First technical Report:
Land Degradation Baseline

Madagascar: Land Use Planning for Enhanced Resilience of Landscapes
(LAUREL)

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Client
World Bank

Preface

The World Bank has initiated a program of technical assistance in Mozambique and Madagascar (LAUREL), intended to support integrated decision making for landscape management across sectors and levels of government. The **premise** of the program is based on the principle that improved tools for land use planning will result in more informed and evidence based decision making around long term sustainable land use of landscapes which in turn will result in improved resilience and landscapes ability to deliver ecosystem services in general and development benefits specifically.

The overall **objective** is:

> to support integrated, evidence based decision making for landscape management in Madagascar, through improved spatial data on land degradation and SLM, and through the development of prototype Knowledge Management (KM) platforms for assessing, simulating, evaluating, and re-orienting land use and land use change processes.

The expected **result** is:

> a prototype land use change simulation platform to be used by Government to assess the consequences of alternative decisions (primarily investment) on the achievement of development objectives (e.g. food security) and environmental objectives (e.g. forest cover, carbon storage).

The **activities** are split into two components:

- Development of a land degradation baseline
- Development of a Prototype Land Use Change Simulation Platform (LANDSIM-P)

This First Technical Report highlights the progress with the Development of a land degradation baseline. A parallel Technical Report is prepared on the LANDSIM-P.

Acknowledgements

The results described in this report would not have been possible without the enthusiastic contribution of the national experts participating in the national mapping workshop that was held in Anatananarivo in February 2018 (see Annex I).

FOFIFA and World Bank Tana office deserve thanks for organising and hosting the mapping workshop.

Further thanks are due to Lehman Lindeque and Francois Koegelenberg from S. Africa for helping in facilitating the workshop and with preparing the GIS files.

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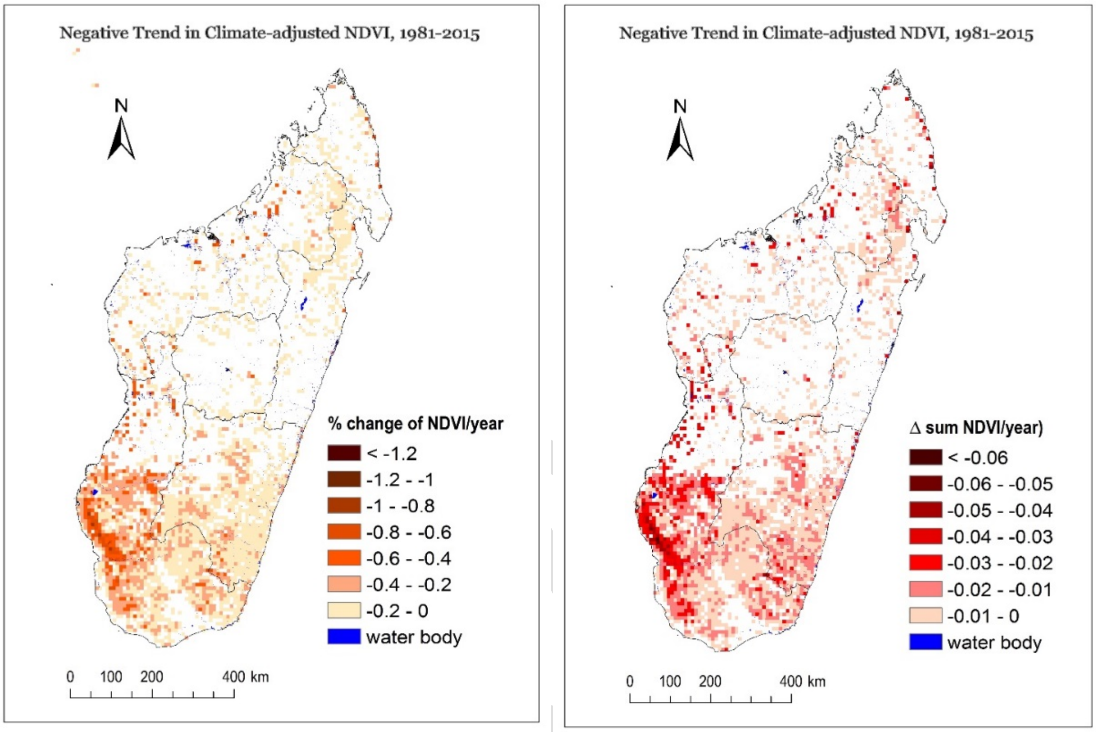
Acronyms

AVHRR	Advanced Very High Resolution Radiometer, National Oceanic and Atmospheric Administration, USA
CRU TS	Climate Research Unit, University of East Anglia, Time Series
EM	Electromagnetic
ESA CCI-CL	European Space Agency Climate Change Initiative – Land Cover
EUE	energy-use efficiency
fPAR	Fraction of Photosynthetically Active Radiation
GIMMS	Global Inventory Modelling and Mapping Studies
GLADA	Global Assessment of Land Degradation and Improvement
LPD	Land Productivity Dynamics
LUCC	Land Use/Cover Change
LUS	Land Use System
LAUREL	Land Use Planning for Enhanced Resilience of Landscapes for Madagascar and Mozambique
MODIS	Moderate-Resolution Imaging Spectroradiometer
NDVI	Normalized Difference Vegetation Index
NOAA	National Oceanic and Atmospheric Administration, USA
NPP	Net Primary Productivity
PADAP	Projet Agriculture Durable par une Approche Paysage (Sustainable Landscape Management Project)
RUE	Rain-use Efficiency
SAR	Synthetic Aperture Radar
SLM	Sustainable Land Management
UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle
WOCAT	World Overview of Conservation Approaches and Technologies

1 Remote sensing of land degradation in Madagascar

1.1 NDVI analysis

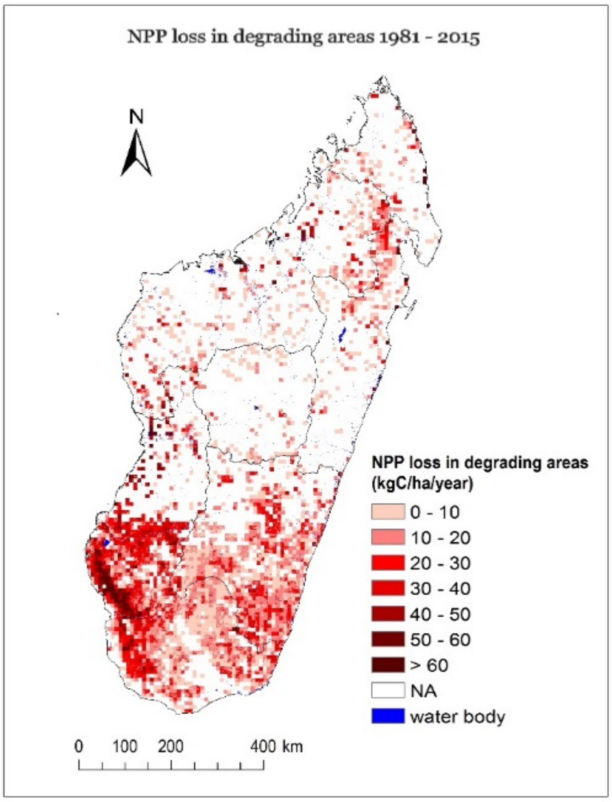
The LAUREL project document proposes to use the GLADA approach, *i.e*. climate-corrected biomass change proxy (Bai *et al*., 2008a,b; 2010; details in the approach paper) to identify land degradation hotspots in Madagascar, using latest relevant datasets. Map 1 shows areas where the climate adjusted NDVI declined from 1981 to 2015 with a negative trend in NDVI. The left panel shows an estimate of the % change in climate adjusted NDVI per year, the right panel shows the reduction in NDVI over the entire period. Together, these two figures reveal a decline in NDVI in South Western Madagascar, suggesting that land has been degrading in this area over this period.



Map 1: Land degradation hotspots in Madagascar identified by climate-corrected NDVI changes (left: relative change; right: absolute change).

To provide a more tangible measure of land degradation, the loss in NDVI was translated to an estimate of the loss in net primary productivity (NPP, tonne ha^{-1} year^{-1}). This biomass loss which was calculated for the 34 year period while using a model to convert NDVI to NPP based on the relation between NDVI and the MODIS (Moderate-Resolution Imaging Spectroradiometer) NPP data at 1km resolution (Running *et al*., 2004) for the overlapping period 2000–2015 (Map 2).

Map 3 shows the extent and degree of land improvement bright spots, expressed by climate-corrected positive changes in NDVI over 1981–2015.Here the NDVI was also translated to net primary productivity (NPP, tonne ha^{-1} year^{-1}), using MODIS NPP data for the overlapping period 2000-2015 (Map 4), to be used as input layer in models for further land use planning. Figure 3 reveals that NDVI and NPP improved in isolated areas throughout the country, with some hotspots in northern and eastern Madagascar.

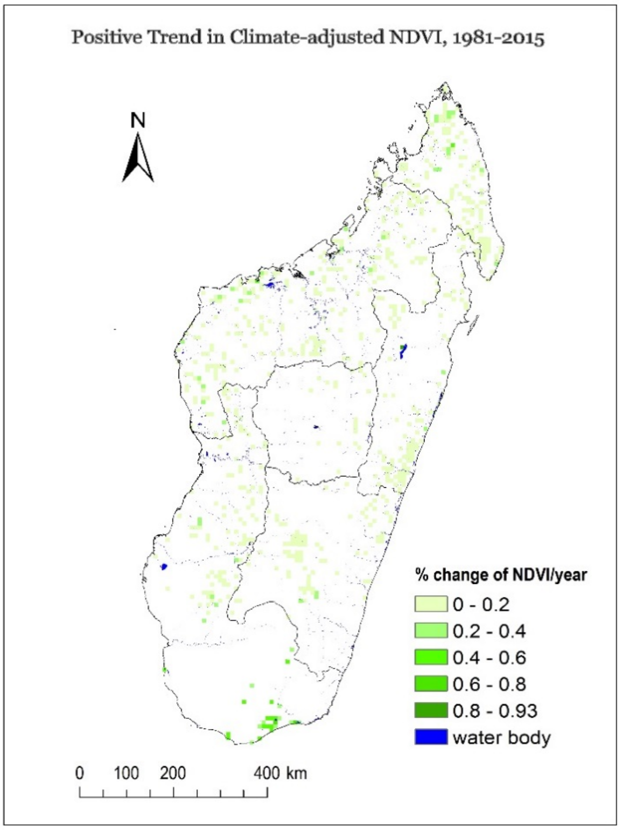


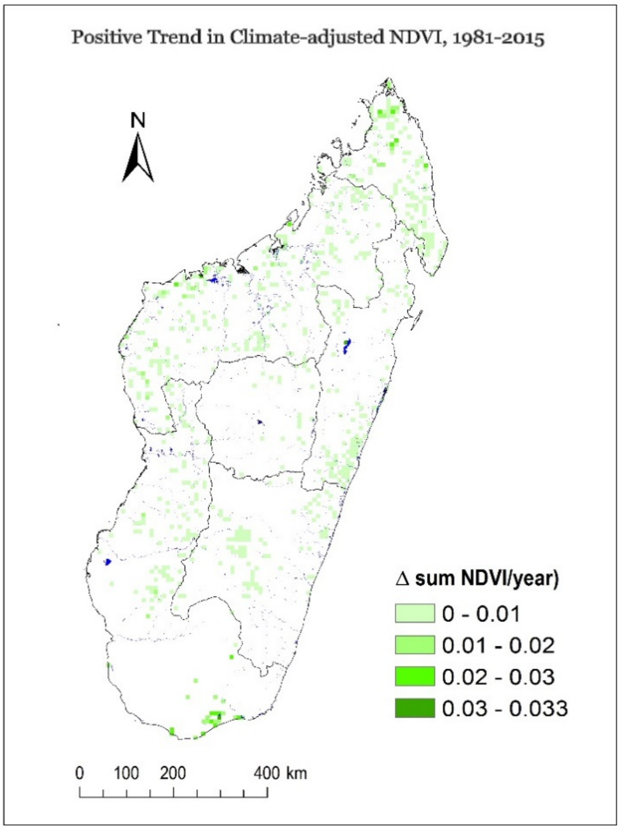
Map 2: Biomass (NPP) loss in the hotspots in Madagascar.

The above analysis of trends in NDVI and NPP was used to identify hotspots of land degradation and hotspots where the productivity of land improved. The trends in NDVI were adjusted for climatic variability over the same period (i.e. inter-annual variability in rainfall 1981 - 2015). The resulting climate adjusted trends in NDVI and NPP thus highlight areas where productivity of land changed because of changes in the land resource base. The climate adjusted trends do not reflect the influence of inter-annual variability in weather conditions, because it is assumed that the climate adjustment removed the effect of the weather conditions on NDVI and NPP.

Decisions to be made remain:

1. Whether climate-induced changes in biomass productivity are to be considered in the Madagascar land planning (LAUREL) or not.
2. Are the above-mentioned NPP changes considered as standalone proxy of land degradation or improvement, or they should be considered only as one of the three UNCCD land degradation indicators, *i.e.,* changes in NPP, land cover and soil organic carbon (SOC)?





Map 3: Land improvement (bright spots) in Madagascar identified by climate-corrected positive NDVI changes (left, relevant change; right, absolute change).

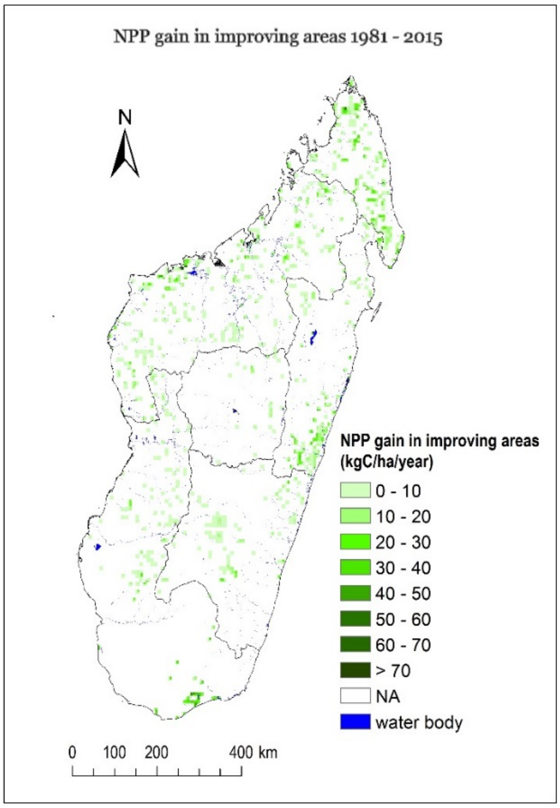
In terms of the UNCCD three land degradation indicators, ISRIC has assessed the indicators using different data sources and compared to what Malagasy colleague Dr. Harifidy Ratsimba did as explained below.

1.2 Land cover change

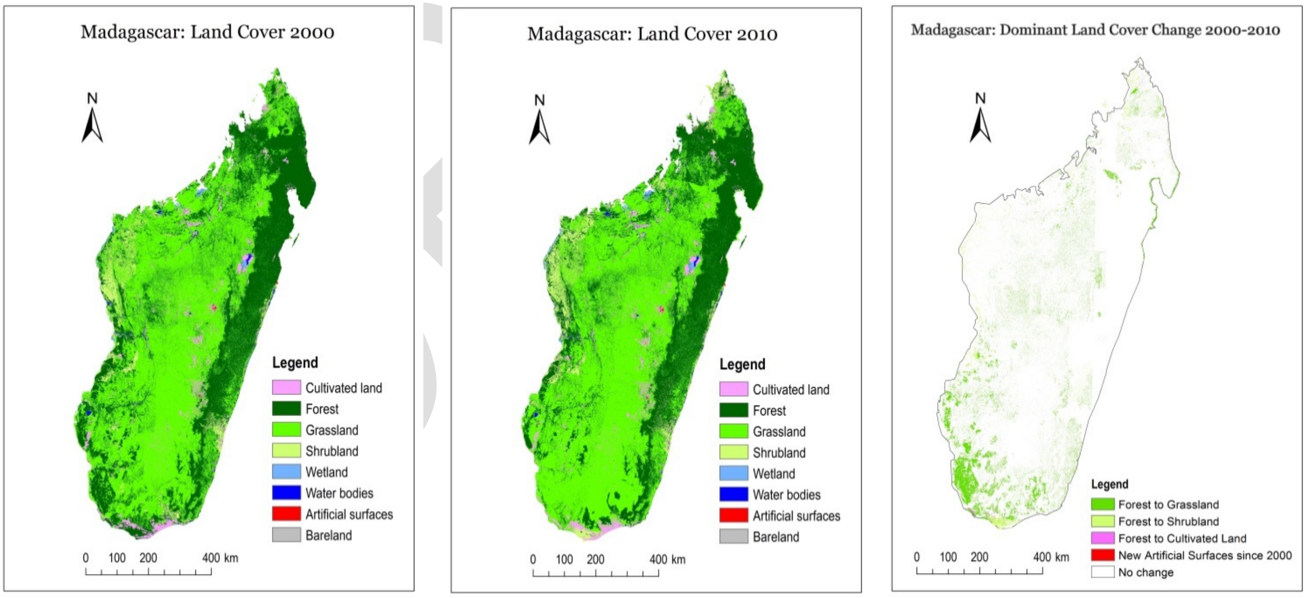
ISRIC used the 30 meter resolution GLOBELAND30 land cover product to produce land cover maps for the years 2000 and 2010 and changes between those two years (Figure 5.1); The GLOBELAND30 classifies land cover into 10 classes, *i.e.*, cultivated land, forest, grassland, scrubland, wetland, water bodies, tundra, artificial surfaces, bare land, permanent snow and ice.

Map 5.1 is significantly different from Map 5.2 that Ratsimba created using ESA CCI-Land Cover product at 300 meter resolution;.

