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Land degradation in Switzerland. An application of the Trends.Earth model

Report presented by

Thanh Diu-Celeste TRAN

Supervisor: Gregory GIULIANI

Jury: Hy DAO

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Abstract

Land degradation is a matter of international interest: the protection and restoration of soils is crucial to preserve biodiversity and ecosystem services which affect human quality of life. The Millennium Ecosystem Assessment (2005) affirmed that over 2 billion people live in dry areas and that 20% of this ecosystem was degraded; while, recently, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) reported that approximately 3.2 billion people across the World are currently affected by the effects of land degradation. Concerning the European Union, in 2013 the Joint Research Centre pointed out that 85.1% of the total EU area was not affected by land productivity decline, 7.9% showed a stable but stressed land productivity, 5.6% showed early signs of decline, while 1.5% was declined (6 037 500 ha).

The United Nations Convention to Combat Desertification (UNCCD) developed a conceptual framework in order to support countries to achieve the Goal 15 “Life on Land” of the Sustainable Development Goals (SDGs). This includes the report of the indicator 15.3.1 (“portion of land that is degraded over total land area”). Earth Observations (EO) and Geographic information Systems (GIS) might serve as powerful tools to monitor and map land degradation by computing the 15.3.1 indicator. On this issue, the Conservation International developed the Trends.Earth plug-in – available in QGIS – which allows the monitoring of land change (i.e. changes in land productivity, land cover, soil organic carbon, etc.).

This paper has a double aim: 1) to explore Trends.Earth model, investigate its sensibility and scientific pertinence and to compare it with the UNCCD model presented in the Good Practice Guidance (GPG); 2) to tackle and provide an overview of land degradation in Switzerland. This land degradation was estimated by using the Trends.Earth plug-in, once with the UNCCD model and once with the Trends.Earth dataset. Finally, according to the UNCCD model, 9.7% of total Swiss land area was degraded, 52.5% was stable and 33.4% was improved. Similar results were obtained with the Trends.Earth model: 13% was degraded, 61% was stable and 21.5% was improved.

The exploration of the Trends.Earth plug-in allowed to ascertain the usefulness of remote sensing tools in tracking the progress towards the Land Degradation Neutrality (LDN) with an approach which is neither time nor cost-consuming. However, the model does not provide any local knowledge for the interpretation of the results. Nevertheless – as the implementation of the indicator highly depends on regular data generation and this availability changes depending on the capacities of the countries – Trends.Earth can avoid the lack of geospatial data.

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List of acronyms

ARE	Federal Office for Spatial Development
CBD	Convention on Biological Diversity
CCI-LC	Climate Change Initiative Land Cover
CRS	Coordinate Reference System
EFU	Ecosystem functional unit
ESA	European Space Agency
ET	Evapotranspiration
EU	European Union
FAO	Food and Agriculture Organization

FDFA	State Secretariat for the Federal Department of Foreign Affairs
FI	Factor of input to soil
FLU	Factor of Land Use
FMG	Factor of Management practice
FOAG	Federal Office for Agriculture
FOEN	Federal Office for the Environment
FOPH	Federal Office for Public Health
FOPP	Federal Office for the Protection of the Population
FSO	Federal Statistical Office
GEE	Google Earth Engine
GEF	Global Environment Facility
GPG	Good Practice Guidance
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
JRC	Joint Research Centre
LC	Land cover
LCCS	Land Cover Classification System
LCML	Land Cover Meta Language
LDN	Land Degradation Neutrality
LNS	Local Net Scaling
LPD	Land Productivity Dynamics
LU	Land Use
MONET	Sustainable Development Monitoring
NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
NIR	Near Infrared
NPP	Net Primary Productivity
RESTREND	Residual Trend Analysis
RUE	Rain Use Efficiency
SDC	Swiss Agency for Development and Cooperation
SDGs	Sustainable Development Goals
SEM	State Secretariat for Migrations
SIF	State Secretariat for International Finance
SLM	Sustainable Land Management

