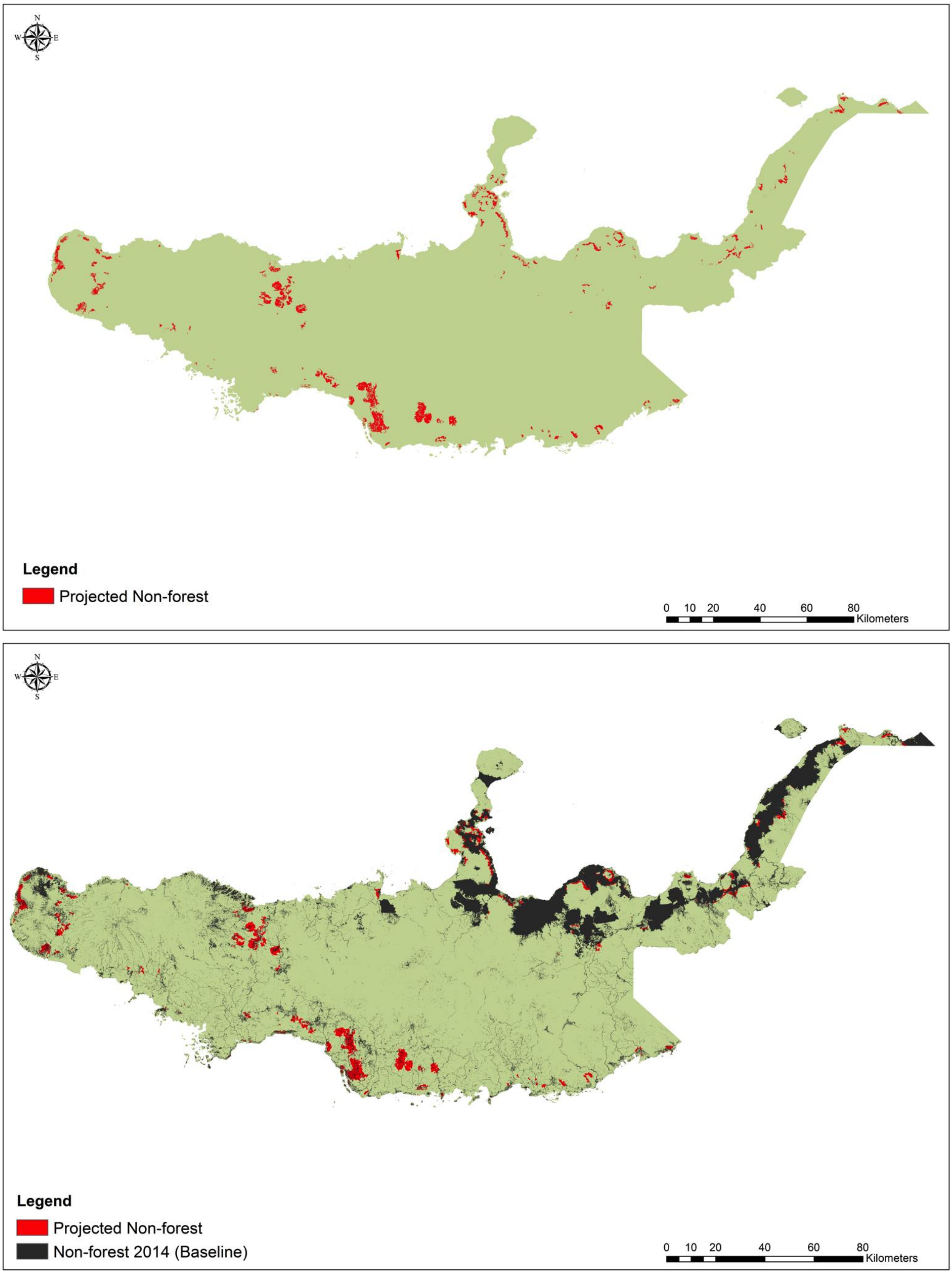
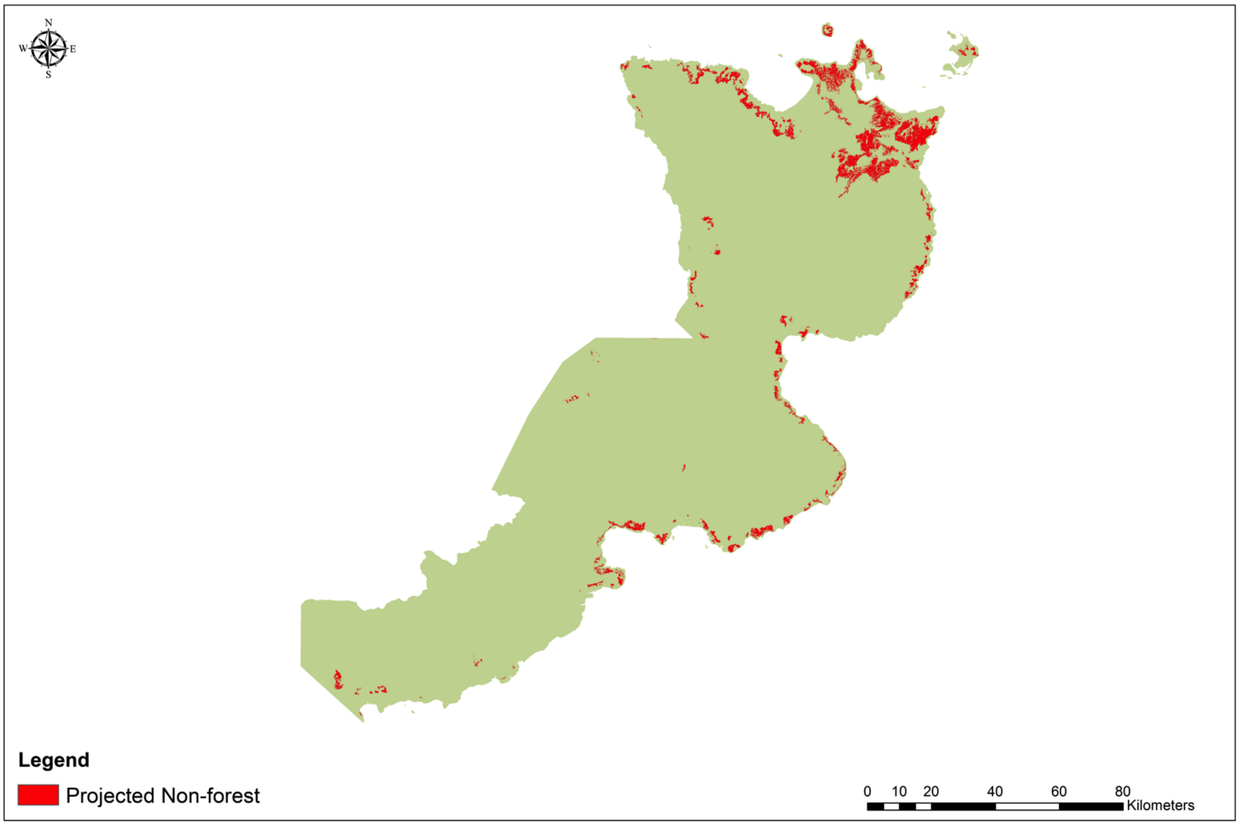