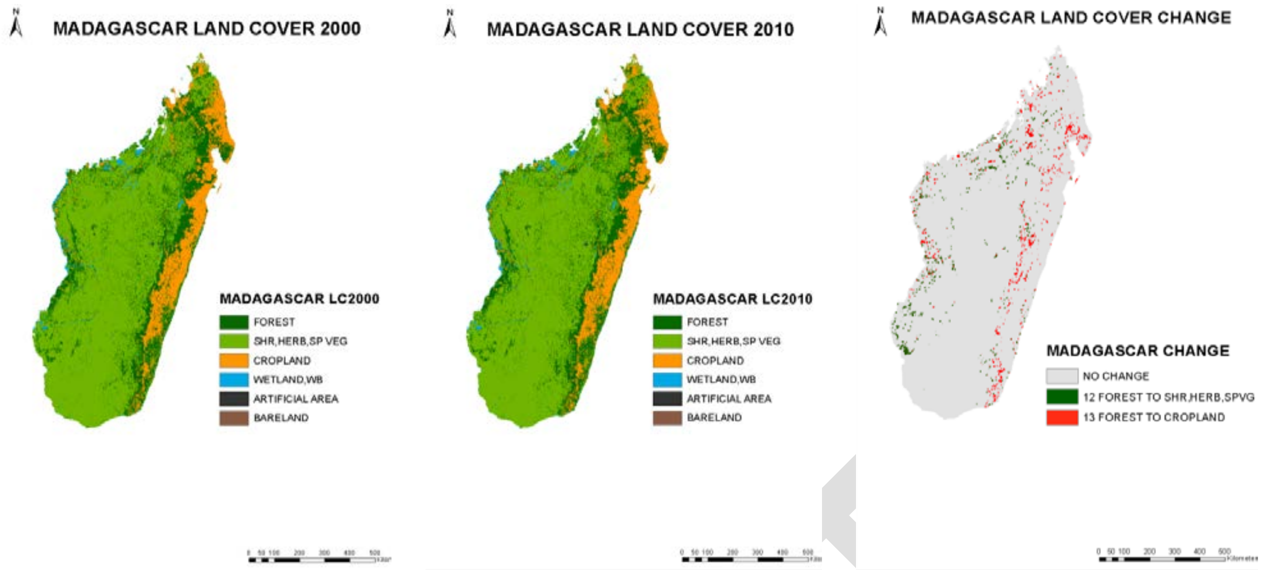
This product has a large number of classes, several of these are mixtures of tree cover and grass cover. The difference between GLOBLAND could be the result of the treecover thresholds used for forest in GLOBCOVER and the tree cover thresholds used for the ESA CCI LC class aggregation carried out by Ratsimba (see Table 1)



Map 4: Biomass (NPP) gains in the land improvement bright spots in Madagascar.



Map 5.1: Land cover and changes produced by Bai/ISRIC



Map 5.2: Land cover and changes produced by Ratsimba.

Table 1.

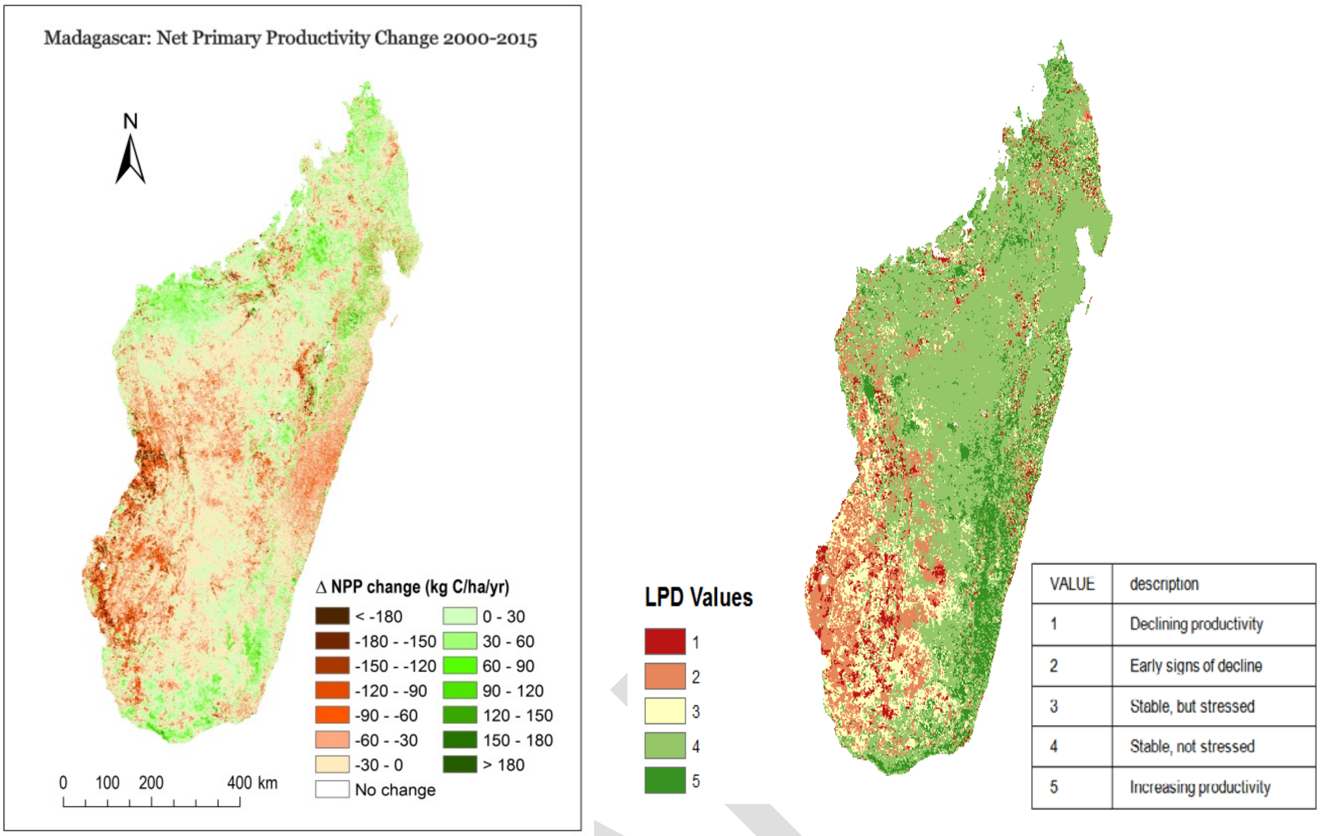
VALUE	Description	ESA CCI-LC classes (codes)
1	**Forests**	Tree broadleaved evergreen, Tree broadleaved deciduous, Tree needle leaved evergreen, Tree needle leaved deciduous, Tree mixed leaf type, Mosaic tree, shrub / HC, Tree flooded, fresh water (50, 60, 61, 62, 70, 71, 72, 80, 81, 82, 90, 100, 160)
2	**Shrubs, grasslands and sparsely vegetated areas**	Mosaic vegetation / cropland, Mosaic HC / tree, shrub, Shrub land, Grassland, Lichens and mosses, Sparse vegetation (40,110, 120, 121, 122, 130, 140, 150, 152, 153)
3	**Cropland**	Cropland, rainfed, Cropland irrigated / post-flooding, Mosaic cropland / vegetation (10, 11, 12, 20, 30)
4	**Wetlands and water bodies**	Tree flooded, saline water, Shrub or herbaceous flooded, Water bodies (170,180,210)
5	**Artificial areas**	Urban areas (190)
6	**Bare land and other areas**	Bare areas, Permanent snow and ice (200, 201, 202, 220)

1.3 NPP change

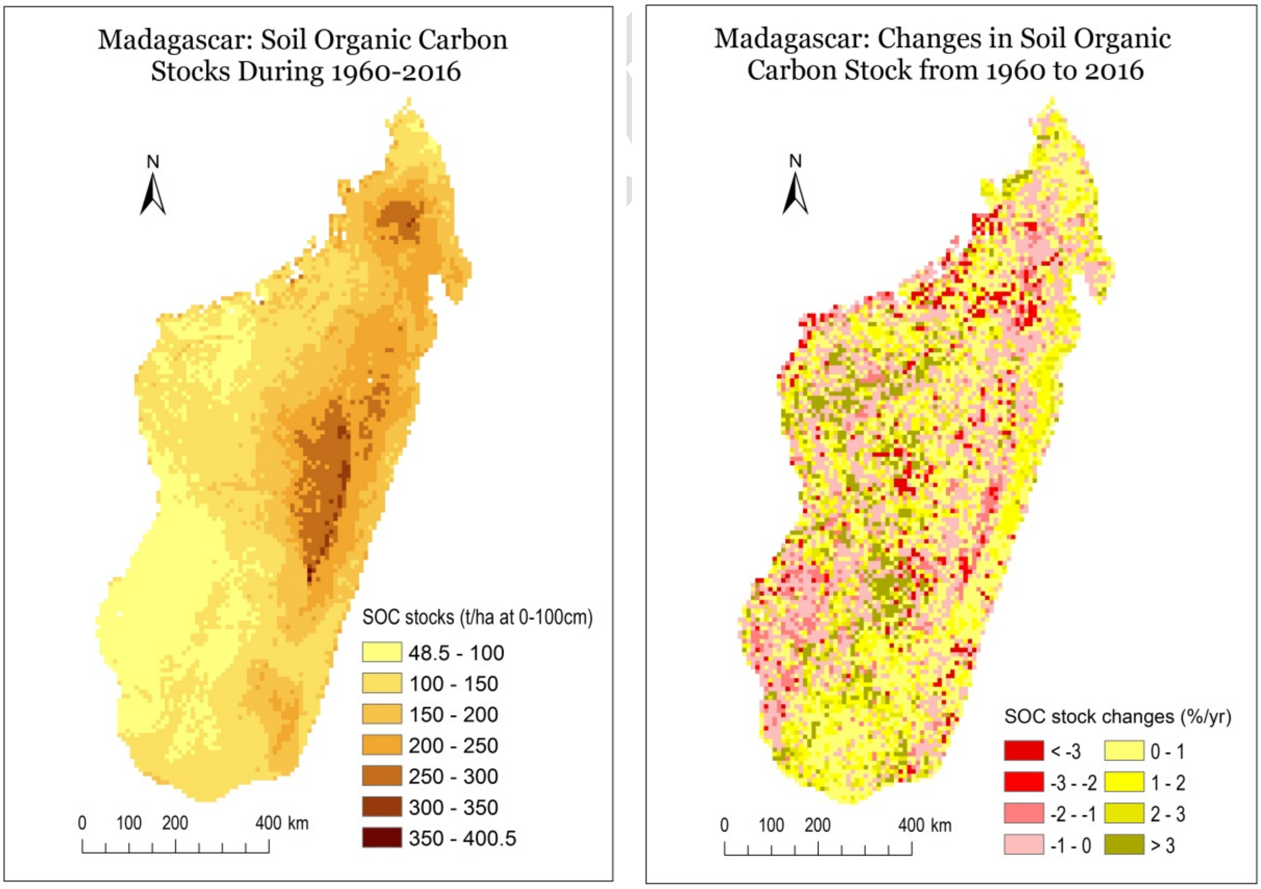
ISRIC used time series annual MODIS net primary productivity (NPP) product (2000 -2015) at 1km resolution and produced NPP trend (Map 6 left), expressed by kg Carbon per hectare per year - which is quantifiable for economic analysis. It's not clear which MODIS product Ratsimba used in the mapping of land productivity dynamics (Figure 6 right) classified as 6 categories.

1.4 Soil organic carbon stocks change (SOCS):

ISRIC, together with Woods Hole Research Centre of USA produced SOCS for the years 900AD, 1800AD, 1960AD, 1990AD, 2010AD and 2016AD at a resolution of 10km (Sanderman, et al., 2017). Significant deforestation in Madagascar started in 1960s (https://en.wikipedia.org/wiki/Deforestation_in_Madagascar), as reflected in the Map 6 and Map 7, showing the status of SOCS and changes during 1960-2016.



Map 7: Left: NPP changes by Bai/ISRIC; Right: map of Land Productivity Dynamics by Ratsimba.



Map 6: Soil Organic Carbon Stocks and changes between 1960 and 2016

It seems that Ratsimba took ISRIC SoilGrids250m SOCS data as a baseline for the year 2000, and estimated SOCS changes through land cover change during 2000-2010 *i.e*. IPCC approach (to be clarified by Ratsimba). SoilGrids250m is a global prediction for standard numeric soil properties and these predictions were based on ca. 150,000 soil profiles which were sampled globally spanning from 1925 to 2015 (Hengl et al., 1017); most of the profiles in Madagascar were sampled in 2009, a few in 1970s and in 1965. Therefore, taking the SoilGrids250m SOCS for the year 2000 as a baseline is questionable.

Local knowledge on the land degradation status in Madagascar collected through WOCAT QM (Questionnaire Mapping) could be useful to improve the assessment of land degradation. Unlike the methodology discussed above, the WOCAT mapping method also specifies (among other things) what type of degradation processes (e.g. erosion, salinisation) were active in an area and what the impacts of these processes on various ecosystem services were, as well as the SLM measures taken to combat degradation (type, effectiveness, etc.).

References

Bai, Z.G., Dent, D.L. Olsson, L. and Schaepman, M., 2008a. Global assessment of land degradation and improvement 1. Identification by remote sensing. LADA Technical Report #12, FAO-ISRIC.

Bai, Z.G., Dent, D.L. Olsson, L. and Schaepman, M., 2008b. Proxy global assessment of land degradation. *Soil Use and Management* 24, 223-234.

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2 Madagascar Base Map

The WOCAT mapping method requires a base map with unique mapping units for which the state of land degradation and SLM needs to be evaluated. A mapping unit consists of one or more polygons with the same unique combination of properties. The WOCAT Questionnaire on Mapping ("QM") suggests the use of "Land Use Systems" as base mapping units, but where these do not exist, another base map can be used, though always taking land use as a starting point (so each mapping unit only has one land use type). In the case of Madagascar, relief/topography is an important additional factor and was therefore be taken as a secondary criterion.

The final base map should not have too many mapping units (as this would increase the workload for the national assessment), yet sufficient to be representative at a national scale and recognisable for the contributing experts.

2.1 Input data

We have explored several alternative maps and data sources to create several base maps, and reviewed these through consultations with local experts before the mapping workshop, in order to select the one best reflecting the variation in land units across the country.

Figure 1 shows a schematic overview of the followed process, run in ArcGis. Different modules were created to automatize the process, which facilitate future changes in used thresholds or inputs.

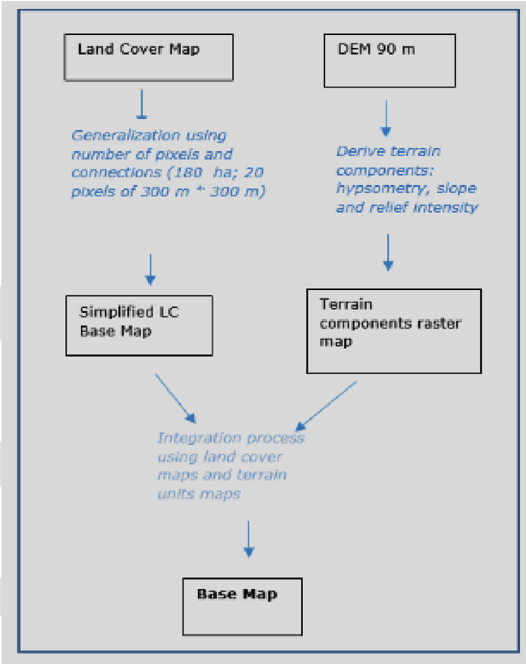


Figure 1: Summary of the process

The base map mapping units are composed by a unique combination of two properties:

- Land cover (rather than land use)
- Terrain information.

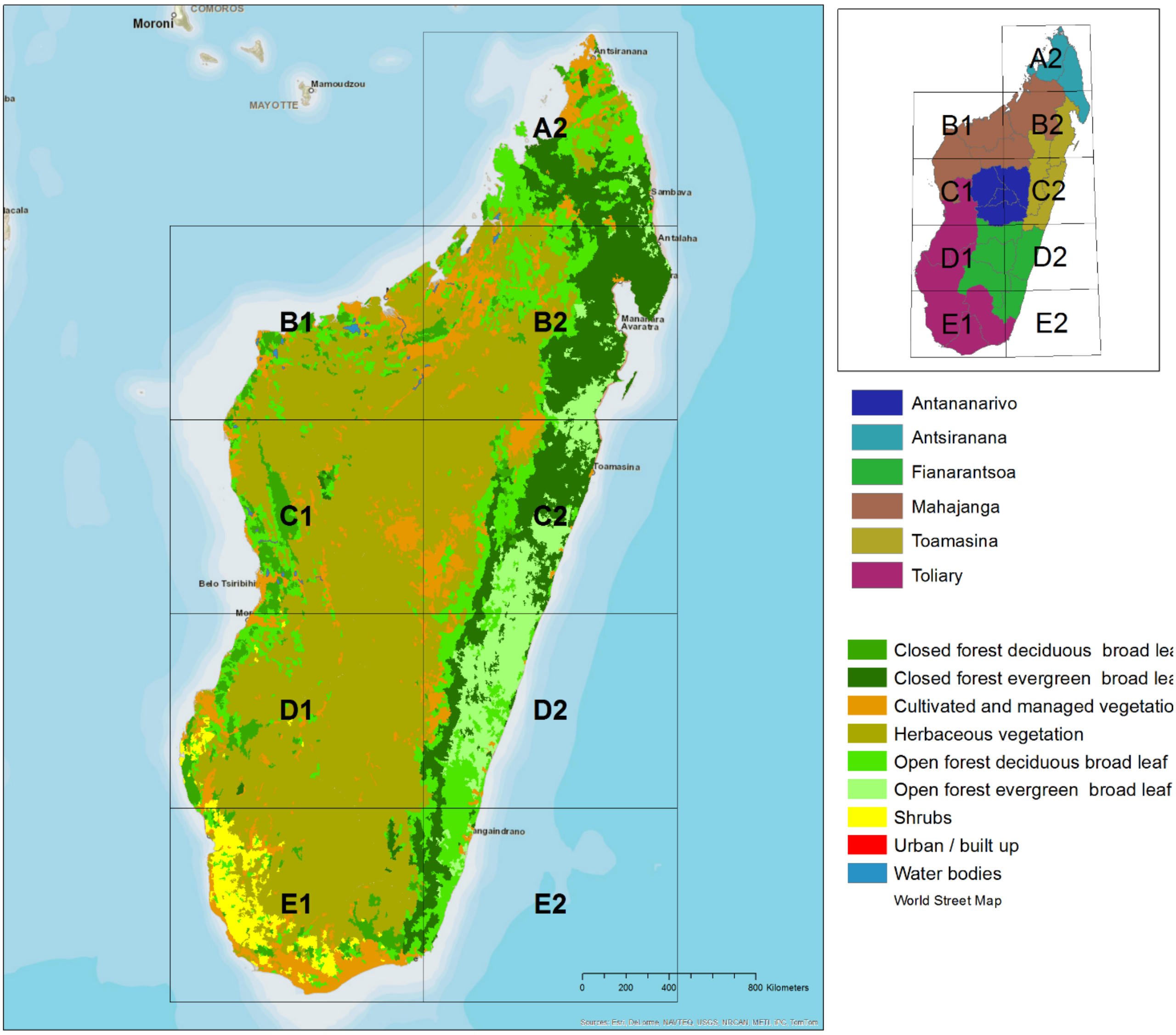
For the land cover information several available maps were evaluated. In particular:

Table 1: Different Land Cover maps evaluated for the base map

Land Cover Map	Extent	Spatial resolution	Temporal coverage	More information
Madagascar Vegetation map	Madagascar	30 m	2001	http://www.vegmad.org/
ESA Globcover regional	Global	300 m	2006	http://due.esrin.esa.int/page_globcover.php
ESA Globcover regional	Global	300 m	2009	http://due.esrin.esa.int/page_globcover.php
GlobeLand30	Global	30 m	2010	http://www.globallandcover.com/GLC30Download/index.aspx
Land Cover from Copernicus Global Land Service	Africa	100 m	2015	http://land.copernicus.eu/global/products/lc
ESA Land Cover Prototype	Africa	20 m	2016	http://cci.esa.int/content/cci-land-cover-prototype-high-resolution-land-cover-map-africa-released

Advantages and disadvantages are present on the different alternatives in terms of resolution, temporal coverage, and appropriateness of the land cover classes for Madagascar.