SOC	Soil organic carbon
UNCCD	United Nations Convention to Combat Desertification
UNCCD-GM	United Nations Convention to Combat Desertification Global Mechanism
UNFCCC	United Nations Framework Convention on Climate Change
WAD	World Atlas of Desertification
WUE	Water Use Efficiency

1 Introduction

Life on Earth is assured by soils, which provide land resources such as water, food and materials. However, land productivity is deteriorating and soils are threatened by population and economic growth: demand on global land resources proportionally increases with world's population growth and changes in consumption patterns (Gonzalez-Roglich et al., 2019; Montanarella et al., 2016). Land degradation is a complex and multifaceted phenomenon that concerns all parts of the terrestrial world (IPBES, 2018) and has economic and socio-political consequences varying within space, scale and context (Cherlet et al., 2013). Competing for land use – considering the actual context of climate change – will exacerbate food insecurity and poverty and lead to social and political conflicts.

The Millennium Ecosystem Assessment (2005) affirmed that over 2 billion people live in dry areas – drylands cover about 41% of the Earth's land surface (FAO, 2016) – and that 20% of this ecosystem is degraded. Moreover, according to the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES, 2018), loss of ecosystem services and biodiversity through land degradation is already impacting the well-being of 3.2 billion people. From 1999 to 2013, one fifth of the Earth's land covered by vegetation showed declining productivity trends: 24 million km^2 of land are impacted (UN, 2018).

Concerning the European Union (EU), key drivers of land degradation are linked to an inappropriate intensification of agriculture, soil sealing, ecosystem fragmentation, pollution and increased frequency of climatic extremes and meteorological events, agro-silvo-pastoral land abandonment, etc. (Cherlet et al., 2013). Consequences are reported by the Joint Research Centre (JRC) (Cherlet et al., 2013): 85.1% of the total EU area is not affected by land productivity decline, 7.9% shows a stable but stressed land productivity, 5.6% shows early signs of decline, while 1.5% is declined (6 037 500 ha). The percentage of early signs of a decline increases up to 10% (about 2 million ha) if only the most productive soils in the EU are considered (Cherlet et al., 2013).

In the light of these numbers and facts, the struggle to keep land in a healthy state is a matter of worldwide interest. The concept of Land Degradation Neutrality (LDN) was developed and defined as "*a state whereby the amount and quality of land resources necessary to support ecosystem functions and services and enhance food security remain stable or increase within specified temporal and spatial scales and ecosystems*" (UNCCD-GM, 2016). The introduction of LDN in a global dialogue – in 2012 – has the aim to encourage implementation of measures to *avoid, reduce and/or reverse* land degradation in order to secure a healthy state of the land (Cowie et al., 2018; Gilbey, s.d.; IPBES, 2018; UNCCD-GM, 2016). As summarized by the UNCCD (Orr et al., 2017), the goals of LDN are to:

- *maintain or improve the sustainable delivery of ecosystem services;*
- *maintain or improve productivity, in order to enhance food security;*
- *increase resilience of the land and populations dependent on the land;*
- *seek synergies with other social, economic and environmental objectives; and*
- *reinforce responsible and inclusive governance of land*

Thus, LDN translates the global Target 15.3 of the 2030 Agenda of the Sustainable Development Goals (SDGs) and was adopted in 2015 as the target of the United Nations Convention to Combat Desertification (UNCCD). It should support other targets, such as the 2°C and the Aichi Biodiversity targets, of, respectively, the United Nations Framework Convention on Climate Change (UNFCCC) and Convention on Biological Diversity (CBD) (IUCN, 2015).

The SDGs provide a framework in order to help countries to strengthen their policies for a sustainable use of land and soils. UNCCD, as the custodian agency for SDG indicator 15.3.1, aim to support member countries to achieve LDN by Sustainable Land Management (SLM) approaches (Trowbridge, 2018).