Figure 32: Projected non-forest resulting from oil palm expansion in the Lax scenario in West New Britain



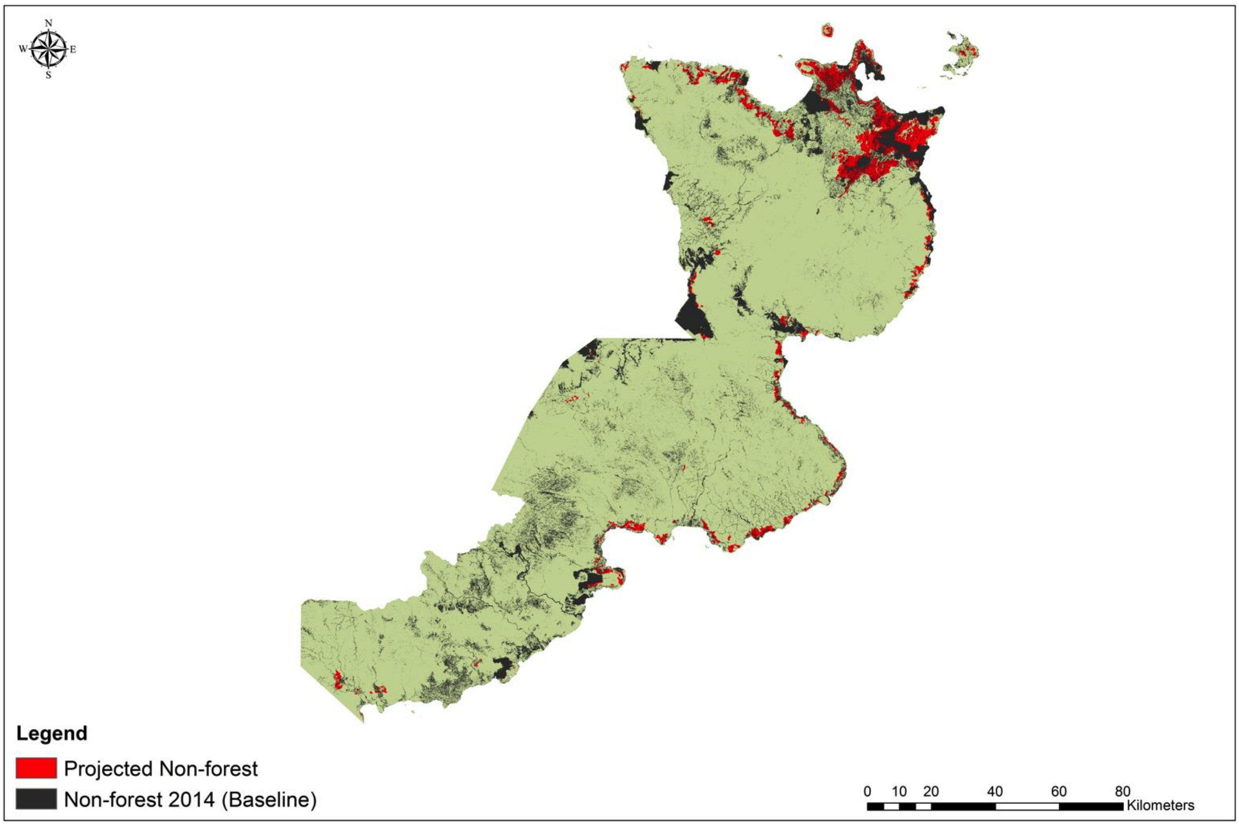


Figure 33: Projected non-forest resulting from oil palm expansion in the Lax scenario in East New Britain