Preference was finally given to the Copernicus Land Cover map (Map 10) because of its resolution and appropriate classes, as well as good reviews in the literature. The base map derived from the (aggregated) Land Cover Copernicus map seems to distinguish properly the cropping areas but has a very large area coded as "herbaceous vegetation" in the central highlands of Madagascar. However, this was judged as realistic by the experts.



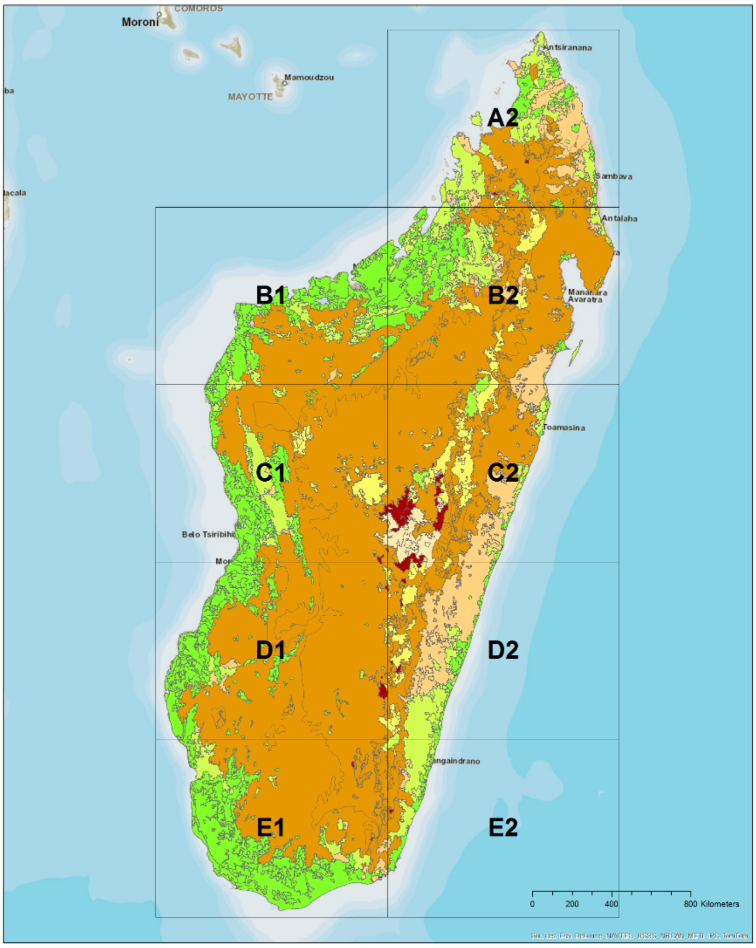
Map 8: Copernicus Land Cover map

Terrain information is important in Madagascar due to the heterogeneity of the topography. For the terrain information the SOTER methodology was applied, which has been developed by ISRIC and used by many other organisations. A SOTER class map of Madagascar was derived from a digital elevation model. Steps to create this map are:

- Slope and relief intensity map calculation, following method proposed by Dobos et al. (2005).
- Reclassification of elevation, slope and relief intensity maps based on adapted SOTER classes described by van Engelen and Dijkshoorn (2013).
- Calculation of the SOTER class map as combination of classes of elevation, slope and relief intensity. Some slope classes were aggregated and as relief intensity turned out to be only very weakly distinctive, it was finally omitted as a distinctive criterion.
- Generalization of the SOTER class map from a 90 m spatial resolution to a 900 m spatial resolution grid.

The resulting SOTER class map has 9 classes with a unique code that is the combination of the slope class and elevation class. For example class 112 means “Level land (<10% slope) at medium elevation (600-1500m)”, and class 323 means “Steep land (>30% slope) at high elevation (>1500m), reflecting a relatively small area in the centre of the country.

TU_cl	Slope	Elevation
111 Level land, low	0-10%	<600m
112 Level land, medium	0-10%	600-1500m
211 Slope land, low	10-30%	<600m
221 Slope land, medium	10-30%	600-1500m
224 Slope land high	10-30%	>1500m
321 Steep land, low	>30%	<600m
322 Steep land, medium	>30%	600-1500m
323 Steep land , high	>30%	>1500m
Water (flat)		

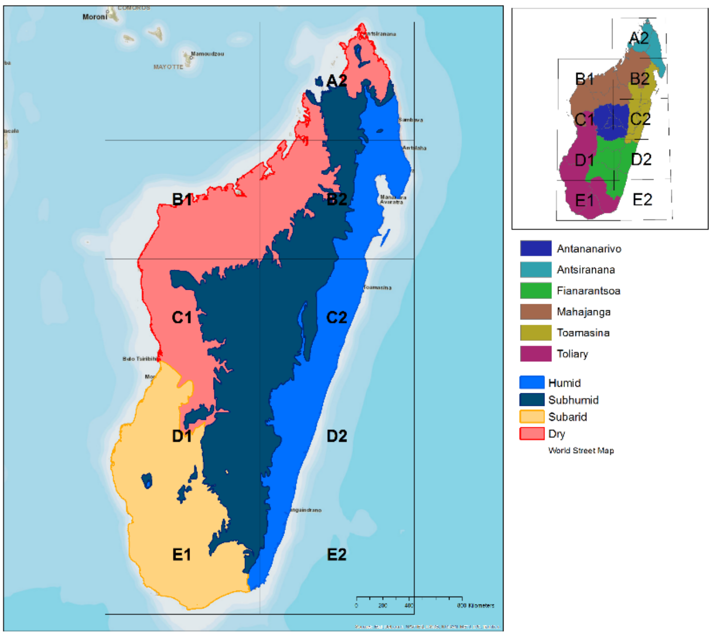


Map 9: Madagascar Terrain class map based on SOTER criteria

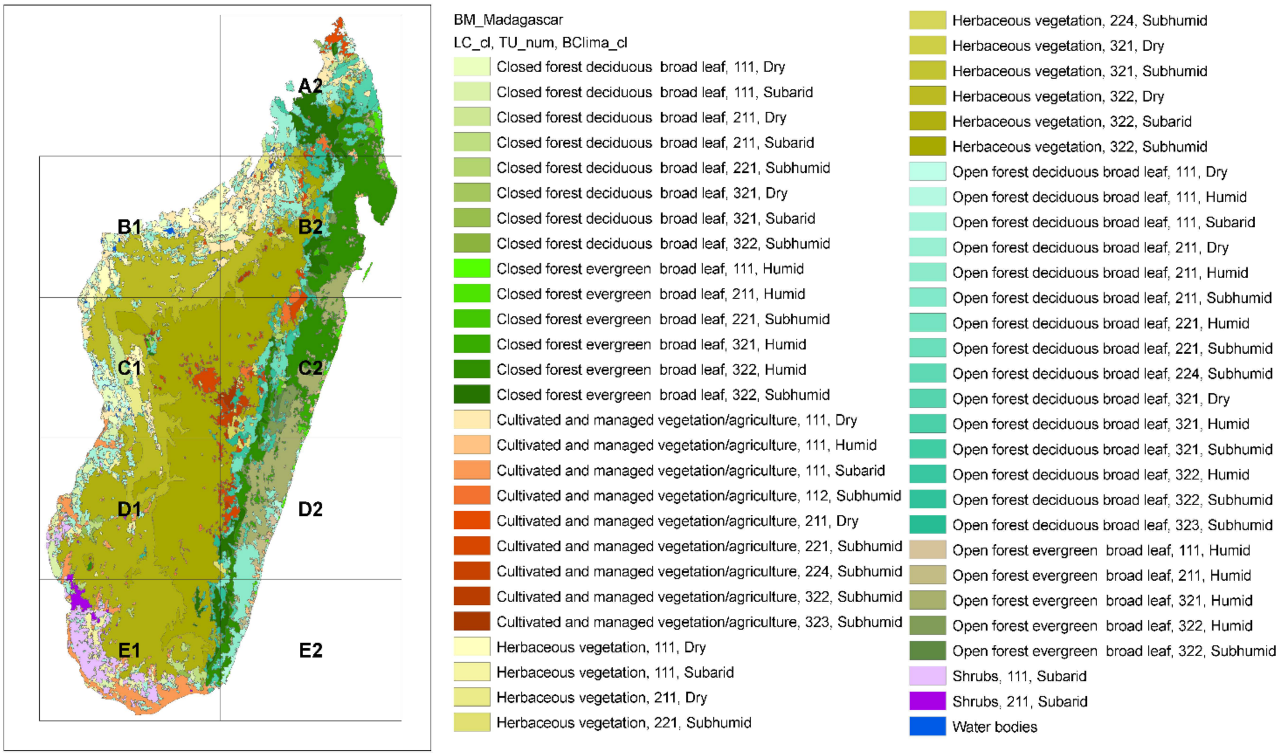
Finally, a coarse bio-climatic map was used to separate the wetter areas (mainly in the central and eastern part of the country) from the drier parts (West and South).

The final base map (Map 13) thus counted 56 mapping units for which the degradation and conservation status was to be assessed.

Several suggested base maps were distributed among experts before the workshop with the request to indicate a preference, but no comments were received until the workshop itself (see below). It was then decided to use the base map as presented, and make any possible amendments later, e.g. by overlaying specific additional land cover classes – if available – in order to locate some land cover class – specific information.



Map 10: Bio-climatic map of Madagascar



Map 11: Madagascar Base Map, combining Land Cover classes, Terrain classes and broad bio-climatic classes

2.2 Further developments and recommendations by the experts

- The number of classes can be increased or decreased by adjusting thresholds in the process. Smaller areas for the aggregation will mean a larger number of mapping units.
- Water bodies were assessed as a separate unit and subdivided into various subunits. Yet for some of these surface area figures are unavailable (e.g. Ocean West and Ocean East), so these are missing in some of the graphical summaries and analyses given below. A separate analysis may be added in an Addendum afterwards.
- It was remarked during the workshop that plantations and mangroves each deserve a separate category, as these are very specific land cover systems not sufficiently covered by the Copernicus classes. However, for practical reasons and time constraints, this could not be adjusted anymore during the workshop (see above).

References

Engelen, VWP van and Dijkshoorn, JA 2013. Global and National Soils and Terrain Digital Databases (SOTER) - Procedures manual (Ver. 2.0). ISRIC Report 2013/04, IUSS, ISRIC and FAO, Wageningen, 191 p. http://isric.org/documents/document-type/isric-report-201304-global-and-national-soils-and-terrain-databases-soter

Dobos, E., J. Daroussin and L. Montanarella. (2005). An SRTM-based procedure to delineate SOTER Terrain Units on 1:1 and 1:5 million scales. EUR 21571 EN, 55 pp. Office for Official Publications of the European Communities, Luxembourg. http://eusoils.jrc.ec.europa.eu/ESDB_Archive/eusoils_docs/other/SOTER/SOTER_endre.pdf

3 Mapping Land Degradation and SLM

The method used to assess the status of Land Degradation and SLM interventions is described in detail in the Annex of the Approach Paper. It follows the mapping method developed in the WOCAT programme based on expert opinion. Experts are asked to evaluate for predefined mapping units (see Chapter 2) the status of land degradation (a.o. type, extent, degree, trend, causes, impact) and the conservation practices applied (SLM: type of intervention, type of measure, extent, effectiveness and eff. trend, impact). The mapping exercise was organized to reach consensus among the experts so that the results reflects the *communis opinio*. The resulting maps are also sometimes described as “perception maps”. Some minor adaptations were made to the WOCAT method, especially in the data recording forms.

It is important realise that the RS approach described in Chapter 1 provides an analysis of trends in land productivity, whereas the “WOCAT” mapping method describes a mixture of the land degradation type, status, its impact and the trends as perceived by the experts.

The experts who participated in the national mapping workshop were selected on the basis of a set of criteria, e.g. they were expected to have a broad overall knowledge of degradation and conservation in the country (full criteria in Annex 3). The mapping guidelines and a document describing the procedures used to define the base map with mapping units to be evaluated during the workshop were sent to the participants beforehand.

Finally 12 experts from different national institutions or ministries (Annex I) participated in the mapping workshop which took place from 12 – 17 February 2018 in the premises of the World Bank at Antananarivo. After a one-day introduction to the method and to the objectives of the mapping exercise, the experts worked in groups (one group per land cover class) on the assessment of the degradation and SLM status. Each group covered a major land cover class and filled in information on land use trends, and on the actual status of degradation and SLM.

3.1 Results

Some preliminary results were already made available during the workshop so that experts could immediately discuss and correct these if needed. This draft document should enable experts to have a deeper insight in the results of the data collection and enable them to provide further comments or make corrections where needed.

3.1.1 Land Use/Cover

Mapping units were based on (Copernicus) LandCover classes, so these were unique for each unit. Additional land use information related to possible trends in area (did a certain land use decrease or increase in area) and intensity (e.g. more use of mechanisation, increased inputs such as fertiliser).

The results show that more than 50% of the country is classified as “Herbaceous”, of which most is on steep land with medium elevation and under sub-humid climate (Figure 2, Figure 3).

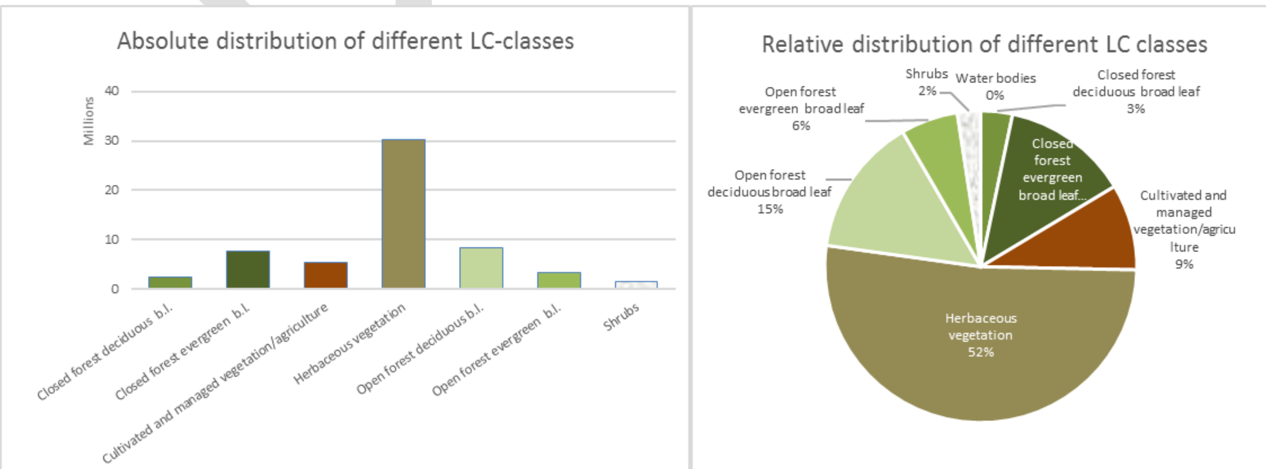


Figure 2: Absolute and relative distribution of land cover classes

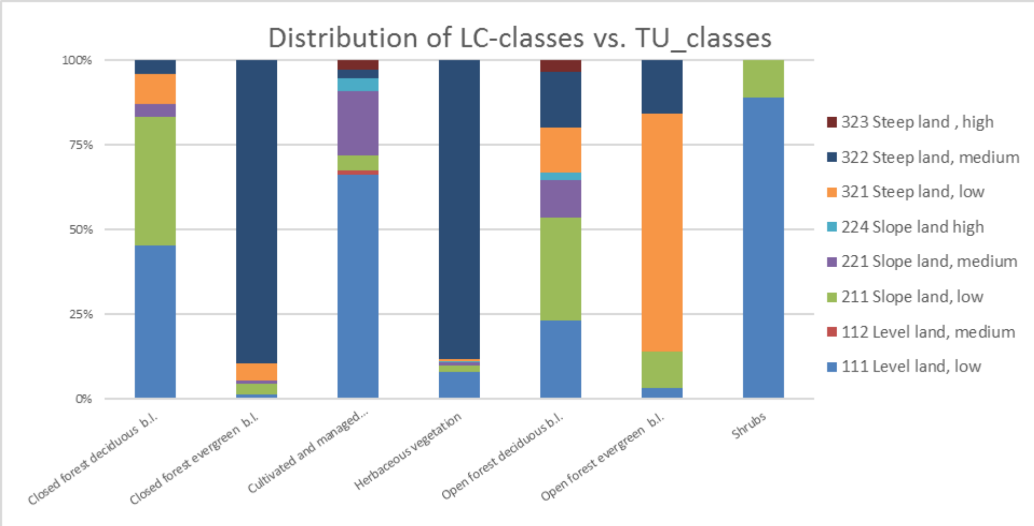


Figure 3: Land Cover classes vs. Terrain classes

Trends in land cover *area* and in land *use intensity* were assessed for each mapping unit (Figure 4). A positive area trend is only observed in Cultivated land and Water bodies. The table below (and the reasons given for the increase of cultivated land) illustrates that the positive trend in cultivated land is at the expense of forest lands in particular, often due to population increase. The positive intensity trends for (esp.) forest lands are explained by higher demand for forest products, and also stricter application of laws and regulations.