1.1 Objectives

The land, defined by the UNCCD as the "*terrestrial bio-productive system that comprises soil, vegetation, other biota, and the ecological and hydrological processes that operate within the system*" (2017), needs to be sustainably managed by taking into account its multi-dimensional character. In fact, land can be understood at the global or at the local level (i.e. international, national and sub-national) as a private property or a public good; and also as a sense of place (UNCCD, 2017). So, for the management of land, especially of its healthy state, a wide range of actors are called upon: governmental agencies, land users, private service providers, civil society organizations, developments partners, national and international research institutes, etc. (UNCCD-GM, 2016). Thus, comprehensive and harmonized assessments on LDN and availability of reliable and regular data are primordial. Moreover, an agreed scientific conceptual framework for LDN will be able to guide LDN monitoring and an easier implementation, and will allow a common point of reference in the global dialogue (Orr et al., 2017).

Governments are then supposed to report on the 15.3.1 indicator yearly from 2018 in order to enable the different countries to monitor their portion of degraded land and progress on target 15.3 to support the achievement of LDN by their policy decisions (Trowbridge, 2018). The Good Practice Guidance (GPG) of the UNCCD aims to help member countries to build data evidence. Providing this evidence on land degradation also requires a systematic mapping, measuring and monitoring based on robust scientific process and knowledge (Cherlet et al., 2013).

For these purposes, the Global Environment Facility (GEF) funded a project named "*Enabling the use of global data sources to assess and monitor land degradation at multiple scales*". A plug-in model – in QGIS – was conceived by the Conservation International as a part of this project: Trends.Earth. It is a free open source tool that uses Earth observations to provide intelligible information on land degradation. It includes the SDG 15.3.1 indicator as well as the SDG 11.3.1 on sustainable urbanization.

This study has a double aim: 1) to explore Trends.Earth model, investigate its sensibility and scientific pertinence and to compare it with the UNCCD model presented in the GPG; 2) and to tackle and provide an overview of land degradation in Switzerland.

It is interesting to test the model in the Swiss territory as – since the adoption of the 2030 Agenda for Sustainable Development – Switzerland provides an overview of the progress made towards the 17 SDGs of the UN via its own MONET 2030 indicator system. This system is a collaboration within the Federal Statistical Office (FSO) and the Federal Office for Spatial Development (ARE), the Swiss Agency for Development and Cooperation (SDC), the Federal Office for the Environment (FOEN), the Federal Office for Agriculture (FOAG), the Federal Office for the Protection of the Population (FOPP), the Federal Office for Public Health (FOPH), the State

Secretariat for the Federal Department of Foreign Affairs (FDFA), the State Secretariat for Migrations (SEM) as well as the State Secretariat for International Finance (SIF).

This system counts more than 100 indicators and 23 key indicators (table 1) that are designed to briefly summarize the SDGs (FSO, 2020a).

Table 1. This table summarizes the 23 key indicators of the MONET 2030 indicator system which should promote the achievement of SDGs by 2030.

1. Poverty rate	2. Fruit and vegetables consumption	3. Nitrogen balance from agriculture	4. Years of potential life lost
5. Reading skills of 15-year-olds	6. Wage gap between women and men	7. Domestic violence	8. Nitrate in groundwater
9. Renewable energies	10. Labour productivity	11. Young people neither in employment nor in training	12. Material intensity
13. Expenditure on research and development	14. Distribution of equivalised disposable income (S80/S20)	15. Duty-free imports from developing countries	16. Housing costs
17. Total municipal waste generation	18. Greenhouse gas emissions	19. Nitrogen load exported	20. Soil sealing
21. Populations of breeding birds	22. Violent offences	23. Official Development Assistance	

The Swiss target 15.3 aims for "*Soil functions are sustainably conserved. Land use does not lead to degradation and where possible soils and their functionality are restored*" (FSO, 2020b) and the indicator designed for this purpose is "Soil sealing", which includes buildings, greenhouses and areas covered with hard surfaces (asphalt, concrete, artificially laid gravel or stone surfaces, etc.). Data to derive this indicator stem from the FSO land use statistics. They provide information on land cover and use; based on aerial photographs taken by the Federal Office of Topography (Swisstopo).

Moreover, as a confederation, it could be interesting to investigate the differences in land degradation area by cantons. As a matter of fact, responsibilities for the achievement of SDGs concern the cantonal and communal levels too.