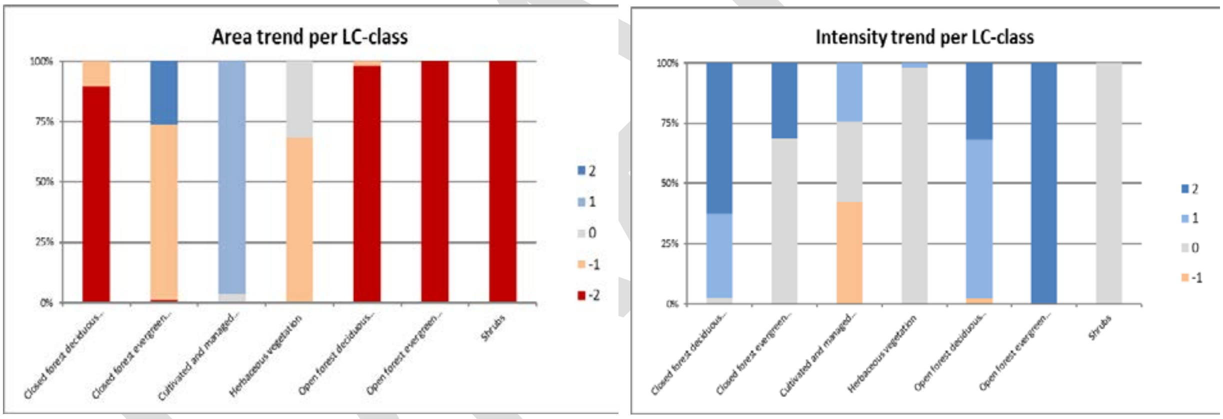


Figure 4: Land use Area trend and Intensity trend

The following reasons for negative area trends are given:

Table 2: Reasons for (negative) area trends

Land Cover class	Reasons	Frequency
Herbaceous vegetation	• Transformation in cultivated land	2
	• New plantations	1
	• Increasing population, or (elsewhere)	1
	• Low population density	1
	• Reforestation	1
	• Irrigation zone	1
	• Mining & oil exploitation	1

Closed Forest (deciduous/evergreen)	• Forest exploitation for firewood and timber • Conversion to cultivated land • Mining (incl. illegal activities) • (Controlled) fire • Protected area • Difficult access • Medicinal plant collection	14 10 9 5 3 2 1
Open Forest (deciduous/evergreen)	• Land clearing and controlled / wild fires • Mining (incl. illegal activities) • Exploitation of valuable wood species • Deforestation • Development into economic area (port, etc.) • Increase of rice area • Destruction of mangroves for shrimp production • Population pressure • Cacao tree plantation • Expansion of rainfed agriculture • Production of charcoal	12 9 6 6 4 2 1 1 1 1 1
Shrubland	• Population pressure (--> wildfire, charcoal) • Big temperature fluctuations, low rainfall, violent winds • Deforestation (firewood --> difficult regeneration of vegetation) • Controlled fire for cultivation	2 2 2 2

3.1.2 *Land Degradation*

Per mapping unit, contributors were asked to indicate up to a maximum of three LD types or combinations. Each combination again, occurring in one and the same part of a mapping unit, can consist of three different degradation types (DegType1, Degtype2 and possibly DegType3).

There are six "Main types" of degradation, indicated with a capital letter, such as "W" for Water erosion, or "B" for biological degradation. Each main type has several subtypes, indicated by an additional lower case letter, such as Wt for water erosion: loss of topsoil/sheet erosion.

For each degradation type (or combinations) various other parameters were assessed, such as the extent (percentage of the map unit affected), degree (intensity of the degradation process), rate (or recent trend), causes and impacts

Figure 5. indicates that almost all Land Cover classes are affected by some kind of land degradation for more than 60% of their area. However the Degree of degradation differs considerably between the LC classes (): mostly light and moderate for cultivated land, but strong for the majority of the Closed Forest Deciduous, Herbaceous and Open Forest evergreen. Figure 7 and Map 12 clearly show that water erosion is by far the most widely occurring degradation type: 30 M Ha is affected by some form of water erosion, sheet erosion (Wt) being the most widespread

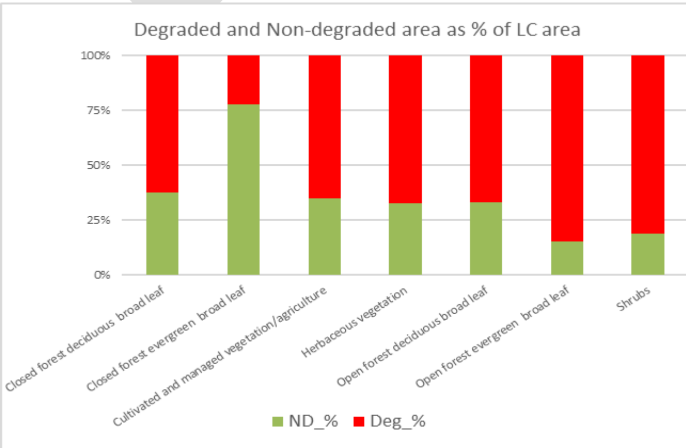


Figure 5: Percentage of (non-)degraded area per LC class

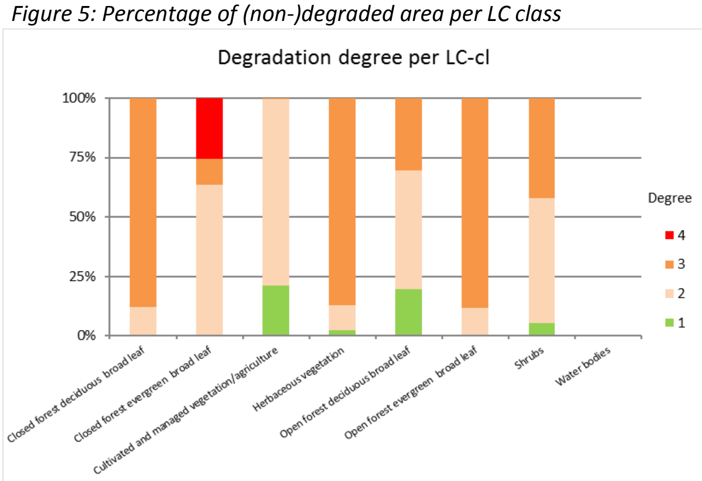


Figure 6: Degree per LC-class

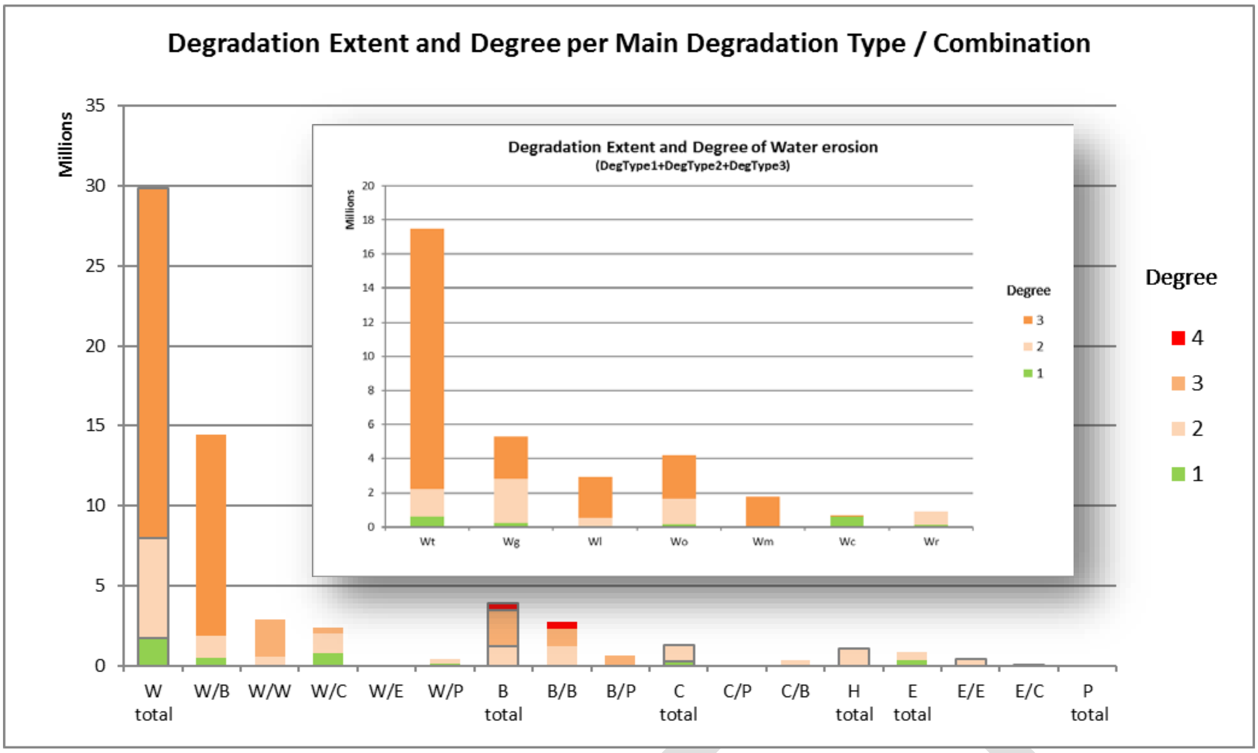
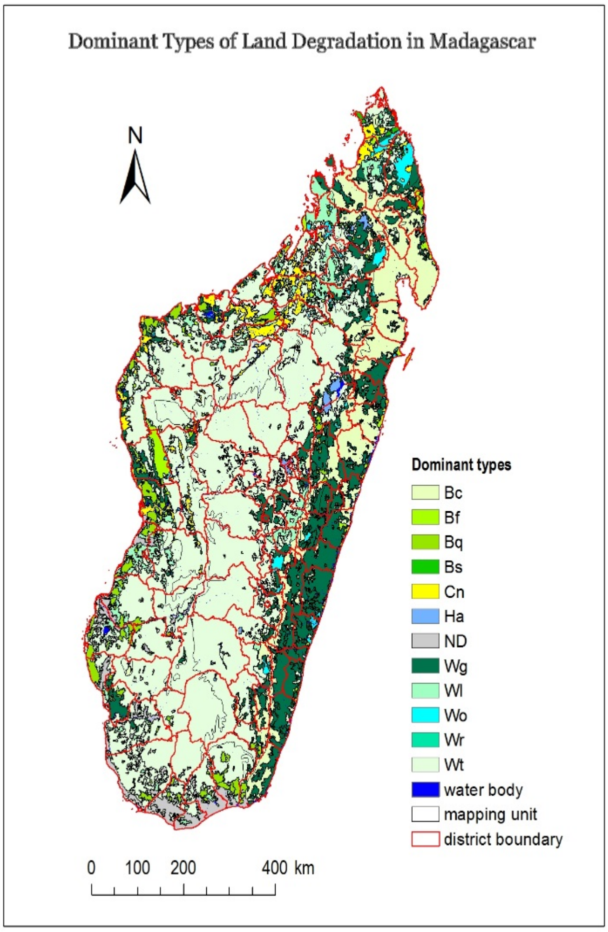
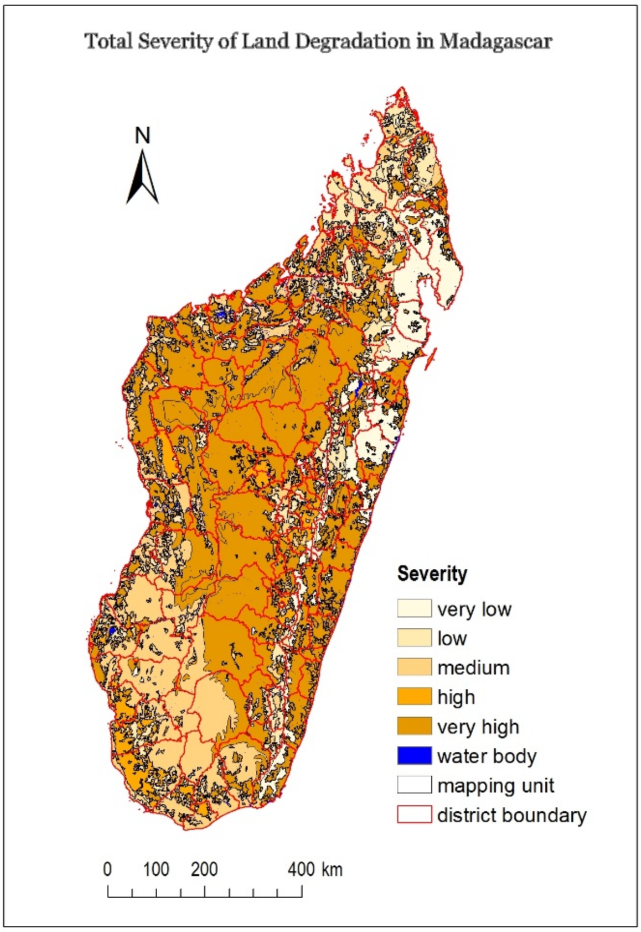


Figure 7: Distribution of main degradation types and combinations in M.Ha.
Insert: Distribution of various subtypes of water erosion.



Map 13: Dominant degradation types (based on extent and degree)



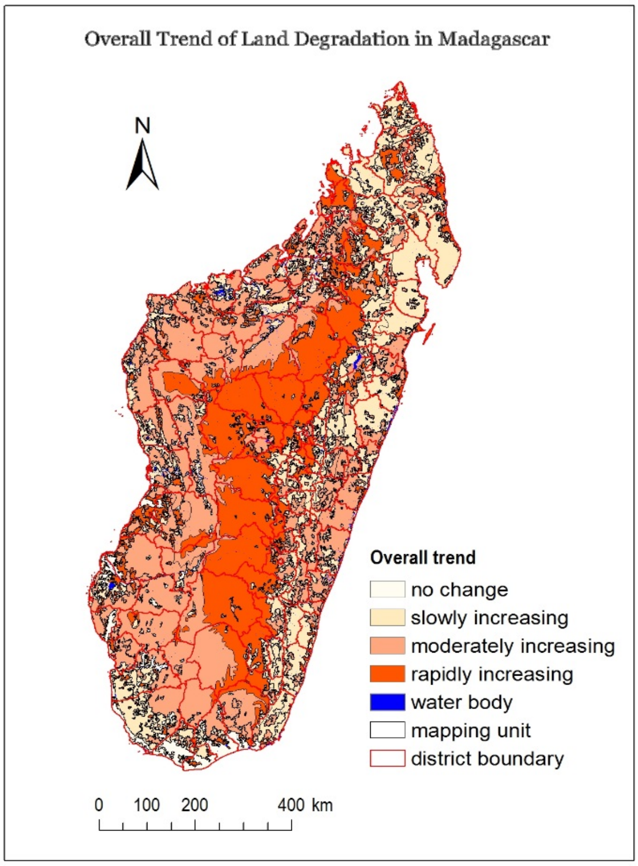
Map 13: Total severity (sum of weighted degree for all degradation types per mapping unit)

(1.5 M Ha), with mostly a strong degree (3). About half of the occurring water erosion is in combination with some form of biological degradation (mostly Wt/Bf), also most of which with has a strong degree (3).

In the following graphs the total occurrence of the different degradation types is considered, so whether as first, second or third degradation type in a combination. Because of occurring combinations, the total of different degradation subtypes (such as in the inserted graph below for water erosion) can be higher than the total for the main type, as for “W total” in the main graph of Figure 6 below.

Map 13 shows the “total severity of degradation” per mapping unit. This is calculated by multiplying degree and extent in order to get a “weighted degree”, which means that for instance a small area (10% of a mapping unit) with a high degree (3) will get a lower score (0.1*3 = 0.3) than a large area (e.g. 80%) with a somewhat lower degree (e.g. 0.8*2 = 1.6). The scores have been reclassified into classes very low – very high to make them a bit more meaningful.

Map 14 shows the (weighted) trend of land degradation in the past 10 – 15 years. In almost the entire country there is an increasing trend in degradation, especially on the herbaceous steep, medium elevation land in the centre.



Map 14: Trend of degradation

Figure 8 shows a breakdown of degradation trend per land cover class. The rapid increase in degradation for Herbaceaous land is evident, while the rate on Cultivated land and Shrubland is relatively low. Please note that the values in the graph (not weighted) do not fully correspond with the classes in the map (weighted).

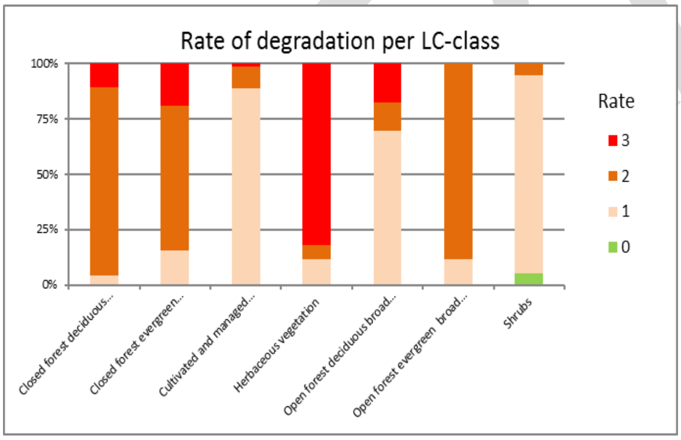
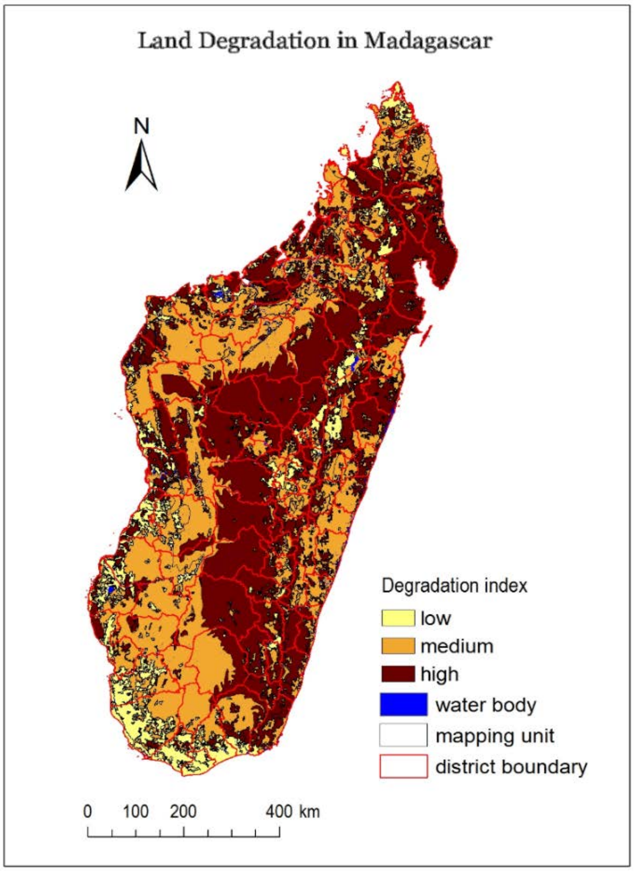


Figure 8: Trend of degradation

A “Degradation Index” was calculated following the method developed by Lindeque et al (2009)., combining Extent, Degree, Rate (trend) and Level of impact of land degradation on Ecosystem Services. Purpose of this map is to identify major areas of concern (priority areas) were land degradation poses a threat to the maintenance of ecosystem services and sustainable agricultural production – the higher the DI score, the higher the levels of current LD happening at that specific Mapping Unit (Map 15). As can be expected, this map shows large similarity with Map 13, with some exceptions such as in the Northeast.



Map 15: Degradation Index

But it is more meaningful than a map showing only degree (and extent), since it also includes trends and impact. For instance, an area with strong degradation can have a declining trend and may hence be less at risk than an area with – still – low degradation but a rapidly increasing trend. Likewise, a strong degree of degradation (indicating the intensity of the process, such as strong soil loss) may have negative impacts (most often) but also positive ones (benefits of fertile sedimentation downstream).

The distribution of the different degradation types over Land cover classes and Terrain classes is shown in Figure 9.

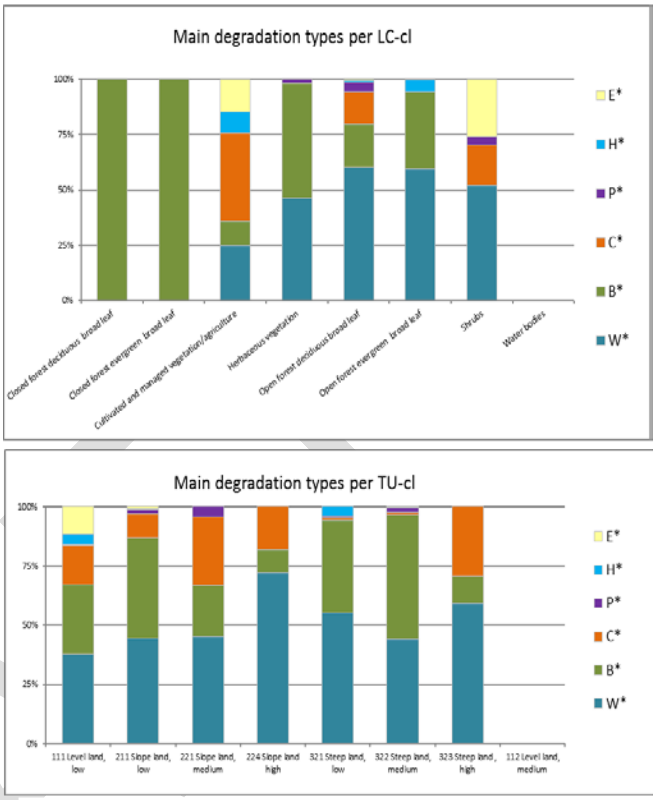


Figure 9: Relative distribution of degradation main types per Land Cover class (top) and Terrain class (bottom)

The Impact of degradation on Ecosystem Services (ES) is calculated by summing the maximum (negative) impact for each ES, weighted by its extent (e.g. a degradation type with an extent of 45% and an impact of -2 will have a weighted impact of (45*-2/100 =) 0.9.

Cultivated land/managed vegetation has the highest diversity of degradation types, with a predominance of water erosion, with a moderate degree (mostly Wt: sheet erosion), and chemical degradation (mostly Cn: Loss of nutrients and organic matter), with a light to moderate degree. This also applies to Level land at low altitude, which coincides with 2/3 of the Cultivated land. It is remarkable that there is not a very large difference for the occurrence of water erosion between level and sloping/steep land. This is probably because the "level" land includes slope categories up to 10%, which may well be prone to erosion, and is often more intensively used for agriculture than steeper land (Figure 3). The degradation problems on cultivated land are mostly associated with direct causes improper crop management and/or *improper soil management*.

The degradation impact on ES is highest for Productive services - P1: production of animal / plant quantity and quality including biomass for energy, followed by E3: Soil organic matter status Figure 8).

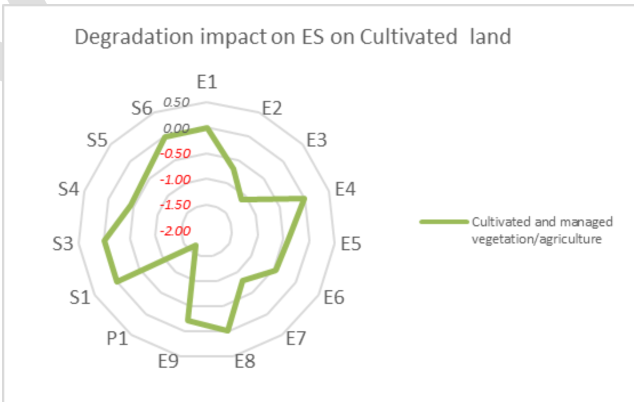


Figure 8: Impact of degradation on Cultivated land

Closed Forest exclusively shows biological degradation, with Bc (Reduction of vegetation cover / increase of bare land) occurring for more than 68% of the Evergreen and Bq (biomass decline) for about half of the Deciduous type. This is mainly caused by *Over-exploitation of vegetation for domestic use* and by *large-scale commercial forestry, mining* (specifically for Deciduous) and d*rought* (specifically for Evergreen). The degradation impact on Forest land is also highest for Productive services - P1, followed by E6 (nutrient cycle and carbon cycle) and E8 (Biodiversity) for the Evergreen type only (Figure 9).

Open Forest shows a higher diversity of degradation types than Closed Forest, dominated by water erosion (>50%) and followed by biological degradation and (deciduous only) some chemical degradation (Cp: pollution and Cn: loss of soil fertility and OM). Predominant causes are *deforestation*, *improper soil management* (exclusively Deciduous), *natural causes* and a few minor other ones. The degradation impact is high for E3 - Soil organic matter status (Deciduous type only), followed by E4 – soil cover, and quite low to zero for most other impact types (Figure 10).

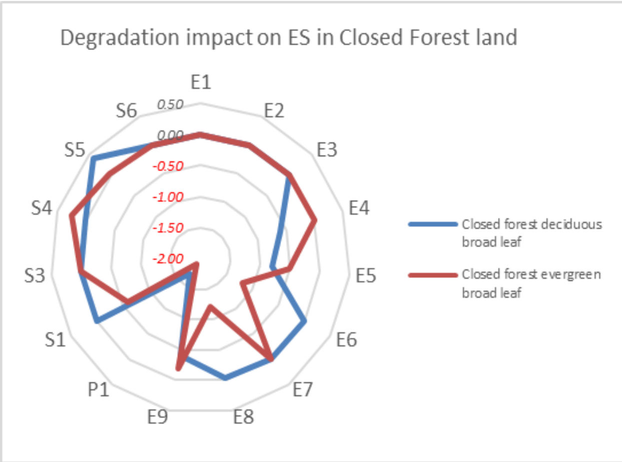


Figure 9: Impact of degradation on Closed Forest land

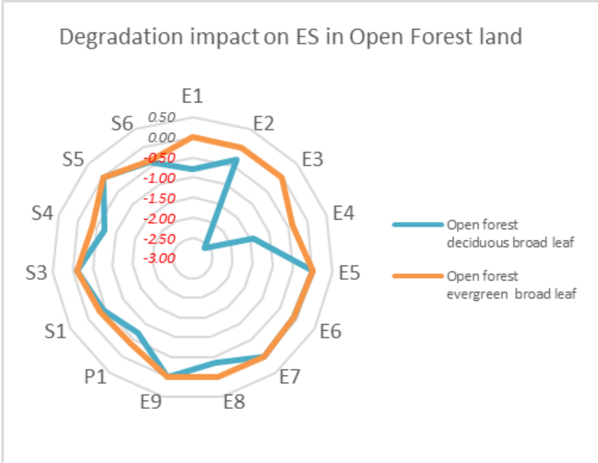


Figure 10: Impact of degradation on Open Forest land

Herbaceous land, for 85% occurring on steep land with medium elevation, is mainly affected by water erosion and biological degradation – the latter almost exclusively in combination. Most common causes are *Overgrazing*, *improper soil management* and *Deforestation.* As shown in Figure 11, here again the highest impact is on Productive Services (P1) and minor impacts on Ecological Services E2 (water), E5 (soil structure) and Socio-cultural service S6 (net income).

Shrub land, which occurs for nearly 90% on level land with low elevation, nevertheless shows a relatively high occurrence (>50%) of water erosion, followed by wind erosion (>25%), being the most widespread here of all land cover classes. The causes of degradation provided are diverse, such as *natural factors*, *overgrazing* and *inappropriate soil or crop management*. A relatively strong impact (1.8) is shown for E3: Soil organic matter status, followed by E8 – biodiversity (Figure 11).

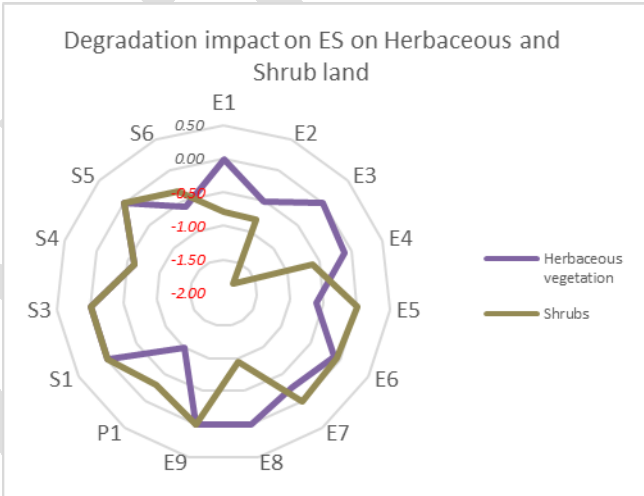


Figure 11: Impact of degradation on Herbaceous and Shrub land

Causes? *I find it very hard to find a way to assess the causes of degradation per degr. type, let alone for specific land cover/uses, as there can be combinations of 3 degr. types with a combination of 3 causes.*

3.1.3 *Sustainable Land Management*

Besides assessing the status of land degradation in a mapping unit contributors were also asked to provide information on actual land management aimed at reducing or controlling degradation (SLM). This broadly follows the same pathway as for degradation, i.e. determining the type of SLM (either as a Group of specific practices or defined by its technical implementation such as structural or agronomic measures), its extent, the effectiveness, trend in effectiveness and impact on ES.

The extent of degradation and of SLM do usually not counterbalance each other: it is well possible that a mapping unit with a small degraded area also has only little SLM, e.g. if natural conditions prevent degradation (though one could argue that stable natural conditions can also be considered a form of SLM). Table 3 shows that both Open Forest evergreen land and Shrubland have a high percentage of degradation coverage, as well as a high percentage of the area without SLM. However, Herbaceaous land has both a high area percentage which is degraded and 97% without SLM. Moreover in absolute terms this concerns by far the largest part of the country (mostly on steep land with medium elevation).

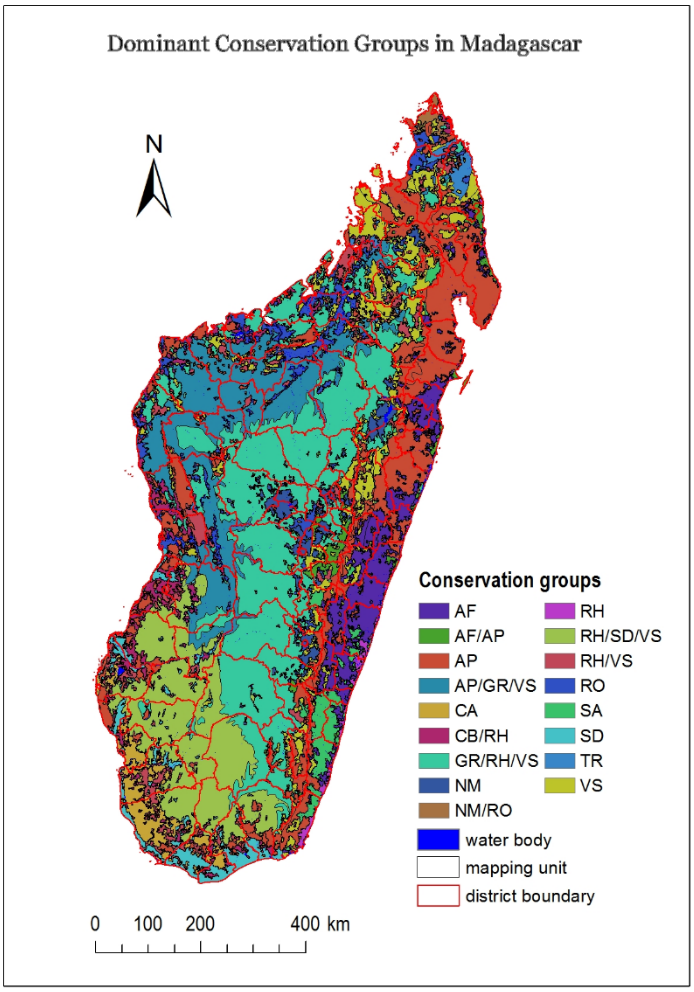
Table 3 Degraded and SLM % per LC-class

Row Labels	Deg_%	NoSLM%
Closed forest deciduous BL	62%	47.88%
Closed forest evergreen BL	22%	22.07%
Cultivated and managed vegetation/agriculture	65%	56.23%
Herbaceous vegetation	67%	97.04%
Open forest deciduous BL	67%	88.51%
Open forest evergreen BL	85%	90.07%
Shrubs	81%	85.42%
Water bodies		
Grand Total	63%	80.72%

Box 1: Conservation groups

Conservation technologies are clustered into groups which have names familiar to most SLM specialists and rural development specialists. The technology groups cover the main types of existing soil and water conservation systems.

AF: Agroforestry
AP: Afforestation and forest protection
CA: Conservation agriculture / mulching
CB: Coastal bank protection
CO: Conservation of natural biodiversity
GR: Grazing land management
NM: Manuring / composting / nutrient management
PR: Protection against natural hazards
RH: Gully control / rehabilitation
RO: Rotational system / shifting cultivation / fallow / slash and burn
SA: Groundwater / salinity regulation / water use efficiency
SC: Storm water control, road runoff
SD: Sand dune stabilization
TR: Terraces
VS: Vegetative strips / cover
WH: Water harvesting
WM: Waste management
WQ: Water quality improvements
OT: Other



Map 16: Dominant Conservation Groups and combinations

Map 16 shows the dominant Conservation Groups on the basis of effectiveness and extent. Although there is a wide range of groups and combinations, the combination GR/RH/VS emerges clearly on Herbaceous land in the steep, medium elevation central part of the country, with RH/SD/VS in the drier Southwestern part and AP/GR/VS in the central western part of Herbaceous land. Actually these are no real “combinations” in the sense that they occur in the same part of the mapping unit, but they all have the same weighted effectiveness and therefore no dominant group could be indicated. Moreover, the extent of SLM generally is very low, around 10%.

The Closed Forest Evergreen areas have a predominance of AP while Open Forest on the eastern coast mostly presents AF. The Shrubland in the southwest has a predominance of CA, with some SD.

In terms of overall area coverage, AP is by far the most widespread SLM technology group, mostly occurring on Closed Forest land (Figure 12). This also shows an overall rather high effectiveness (3) Cultivated land has mostly RO and NM. On Herbaceous land most used SLM technologies belong to VS, RH and GR groups, but as mentioned above SLM is applied on only a small percentage of the Herbaceous area.

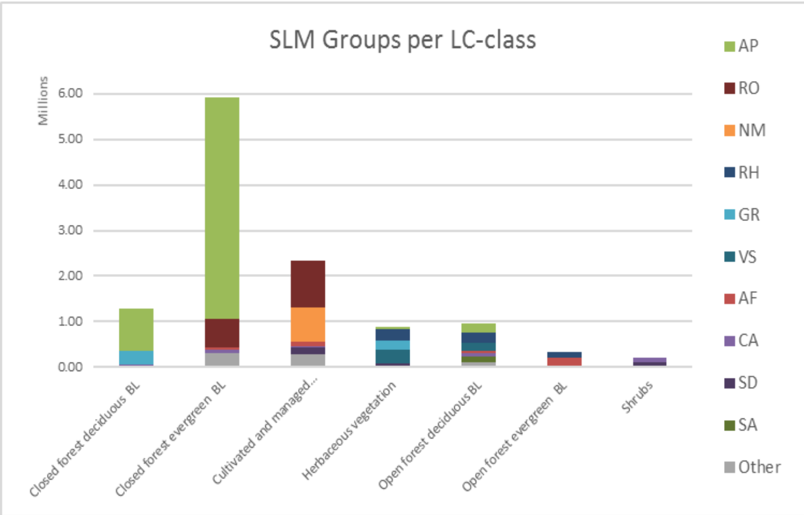


Figure 12: Distribution of SLM Groups per LC-class

Map 33 and Figure 13 show respectively the weighted effectiveness of conservation for the country as a whole and broken down per Land Cover class (not weighted). It is obvious that the overall effectiveness of conservation is low in the country, with the exception of Closed Forest Evergreen land in the (North)eastern part of the country (coinciding largely with Conservation Group AP).