2 SDG indicator 15.3.1 and sub-indicators

This section aims to present the definition of the UN Goal 15, its target and indicator, as well as the sub-indicators involved and the methodology of the UNCCD model in order to contextualize the use of Trends.Earth.

After the twelfth session of the Conference of the Parties of the UNCCD (COP 12), country members agreed to integrate SDGs and the target 15.3 into the implementation of the UNCCD process (UNCCD-GM, 2016). This goal to promote “Life on Land”, its target and indicator, are defined as follows:

– **Goal 15**: *Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss*
– **Target 15.3**: *By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world*
– **Indicator 15.3.1**: *Proportion of land that is degraded over total land area*

2.1 Concepts and Definitions

Article 1 of the UNCCD convention defines land degradation as the “*reduction or loss, in arid, semi-arid and dry sub-humid area, of the biological or economic productivity and complexity of rainfed cropland, irrigated cropland, or range, pasture, forest and woodlands resulting from land uses or from a process or combination of process, including processes arising from human activities and habitation patterns, such as:*

– *soil erosion caused by wind and/or water;*
– *deterioration of the physical, chemical and biological or economic properties of soil; and*
– *long-term loss of natural vegetation*.” (2017)

It involves the loss of: productivity, soil, vegetation cover, biomass, biodiversity, ecosystem services, environmental resilience, etc. (UNCCD, 2017). Direct drivers of these losses mainly consists in agricultural intensification and forestry, urbanization, infrastructure development, energy production, mining and quarrying (UNCCD, 2017); therefore biological, physical, social and economic factors are interconnected (Cherlet et al., 2013).

The SDG 15.3.1 indicator has to take into account the complexity of the land to provide reliable data. Whether the indicator delineates what to measure, metrics describe how it is calculated (Cowie et al., 2018). Thus, the combination of tree sub-indicators has been successfully proven to furnish with valid information on the conditions of the land (Gonzalez-Roglich et al., 2019; Sims et al., 2019):

1. **Land productivity** refers to the above-ground Net Primary Productivity (NPP; metric) considered as the energy fixed by plants minus their respiration, to obtain the rate of biomass accumulation of all land components (Mattina et al., 2018; Sims et al., 2017). In other words, land productivity represent the biological productive capacity of the land, the source of all the

food, fibre and fuel to preserve humans quality of life (Conservation International, 2019). As the quantification of the magnitude of change in NPP is time consuming and engage considerable costs, a qualitative evaluation over time (increasing or decreasing) is proposed for SDG 15.3.1 purposes as there is an indirect relation between these qualitative classes of trends and the lost or gained biomass productivity (Sims et al., 2017).
The most common proxy of NPP is the Normalized Difference Vegetation Index (NDVI), which exploits the physical properties of the vegetation (absorption of energy in the red and reflection in the NIR range). It is calculated as follows:

$$NDVI = \frac{(NIR - R)}{(NIR + R)}$$

with: NIR = near infrared
R = red band

Following the dispositions of the GPG, the land productivity sub-indicator is declined into three metrics based on time-series images: (i) trend, (ii) state and (iii) performance. (i) Trend determines the significance of the magnitude and persistence of changes in vegetation productivity over time by statistical tests; (ii) state represents the comparison between the current level of productivity and the historical productivity of the region taken in consideration; and (iii) performance analyses the local productivity versus the national level (Sims et al., 2019).

2. **Land cover** (LC) refers to the "*observed physical and biological cover of the Earth's surface*" and "*includes vegetation and man-made features as well as bare rock, bare soil and inland water surfaces. It represents the area of land that has been classified according to the spectral signature of its physical cover captured by satellite remote sensing*" (Mattina et al., 2018, p.6). On a practical level, it allows to analyse the transition from one type of land cover to another. This transition can be qualified as improved, stable or degraded.

3. **Carbon stocks** (metric: soil organic carbon, SOC) refers to the portion of carbon contained in the soil organic matter. Stocks of SOC depend on the biomes and therefore on climate, soil type, physiography, vegetation and land use (Cherlet et al., 2018). SOC stocks represent the balance between gains in organic matter and losses caused by the decomposition through the action of soil organisms and physical export (i.e. erosion) (Sims et al., 2017; Smith et al., 2008). Soil carbon plays an important role in recycling nutrients to maintain soil fertility and promote vegetation growth (Mattina et al., 2018). Consequently, losses of SOC or any disturbance, such as management practices, of its cycle could impact soil quality (Sims et al., 2017).

2.2 Methodology and data sources

As presented by the UNCCD, the main steps of the LDN framework are to (fig.1):

- Determine the initial year of analysis (setting the baseline);

– Detect the type of change occurred during the monitoring period;
– Derive the final indicator using the “One Out, All Out[1]” rule.

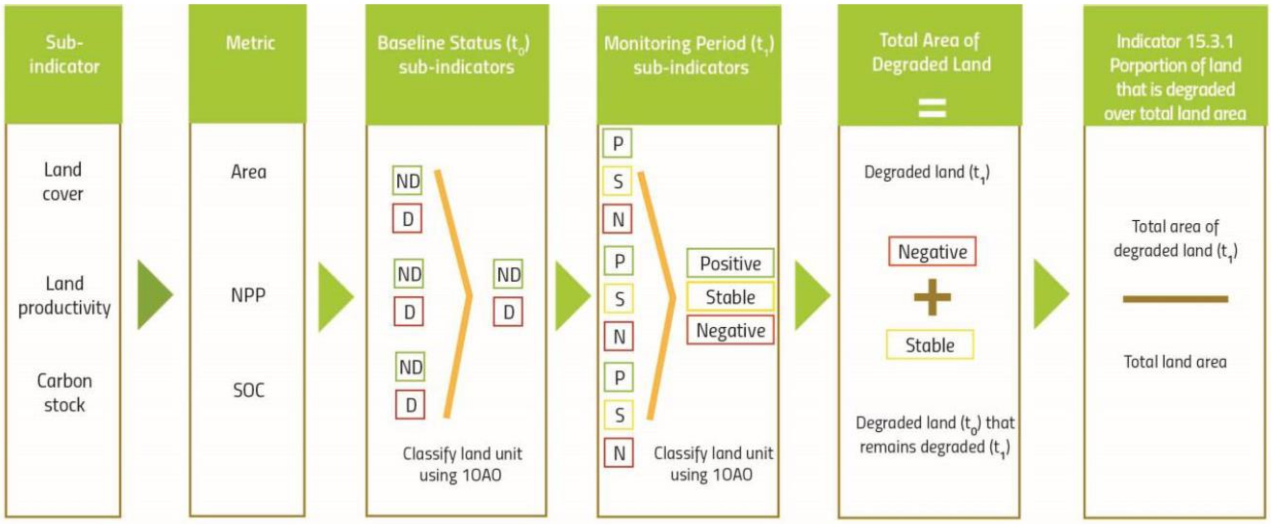


Fig. 1. Main steps to calculate the SDG 15.3.1, which is derived from the three sub-indicators. ND = not degraded and D = degraded. 1OAO = “One Out, All Out" (Source: Sims et al. 2019, p.351).

Information on the UNCCD methodology are principally derived from the GPG.

2.2.1 Land Productivity Dynamics

As recommended by the GPG – and as mentioned above – land productivity change can be derived from three variables: trend, state and performance. That sub-indicator refers to the standing biomass productivity obtained from phenological analyses of a 15-year time series (1999-2013) of global NDVI based on remote sensing inputs (UNCCD, 2017).

Land productivity trend in the WAD (World Atlas of Desertification) framework[2] is processed by aggregating 36 annual NDVI observations – provided by 1km SPOT VEGETATION daily coverage – to form an integrated yearly NDVI (Mattina et al., 2018). Other Earth-observation vegetation indices can be exploited to derive phenological metrics too, such as the FAPAR or the SAVI models (Cherlet et al., 2018; UNCCD, 2017). Then, the linear trend of normalized z-score values of aggregated NDVI values from different time periods is calculated. A Multi Temporal Image Differencing (MTID; see Guo et al., 2008) method is applied – to the same period – to calculate the net change too. Different combinations of trend and change variables are possible: +trend/+change; +trend/-change; -trend/+change; -trend/-change (UNCCD, 2017).