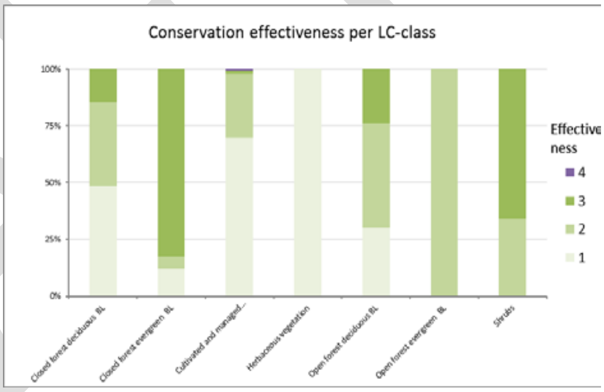
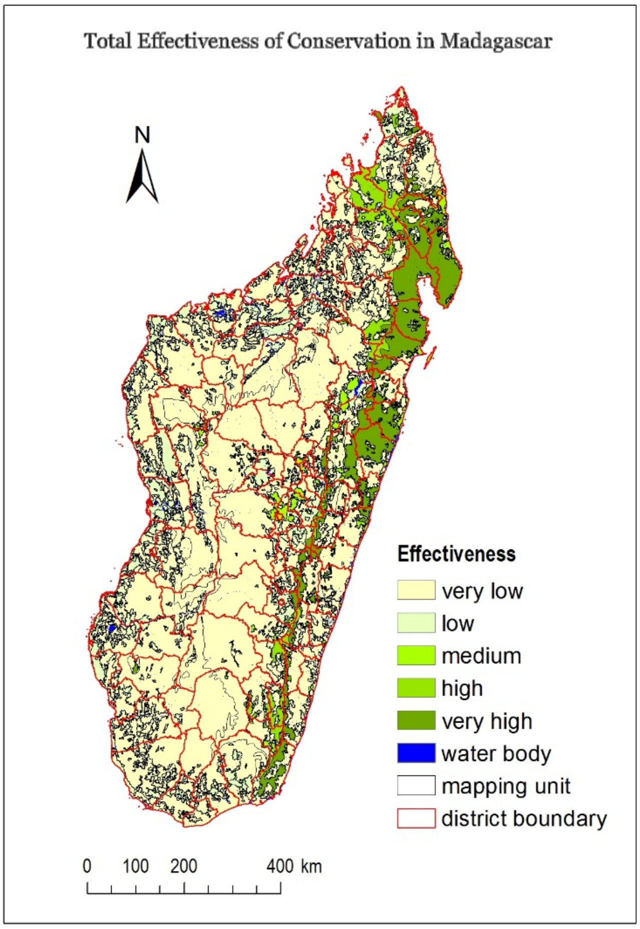


Figure 14: Effectiveness of SLM per LC-class



Map 17: Total effectiveness of SLM (sum of weighted effectiveness for all SLM per mapping unit)

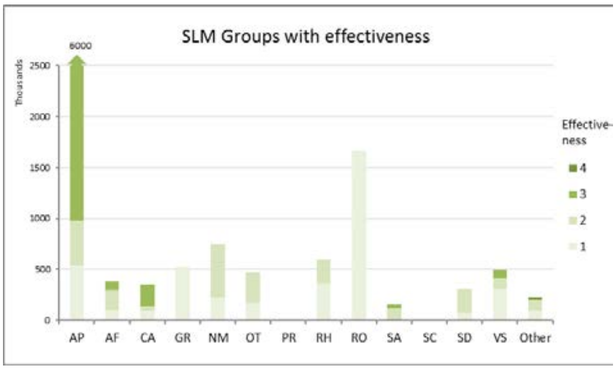


Figure 13: SLM Groups and their effectiveness

Figure 14 indicates that the highest effectiveness is seen in the AP group, mostly coinciding with the Closed Forest (Evergreen) land.

The trend in effectiveness of SLM (Conservation) has also been assessed (Figure 15), displaying a partly decreasing trend in effectiveness for Closed Forest

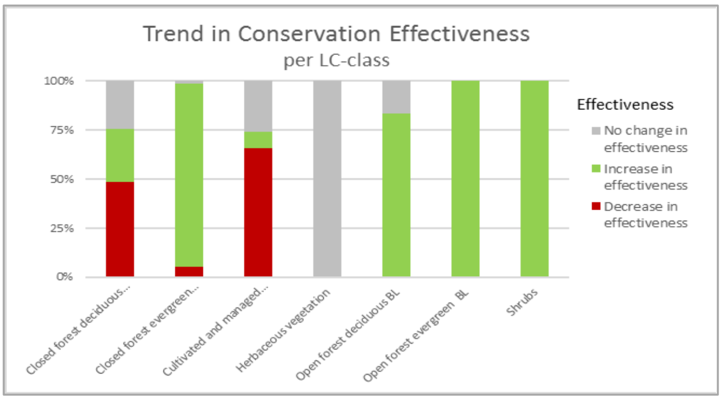


Figure 15: Conservation Effectiveness trend per LC-class

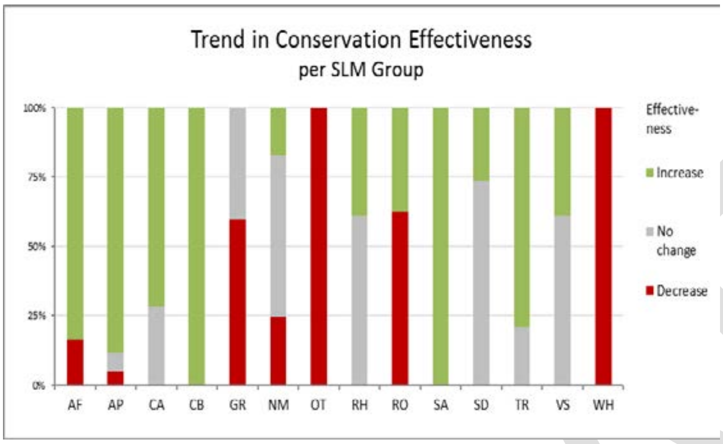


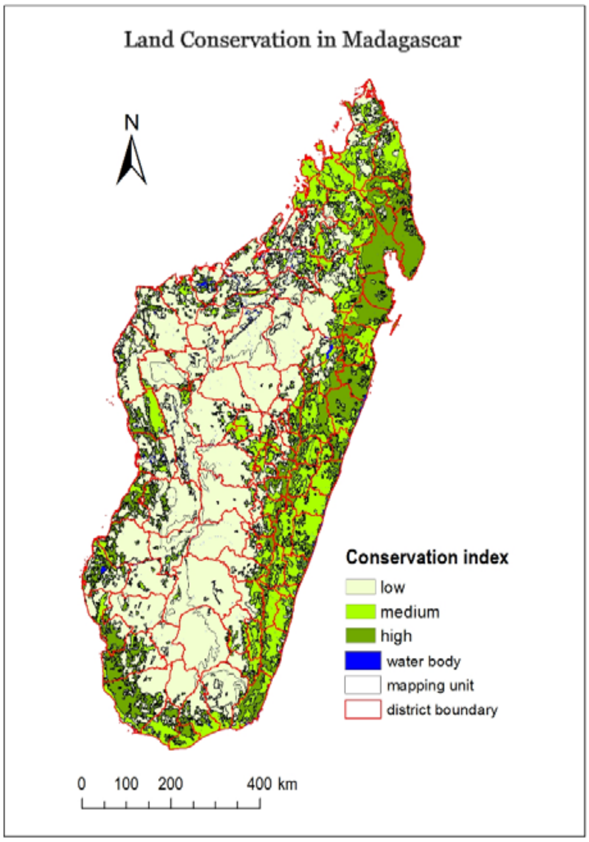
Figure 16: Conservation Effectiveness trend by SLM group

Deciduous (mainly GR and OT), and Cultivated land (mainly RO, WH OT and partly AF). For Herbaceous no change in effectiveness was indicated, whereas Closed Forest evergreen, Open Forest and Shrubland show an increase in effectiveness of SLM for almost all applied SLM .

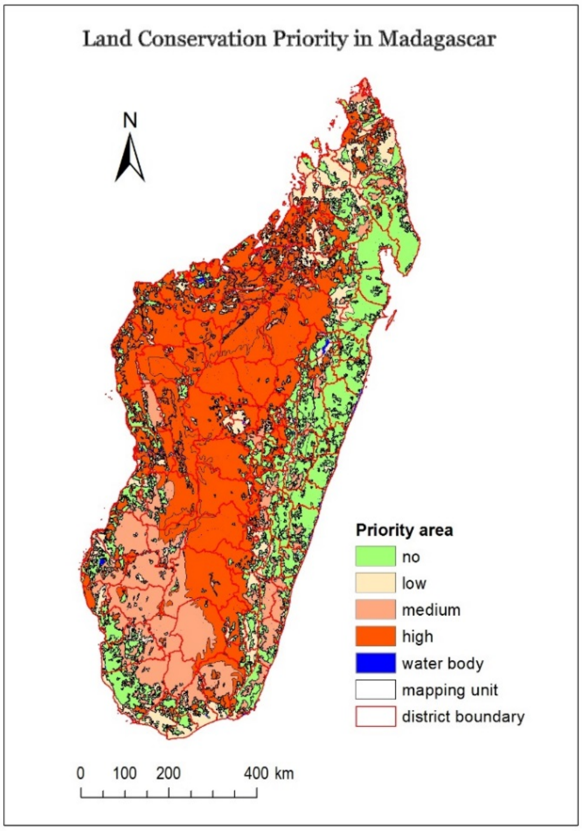
Broken down by SLM group (Figure 16) the trend in effectiveness is negative (decreasing) especially for WH (but this has only a minor occurrence) and for "Others", as well as partly for RO and GR, which already have a low effectiveness. Most positive increase is seen for CB (but minor occurrence) and SA, followed by AF and AP (both with a minor decreasing trend as well), CA and TR (minor occurrence)

A Conservation Index has been calculated similar to the Degradation Index, i.e. by combining extent, effectiveness, effectiveness trend and impact on ecosystem services (Map 20). This provides a slightly more positive picture than the Effectiveness map and shows that the eastern and southern edges of the county are the best protected by SLM.

The Degradation Index and Conservation Index can be combined into a Priority Index (Map 19), indicating the 'gap' between land degradation and conservation.



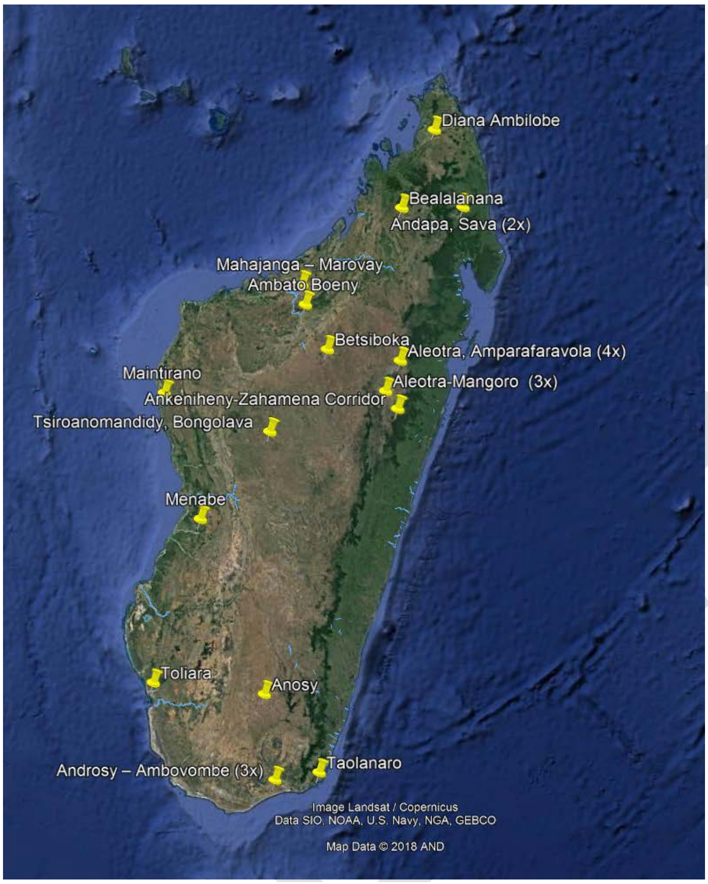
Map 18: Conservation Index



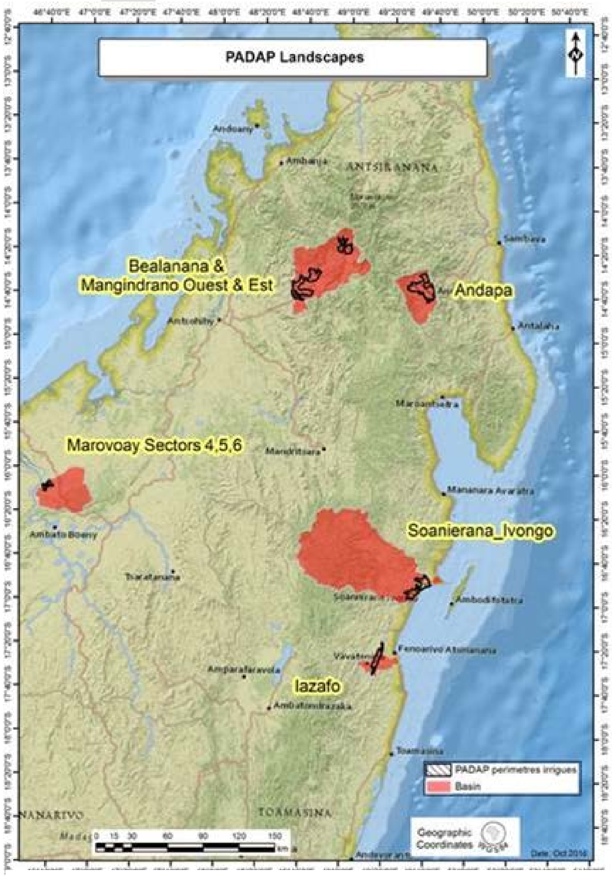
Map 19: Priority Index map

The Priority Index can also be used to identify areas for further study within this project, in combination with recommendations for such sites made by the experts during the workshop (Map 39). Factors like availability of good data and competent staff to participate in such detailed follow-up studies needs to be considered, as well as the location of study sites in the PADAP project (Map 40) – which may well fulfill some of these conditions. Relatively few recommendations by the experts consider the Herbaceous, steep medium elevation land, which comes out from the assessment as a major concern area.

Besides assessing the actual status of degradation and conservation, contributors were also asked to provide SLM recommendations. These were separated in Prevention, Mitigation and Rehabilitation recommendations. In the Prevention category suggestions were made, among others, for better law enforcement, rotational systems with adapted crops, area protection for biodiversity, better water regulation, increasing awareness, fire management and revegetation/reforestation. In the Mitigation category reforestation and revegetation is often mentioned, fertilisation, avoiding damage by mining and charcoal trade. For Rehabilitation much fewer suggestions were given, a.o. setting up nurseries, forest maintenance/management and dune stabilisation.



Map 20: Potential study site recommendations by the workshop participants



Map 21: PADAP Study sites

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Lindeque, L, 2009. Mapping land degradation and conservation in South Africa. Progress report of the LADA project. http://www.arc.agric.za/arc-iscw/Documents/LADA%20Project/LADANProgressReportFeb2009.pdf

Liniger, HP, GWJ van Lynden, F Nachtergaele, G Schwilch, 2008. A Questionnaire for Mapping Land Degradation and Sustainable Land Management

4 LAUREL Flying Sensors

1.1 Background and objectives
Flying Sensors (FSs) are bound to create a revolution in temporal and spatial remote sensing of agriculture and ecophysiology at a close range. Within the PADAP program it is foreseen that stakeholders will purchase FSs for information collection to support sustainable land management activities. Based on this, it was decided that a demonstration of the use of Flying Sensors and training on their use would be included in LAUREL activities.
The objective of the first training (Part I) was to offer an introduction on the use of Flying Sensors (FSs) with the focus on applications for land degradation and sustainable land management. The complete training course (Part I and II) consists of capacity building in the following areas:

- FS piloting skills
- Image processing skills
- Detecting land degradation with FSs
- Monitoring effects of sustainable land management interventions
- Correlating FS outputs to other land degradation monitoring tools and mapping methods

1.2 Practical details
The training on Flying Sensors took place in Antananarivo from 14 to 16 February 2018. The training was conducted by Jan van Til (FutureWater) with support of Tojo Rasolozaka (WWF aerial surveillance and drone specialist). A group of 11 persons was trained. The participants were mostly all engineers and active in land and water management in Madagascar. The training focused especially on FS piloting skills and image processing skills.

Field visits were organized on 14 and 16 February during which RGB and NIR images of a lavaka test area near Antananarivo were captured. The images were taken on an automated flight with the Sensy-M Flying Sensor. Impressions of the field visit are provided in Figures 1 and 2.

After the training was concluded, Jan van Til handed over one Sensy-M kit to Mr. Tojo Rasolozaka. This material will remain at the disposal of the LAUREL project for usage in Part II of the training.

Two training manuals were prepared in French and shared with all participants (Figure 3):
1. Manual Sensy-M
2. Manual Image Processing

A full report of the training is included in Annex IV.

Annex I: Mapping experts participating in the workshop

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Annex II: Degradation Types

ND: **<u>No degradation</u>**

W: ***<u>Soil erosion by water</u>***

Wt: **Loss of topsoil / surface erosion**
Loss of topsoil through water erosion is a process of more or less even removal of topsoil, generally known as surface wash or sheet / interrill erosion. Wt also includes tillage erosion. As nutrients are normally concentrated in the topsoil, the erosion process leads to impoverishment of the soil. Loss of topsoil itself is often preceded by compaction and/or crusting, causing a decrease in infiltration capacity of the soil, and leading to accelerated runoff and soil erosion.

Wg: **Gully erosion / gullying**
Development of deep incisions down to the subsoil due to concentrated runoff.

Wm: **Mass movements / landslides**
Examples of this degradation type are landslides and mudflows, which occur locally but often cause heavy damage.

Wr: **Riverbank erosion**
Lateral erosion of rivers cutting into riverbanks.