The productivity state is calculated by the iso-data classification and differentiation of the average land productivity (annual per pixel derivation) in the initial (1999-2001) and the final (2011-2013) 3 years of the time series (Mattina et al., 2018; UNCCD, 2017). The comparison between the initial and the final standing biomass allows to obtain the land productivity class change layer.

Concerning the productivity performance, weighting functions derived from Local Net Scaling (LNS) are applied to the last 5 years average values of the productivity metric (per year) in

[1] This rule will be explained in section 2.2.4.
[2] WAD used the European Commission’s Joint Research Centre (JRC) LPD datasets as defaults datasets (Ivits and Cherlet, 2013).

ecosystem functional units (EFUs), which represent areas with similar responses to environmental conditions (based on phenological and productivity metrics calculations) (Ivits et al., 2013). The LNS method models the actual productivity (per pixel) by measuring the local potential productivity or maximum production of a land (Ivits and Cherlet, 2013; Prince et al., 2009).

The LPD can be then represented by synthesising and combining these three metrics: a final map is obtained from a logical matrix aggregating the different layers. Thus, there are 5 LPD class values: 1) Persistent decline in productivity; 2) Persistent moderate decline in productivity; 3) Stable, but stressed, persistent strong inter-annual productivity variations; 4) Stable productivity; 5) Persistent increase in productivity (UNCCD, 2017).

2.2.2 Land Cover

The European Space Agency Climate Change Initiative Land Cover (ESA CCI-LC) provides two global default LC datasets: the original (300m; years: 2000, 2005, 2010; v.1.6.1 with 22 classes) and the new dataset, which time series range from 1992 to 2015 (v.2.0.7). These datasets were developed according to specific criteria (Mattina et al., 2018):

- Global coverage
- Validation
- Temporal coverage (i.e. availability of long time series with regular intervals)
- Timeliness (i.e. availability of future updates at regular intervals)
- Relatively fine spatial resolution

Derivation of LC is based on satellite data of NOAA-AVHRR HRPT, ENVISAT MERIS, ENVISAT-ASAR, SPOT VGT and PROBA-V. The full archive of ENVISAT-MERIS 300m resolution (2003-2012) is exploited to define a LC baseline in order to detect changes by aggregating NOAA-AVHRR HRPT dataset (1km; for the period 1992-1999). While SPOT VGT (1999-2012) and PROBA-V (2013-2015) are employed to produce annual global LC change maps (Mattina et al., 2018).

The ESA CCI-LC dataset counts 14 additional classes (level 2), which give more accurate regional information, for a total of 36 classes (22 from level 1, at the global scale).
For UNCCD reporting purposes, the 36 classes are then harmonised and reclassified in 7 classes using the Land Cover Meta Language (LCML) of the FAO Land Cover Classification System (LCCS) (Di Gregorio et al., 2016; Sims et al., 2019): Tree-covered areas; Grassland; Cropland; Wetland; Artificial surfaces; Other land and Water bodies (fig.2).

Changes in LC are assessed by analysing the transition of a pixel from one LC to another or if it remained in the same LC (fig.3). Changes are estimated at the five-year intervals (as net change for 2000-2015) and coded by a two-digit system: the first digit represents the class of the first year change and the second digit refers to the class of the second year of change (Mattina et al., 2018).