Wc: **Coastal erosion**
Abrasive action of waves along sea or lake coasts.

Wo: **Offsite degradation effects**
Deposition of sediments, downstream flooding, siltation of reservoirs and waterways, and pollution of water bodies with eroded sediments.

E: ***<u>Soil erosion by wind</u>***

Et: **Loss of topsoil**
This degradation type is defined as the uniform displacement of topsoil by wind action. It is a widespread phenomenon in arid and semi-arid climates, but it also occurs under more humid conditions. Wind erosion is nearly always caused by a decrease in the vegetative cover of the soil. In (semi)arid climates natural wind erosion is often difficult to distinguish from human-induced wind erosion, but natural wind erosion is often aggravated by human activities.

Ed: **Deflation and deposition**
Uneven removal of soil material by wind action. Leads to deflation hollows. It can be considered as an extreme form of loss of topsoil, with which it usually occurs in combination.

Eo: **Offsite degradation effects**
Covering of the terrain with windborne particles from distant sources ("overblowing"). Includes air pollution from mining activities e.g. mining dust, asbestos etc.

C: ***<u>Chemical soil deterioration</u>***

Cn: **Fertility decline and reduced organic matter content**
Aside from loss of nutrients and reduction of organic matter as a result of topsoil removal by erosion, a net decrease of available nutrients and organic matter in the soil may also occur due to “soil mining”: nutrient outputs (through harvesting, burning, leaching, etc.) are not or insufficiently compensated by inputs of nutrients and organic matter (through manure / fertilizers, returned crop residues, flooding). This type also includes nutrient oxidation and volatilisation.

Ca **Acidification**
Lowering of the soil pH, eg due to acidic fertilisers or atmospheric deposition.

Cp: **Soil pollution**

Contamination of the soil with toxic materials. This may be from local (e.g. waste dumps) or diffuse sources (atmospheric deposition).

Cs: Salinisation / alkalinisation
A net increase of the salt content of the (top)soil leading to a productivity decline.

P: ***Physical soil deterioration***

Pc: Compaction
Deterioration of soil structure by trampling or the weight and/or frequent use of machinery.

Pk: Sealing and crusting
Clogging of pores with fine soil material and development of a thin impervious layer at the soil surface obstructing the infiltration of rainwater. Development of a water-repellent layer (eg beneath surface ashes after forest fire).

Pw: Waterlogging
Effects of human induced water saturation of soils (excluding paddy fields).

Ps: Subsidence of organic soils, settling of soil
Drainage of peatlands or low lying heavy soils.

Pu: Loss of bio-productive function due to other activities
Some land use changes (e.g. construction, mining) may have implications for the biological and productive function (e.g. agricultural production) of the soil and hence a degradation effect.

H: ***Water degradation***

Ha: Aridification
Decrease of average soil moisture content (reduced time to wilting, change in phenology, lower yield).

Hs: Change in quantity of surface water
Change of the flow regime: flood / peak flow, low flow, drying up of rivers and lakes.

Hg: Change in groundwater / aquifer level
Lowering of groundwater table due to over-exploitation or reduced recharge of groundwater; or increase of groundwater table e.g. due to excessive irrigation resulting in waterlogging and/or salinisation.

Hp: Decline of surface water quality
Increased sediments and pollutants in fresh water bodies due to point pollution (direct effluents eg from industry, sewage and waste water in river water bodies) and land-based pollution (pollutants washed into water bodies due to land management practices eg sediments, fertilizers and pesticides).

Hq: Decline of groundwater quality
Due to pollutants infiltrating into the aquifers. Human induced pollution is mainly caused by inappropriate land management practices or deposition of waste.

Hw: Reduction of the buffering capacity of wetland areas
To cope with flooding and pollution.

B: ***Biological degradation***

Bc: Reduction of vegetation cover
Increase of bare / unprotected soil (including duration of exposure).

Bh: Loss of habitats
Decreasing vegetation diversity (fallow land, mixed systems, field borders).

Bq: Quantity / biomass decline
Reduced vegetative production for different land use (e.g. on forest land through clear felling, secondary vegetation with reduced productivity).

Bf: Detrimental effects of fires
On forest (eg slash and burn), bush, grazing and cropland (burning of residues). This includes low severity ("cold") fires (only understory burns, trees survive) and high severity ("hot") fires (reach the crown of the trees and may kill them).

Bs: **Quality and species composition / diversity decline**
Loss of natural species, land races, palatable perennial grasses; spreading of invasive, salt-tolerant, unpalatable, species / weeds.

Bl: **Loss of soil life**
Decline of soil macro-organisms (earthworms and termites) and micro-organisms (bacteria and fungi, …) in quality and quantity.

Bp: **Increase of pests / diseases**
Reduction of biological control (e.g. trough loss or predators).

Annex III: Expert requirements for National Mapping

For the mapping at national level, a small group of experts is envisaged to jointly discuss and agree on the status of degradation and SLM in the mapping units defined in the base map. For a smooth and effective process during the workshop and a good result, it is essential that the experts will meet the criteria below.

- **Good knowledge of Land Degradation and SLM with a broad (national) overview** is crucial.
- Ability to generalize LD & SLM data and break them down per (Land Use) mapping unit.
- Understanding of mapping principles: GIS expertise is an advantage but not essential.
- Experts should represent at least one main land use classes in the country. For example, in Madagascar, natural forests are important, then you need someone in the group with knowledge and experience about forests. The same apply for the other main land use classes according to the base or stratification map.
- Experts should have studied the Mapping method ("Questionnaire on Mapping" / Questionnaire pour la cartographie de la dégradation et de la gestion durable des terres (QM)) in advance, prior to the workshop.
- **A group of different experts and with different (institutional) backgrounds**, working in close consultation, is much preferable to one single expert doing the national assessment.
- A group of **5 to a maximum of 10** experts seems most workable (depending on their knowledge regarding part or whole of the country). Including some **experts from (and with knowledge of) different regions** is recommended.
- The required task will consist of a 2(?) day training/workshop, followed by individual and group work (2-3 days) to reach consensus about the state of degradation/ conservation in different mapping units. The international experts will give the training and provide guidance during the mapping exercise.
- Experts should bring their own computer (laptop) with (possibility to) Internet connection
- All contributing experts will be properly acknowledged as (co-)author in the technical report and other subsequent publications.

Annex IV: Flying Sensor Training Report

LAUREL Flying Sensor Training Part I: Lavaka Monitoring

Training report

Antananarivo, 14-16 February 2018

Authors:
Jan van Til
Gijs Simons

Client:
World Bank

Location training:
World Bank Office, Antananarivo, Madagascar
Antananarivo lavaka test site

Location flight operations:
Antananarivo lavaka test site

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HiView

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Table of contents

1 Introduction

1.1 Background and objectives

Flying Sensors (FSs) are bound to create a revolution in temporal and spatial remote sensing of agriculture and ecophysiology at a close range. Within the PADAP program it is foreseen that stakeholders will purchase FSs for information collection to support sustainable land management activities. Based on this, it was decided that a demonstration of the use of Flying Sensors and training on their use will be included in LAUREL activities.

The objective of the first training (Part I) was to offer an introduction on the use of Flying Sensors (FSs) with the focus on applications for land degradation and sustainable land management. The complete training course (Part I and II) consists of capacity building in the following areas:

- FS piloting skills
- Image processing skills
- Detecting land degradation with FSs
- Monitoring effects of sustainable land management interventions
- Correlating FS outputs to other land degradation monitoring tools and mapping methods

1.2 Practical details

In the framework of the LAUREL program (supported by World Bank) a training on Flying Sensors took place in Antananarivo from 14 to 16 February 2018. The training was conducted by Jan van Til (FutureWater) with support of Tojo Rasolozaka (WWF aerial surveillance and drone specialist). A group of 11 persons was trained. The participants were mostly all engineers and active in land and water management in Madagascar (see list of participants in Appendix II). The training focused especially on FS piloting skills and image processing skills.

Field visits were organized on 14 and 16 February during which RGB and NIR images of a lavaka test area near Antananarivo were captured. The images were taken on an automated flight with the Sensy-M Flying Sensor. Impressions of the field visit are provided in Figures 1 and 2. Appendix I contains the full training program.

After the training was concluded, Jan van Til handed over one Sensy-M kit to Tojo Rasolozaka.

- The Sensy-M kit comprises:
- Mavic Pro quadcopter
- Batteries (3x)
- NIR camera
- Tablet (Samsung Tab A 2016)

This material will remain at the disposal of the LAUREL project for usage in Part II of the training.

Two training manuals were prepared in French and shared with all participants (Figure 3):

1. Manual Sensy-M
2. Manual Image Processing

Figure 1. Training at the lavaka test site near Antananarivo

Figure 2. Lavaka test site near Antananarivo

Figure 3. Manuals prepared for the training.

Figure 4. The training took place in the World Bank office

1.3 Location of lavaka test site

As recommended by WWF Madagascar, the field demonstration was organized at a location to the south east of Antananarivo, where land degradation has resulted in the occurrence of a lavaka.

Figure 5. Location of the lavaka test site

Figure 6. Lavaka test site

2 Results

2.1 Single images

This paragraph demonstrates some of the images captured during the field visits.

Flight operations details

Flying Sensor: Sensy-M
Area: lavaka test site near Antananarivo (490x 290m)
Sensors: RGB & NIR cameras
Flight number: 20180214_F01
Flight date: 14 February 2018

Sensor details

At F01 (flight 1) both RGB (Red Blue Green) and NIR (Near InfraRed) images were taken.
Number of RGB images: 118
Number of NIR images: 90
Resolution: 12 MP, 4000x3000. GSR: 3,5 cm

Figure 7. Single RGB image, lavaka test site 20 m

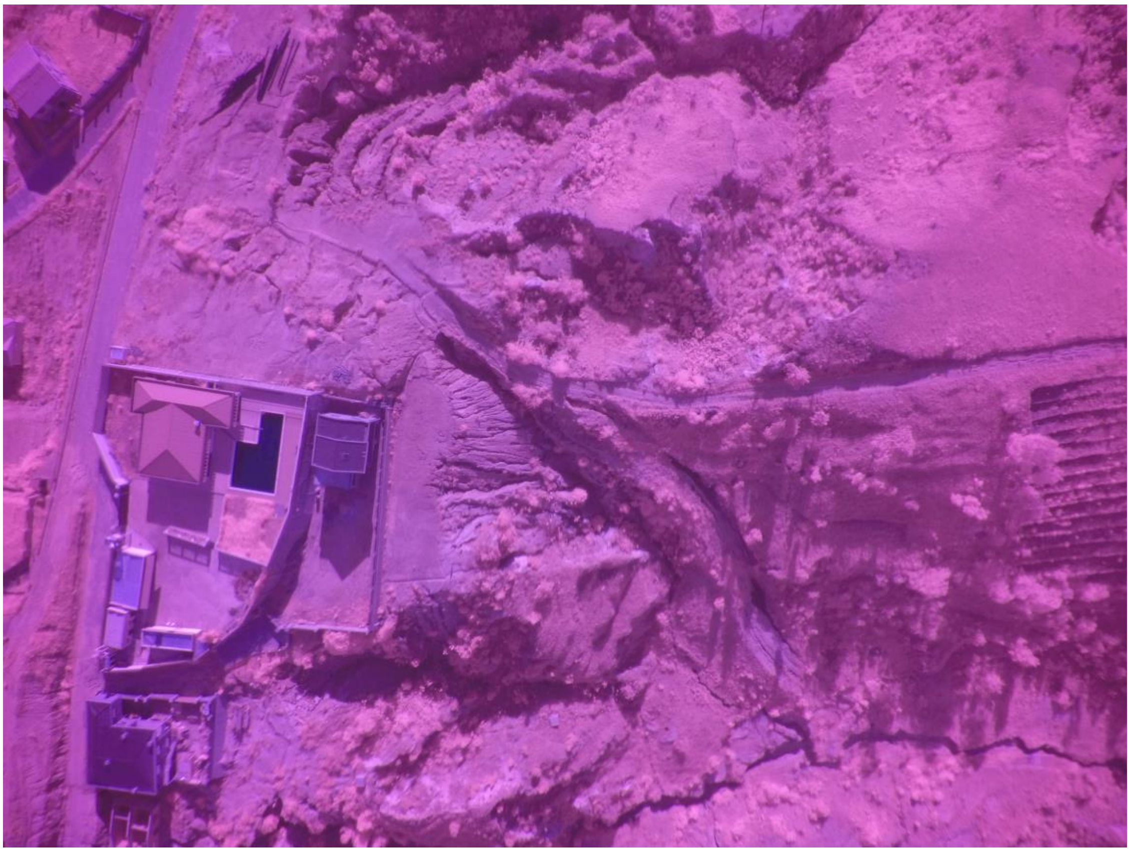


Figure 8. Single NIR image, lavaka test site

20 m

2.2 Processed images

The “raw” images can be processed into different derived products, which can subsequently be applied for different purposes related to land degradation and sustainable land management. Examples of processed images are given below.

1. Orthomosaic RGB, below referred to as Ortho RGB
2. Orthomosaic NIR, below referred to as Ortho NIR
3. Rough DEM/DSM, below referred to as DEM
4. 3D model, below referred to as 3D Model
5. KMZ/KML, below referred to as KML
6. Normalized Difference Vegetation Index map, below referred to as NDVI map
7. Land cover classification map, below referred to as land cover map

Figure 9. Ortho RGB, lavaka test site

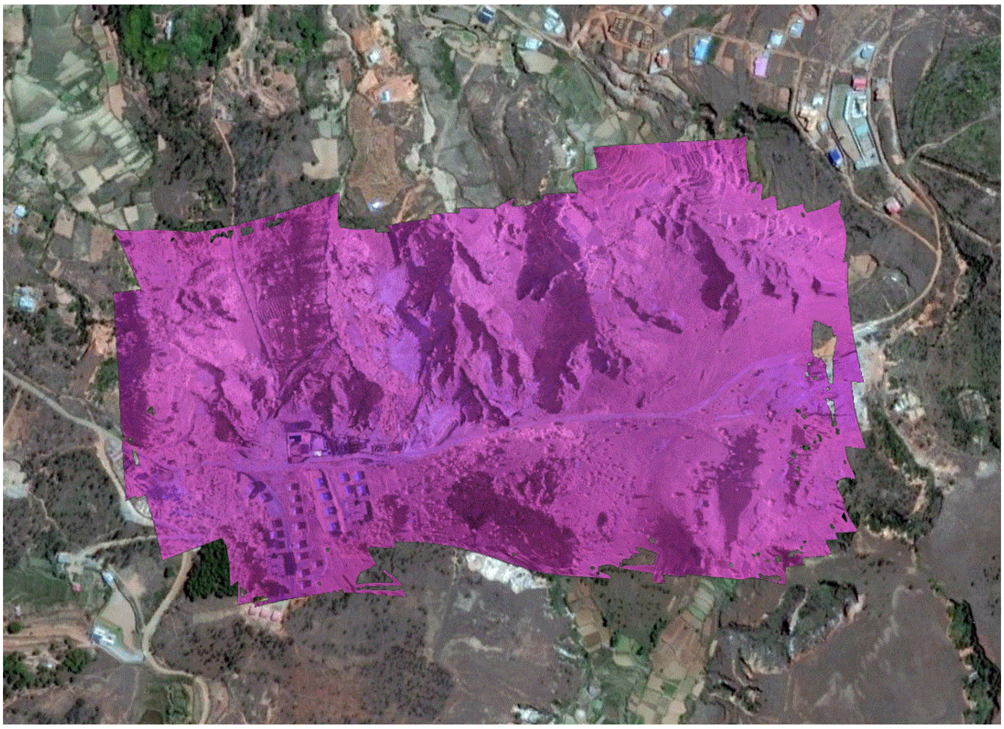


Figure 10. Ortho NIR, lavaka test site projected in Google Earth

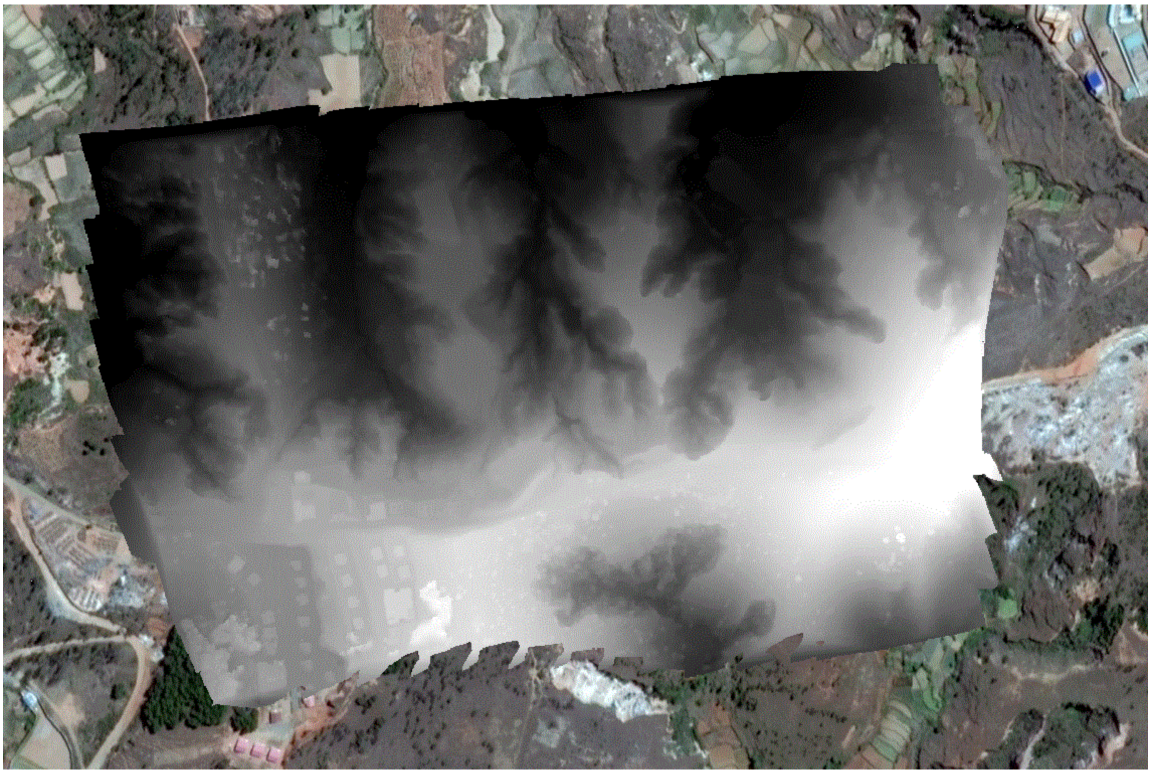


Figure 11. Rough DEM, lavaka test site projected in Google Earth 100 m

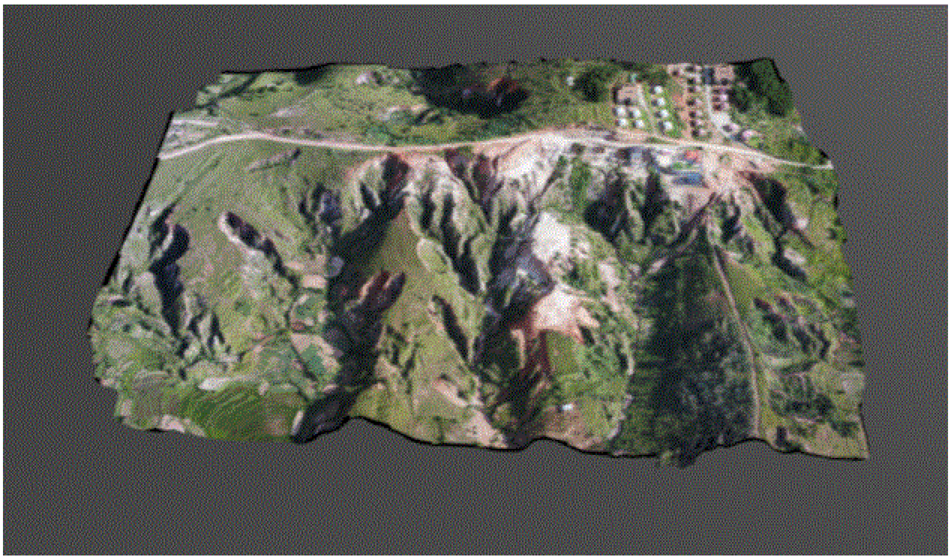


Figure 12. 3D model, lavaka test site 200 m

For an interactive high-resolution 3D model view of the lavaka, see online:

https://sketchfab.com/models/daac1275b064475a9a5273b0e672e4a3

Figure 13. KMZ/KML, lavaka test site projected in Google Earth

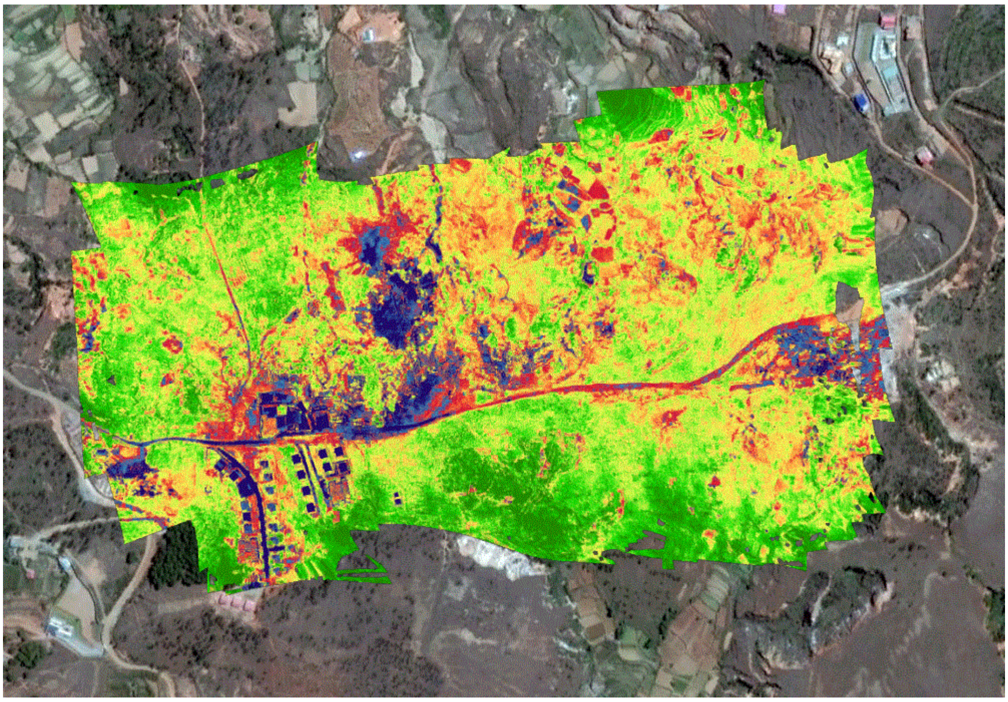


Figure 14. NDVI map, lavaka test site projected in Google Earth

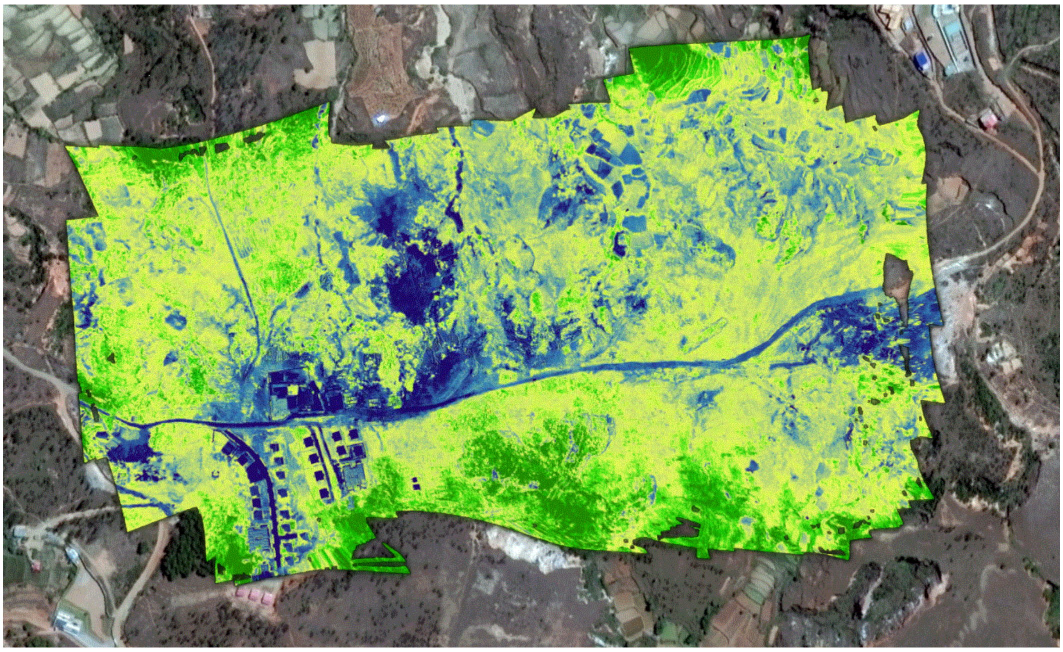


Figure 15. Vegetation cover map, lavaka test site projected in Google Earth. Supervised classification based on NDVI image.

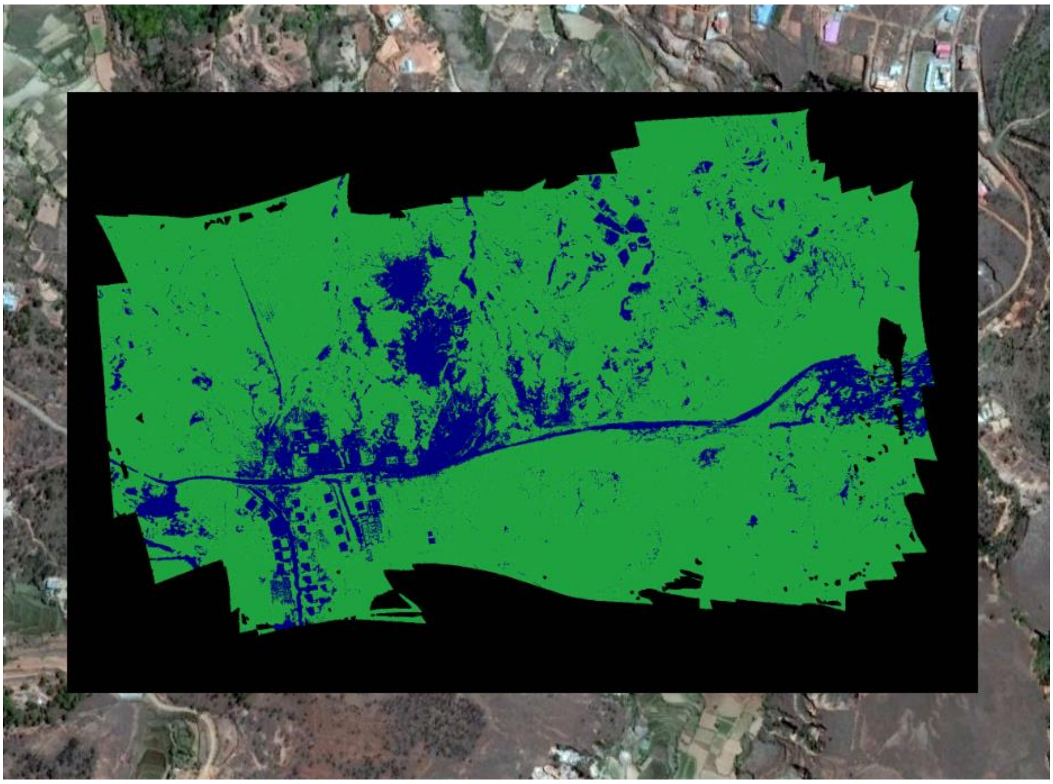
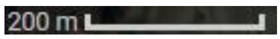


Figure 16. Vegetation map (blue = bare, green = vegetation cover), projected in Google Earth. Supervised classification based on NIR image.



3 Applications and benefits of processed images

The previous chapter demonstrates a number of derived products from FS imagery, all having very high resolution due to observation of the land surface from a relatively short distance. Each processed mosaic, map or model has its own features and potential applications. Different parameters can be determined, such as volume, vegetation conditions, soil conditions and land cover type. Within the context of land and water management in Madagascar, relevant applications include especially:

- inspection of forestry (e.g. illicit deforestation)
- inspection land degradation
- inspection of coastline degradation
- inspection of vegetation

Table 1 shows an overview of FS-derived products, their resolution and example applications.

Table 1. Derived products of FS images and their relevant applications

Description	*Example applications*	*Resolution*
Ortho RGB	Overview image Visual inspection Deriving inputs for biophysical model	Max GSR: 2 cm Common GSR: 10 cm
Ortho NIR	Input for NDVI	Max GSR: 2 cm Common GSR: 10 cm
NDVI map	Vegetation stress diagnosis Assessment lavaka maintenance Assessment bare soil Input for biophysical model	Max GSR: 2 cm Common GSR: 10 cm
Land cover map	Vegetation classification Forestry Land use / land cover change assessment Input for biophysical model	Max GSR: 2 cm Common GSR: 10 cm
DEM	Damage inspection Lavaka volume assessment Evaluating SLM practices / terracing Input for biophysical model	Max x-y res. 5 cm; z res. 5-10 cm Common x-y res. 10 cm; z res. 10-20 cm
3D model	Visualization / dissemination Inspection tool for decision makers	Max x-y res. 5 cm; z res. 5-10 cm Common x-y res. 10 cm; z res. 10-20 cm
KMZ /KML	Localization in Google Earth Visualization / dissemination	Max x-y res. 5 cm; z res. 5-10 cm Common x-y res. 10 cm; z res. 10-20 cm

Within LAUREL, FSs do not only hold potential for monitoring and mapping land degradation, but they also yield valuable data that can be put to use in LANDSIM-P, the modeling component of the project. Notable biophysical model inputs that can be derived from FS imagery include stone cover of the land surface, plant diameter, and vegetation density. A location- and land cover type-specific assessment of these parameters will improve the dynamic modelling of erosion processes by LANDSIM-P, which would otherwise rely on generic literature values.

4 Evaluation and recommendations

At the end of the training, the experiences of the participants were discussed and evaluated. The following points list the most notable feedback from the group:

- The training participants are enthusiastic about the new technology and its great potential. They think it might be very useful to deploy Flying Sensors (FSs) in their professions, for tasks like surveillance, monitoring hotspots of LD, monitoring status of forestry. The participants have experienced the use of FSs and the processing of ortho-mosaics as user-friendly. They were interested to learn more. They were planning to do home studies on processing with the help of the supplied manuals.
- The group came up with the idea to mount other sensors on the FS. That would be a good idea, as long as the sensor is not too heavy. The payload of FS Sensy-M is max. 300 grams.
- Members of the PADAP team suggested that it will be necessary to perform flights at one of the PADAP hotspots. For this purpose a multi-day trip should be organized. This is according to the intentions of the LAUREL team for the second part of the training.
- The presently used FSs are good for medium-sized tasks, but fall short for large- scale monitoring operations. This can partly be solved by establishing the connection with RS. In the long term, it may be an interesting option to explore an upgrade to bigger FSs that can carry out flights with larger range.
- Everybody is looking forward to the continuation of the training (part II) in which we will focus on:
    - Continuation with piloting skills
    - Advanced image processing
    - Exploring further applications based on processed maps and models

Based on discussions with the participants and observations during the training, we further recommend the following:

- Consider other sensors like thermal or lidar. Preferably user-friendly and low budget;
- Consider using a train-the-trainers approach in the next training;
- Organize a multi-day field trip to PADAP hotspots for flight operations to collect the first specific data for the PADAP sites. Preferably in accordance with other LAUREL activities on land degradation during the next mission;
- The needs for the FS training part II should be established in close consultation with the other LAUREL land degradation experts;
- More powerful FS for larger-scale operations may provide added value for the PADAP land degradation monitoring requirements. This will be further explored during the next training session at one of the PADAP sites;
- The following training objectives will need to receive further attention during Part II of the training:
- Detecting land degradation
- Monitoring effects of SLM interventions
- Relating FS outputs to existent land degradation monitoring tools and mapping methods

Appendix I: Training program

Day 1, Wednesday 14 February

Morning

- Preparatory discussions with training supervision team
- Technical preparations: mounting NIR Cam

Afternoon

- Technical preparations: mounting NIR Cam
- Preparatory field visit (FutureWater and WWF) to land degradation hotspot, 8 km SE from downtown Antananarivo
  - Exploration of the area for field visit of Friday 16 February
  - Conducting flights in order to collect images from LD hotspot

Day 2, Thursday 15 February, 8.00-17.00h. Location: office WB
(in French, as shared with participants)

8.00-10.00h Introduction sur FSs

- Introductions de l'équipe de formateur' et des participants
- Historique et vue d'ensemble et présentation des activités de FutureWater et HiView
- FSs: plateformes volantes & capteurs; applications diverses

10.00-10.30h Pause

10.30-12.00h Introduction au Flying Sensor SENSY-M, à l'aide d'un manuel

Le SENSY-M est un quadcopter équipé de deux capteurs : visuel et NIR (NearInfraRed, autrement dit capteur en proche rouge)

12.00-13.00h Déjeuner

13.00-15.00h Suite de l'introduction au Flying Sensor SENSY-M : vols automatiques

Suivi par un court discours sur les activités opérationelles

- Pre-site (préparations, réglementation, listes de vérification)
- On-site (sécurité, préparations, activité de voler)
- Post-site (stockage data, rapportage, postcure)

15.00-15.30h Pause

15.30-17.00h Introduction à quelques traitements d'images

- Orthophotographies
- Cartes de l'indice NDVI (Normalized Difference Vegetation Index)
- Modèles numériques d'élévation (Digital Elevation Models, DEMs)

Day 2, Friday 16 February, 8.00-17.00h. Location: lavaka test site (morning), office WB (afternoon)

8.00-13.00h Visite du site de démonstration.

Localisation : Alasora, sur la route des lotissement IMV

En première partie les participants prendront part aux exercices fonciers du pilotage manuel du FS.

Ensuite, des vols automatiques (à l'aide d'une tablette ou d'un smartphone) seront démontrés ayant pour objectif l'acquisition d'images aériennes en relation avec la dégradation des sols.

13.00-14.00h	Déjeuner et retour au bureau de la Banque Mondiale WB
14.00-16.00h	Traitement des images captées durant le vol de démonstration.
16.00-16.30h	Pause
16.00-17.00h	Evaluation de l'entraînement. Prévision sur la session suivante.

Appendix II: List of participants

	Nom	Profil	Poste occupé/Organisation
01	Herinarivo Razafindralambo	Ingénieur agronome	Assistant technique des opérations/PADAP ; herinarivo@yahoo.fr
02	Andraina Rajemison	Ingénieur forestier	Responsable environnement/foresterie/PADAP ; andrainarajemison@gmail.com
03	Mamy Rasolofoarivony	Ingénieur forestier	Assistant en sauvegarde environnementale et sociale/PADAP ; rasolofoarivonymamy85@gmail.com
04	Fabienne Randrianarisoa	Géographe	Responsable SIG/PADAP ; fabi.msis@gmail.com
05	Tojo Rafidimanantsoa	Ingénieur hydraulicien	Responsable Eau et irrigation/PADAP ; rafidimanantsoa@yahoo.fr
06	Ollier Duranton Andrianambinina	Ingénieur informaticien	Administrateur du système d'information/MNP ; adsi@madagascar.national.parks.mg;
07	Jean Michel Ravoninjatovo	Ingénieur forestier	Collaborateur technique/BNCREDD ; ravoninjatovoj@yahoo.fr
08	Fameno Tahiana Ranaivoson	Géographe	Direction de l'Intégration de la Dimension Environnementale/MEEH ; famenotahiana@gmail.com
09	Noelson Laingo Herizo Randriamasinoro	Ingénieur géomètre topographe	Observatoire de l'aménagement du territoire/M2PATE ; nixonnoelson@gmail.com
10	Rakotondranivo Mihary Nantenaina	Ingénieur forestier	Collaborateur auprès de la Direction Contrôle Forestier/MEEF ; miharynantenaina@yahoo.fr
11	Haja Rabeharisoa	Ingénieur hydraulicien	Chef de service irrigation/MPAE ; hazjah@yahoo.fr