UNCCD CODE	UNCCD LABEL	ESA CCI_CODE	ESA CCI_LABEL
1	TREEE-COVERED AREAS	50	Tree cover, broadleaved, evergreen, closed to open (>15%)
		60	Tree cover, broadleaved, deciduous, closed to open (>15%)
		61	Tree cover, broadleaved, deciduous, closed (>40%)
		62	Tree cover, broadleaved, deciduous, open (15-40%)
		70	Tree cover, needleleaved, evergreen, closed to open (>15%)
		71	Tree cover, needleleaved, evergreen, closed (>40%)
		72	Tree cover, needleleaved, evergreen, open (15-40%)
		80	Tree cover, needleleaved, deciduous, closed to open (>15%)
		81	Tree cover, needleleaved, deciduous, closed (>40%)
		82	Tree cover, needleleaved, deciduous, open (15-40%)
		90	Tree cover, mixed leaf type (broadleaved and needleleaved)
		100	Mosaic tree and shrub (>50%) / herbaceous cover (<50%)
2	GRASSLAND	110	Mosaic herbaceous cover (>50%) / tree and shrub (<50%)
		120	Shrubland
		121	Shrubland evergreen
		122	Shrubland deciduous
		130	Grassland
		140	Lichens and mosses
		151	Sparse trees (<15%)
		152	Sparse shrub (<15%)
		153	Sparse herbaceous cover (<15%)
3	CROPLAND	10	Cropland, rainfed
		11	Herbaceous cover
		12	Tree or shrub cover
		20	Cropland, irrigated or post-flooding
		30	Mosaic cropland (>50%) / natural vegetation (tree, shrub, herbaceous cover) (<50%)
		40	Mosaic natural vegetation (tree, shrub, herbaceous cover) (>50%) / cropland (<50%)
4	WETLAND	160	Tree cover aquatic or regularly flooded in fresh or brakish water
		170	Tree cover aquatic or regularly flooded in salt or brakish water, Mangroves
		180	Shrub or herbaceous cover, flooded, fresh/brakish water
5	ARTIFICIAL SURFACES	190	Urban areas
6	OTHER LAND	200	Bare areas
		201	Consolidated bare areas
		202	Unconsolidated bare areas
		220	Permanent snow and ice
7	WATER BODIES	210	Water bodies

Fig. 2. Aggregation of land covers of ESA versus UNCCD. Codes and labels are provided (Source: Mattina et al., 2018, p.8).

ORIGINAL CLASS \ FINAL CLASS	Tree-covered areas	Grassland	Cropland	Wetland	Artificial surfaces	Other land
Tree-covered areas	Stable	Vegetation loss	Deforestation	Inundation	Deforestation	Vegetation loss
Grassland	Afforestation	Stable	Agricultural expansion	Inundation	Urban expansion	Vegetation loss
Cropland	Afforestation	Withdrawal of agriculture	Stable	Inundation	Urban expansion	Vegetation loss
Wetland	Woody Encroachment	Wetland drainage	Wetland drainage	Stable	Wetland drainage	Wetland drainage
Artificial surfaces	Afforestation	Vegetation establishment	Agricultural expansion	Wetland establishment	Stable	Withdrawal of settlements
Other Land	Afforestation	Vegetation establishment	Agricultural expansion	Wetland establishment	Urban expansion	Stable

Fig. 3. Cross-tabulated land cover data. Negative transitions are highlighted in red, stable is blue and positive transitions are in green (Source: Mattina et al., 2018, p.28).

UNCCD default data are raster (geo-tiff) and vector (shapefile) formats. These geo-referenced spatial layers are provided in WGS84 sinusoidal equal-area projection (SR-ORG:6841; MODIS).

2.2.3 Soil Organic Carbon stock

The selection of default data sources is made by taking into consideration three criteria: immediate availability and readiness; global spatial coverage and appropriate resolution (Mattina et al., 2018). On the basis of this, two types of information are demanded in order to derive SOC trends, namely SOC stocks baseline (tC/ha) for a specific country and year and changes in SOC stocks depending on land use or land cover changes. The International Soil Reference and Information Center's (ISRIC) SoilGrids250m system – especially the SOC% – satisfies these conditions in terms of UNCDD reporting purposes.

Firstly, the baseline SOC stocks is defined by the combination of SoilGrids250m products: SOC concentration, bulk density, gravel fraction and 0-30 cm depth soil profile. IPCC methodology is then adapted in order to estimate stocks changes over time, here 2000-2015. IPCC methodology considers three change factors (Mattina et al., 2018):

- SOC stocks changes in relation to the type of land use (FLU)
- Management practice of the land use taken in consideration (FMG)
- Different levels of carbon input to soil (FI)

Land cover is used as land use proxy: the analysis of the annual transition from one land cover class to another allows to derive a FLU coefficient. LC changes are averaged over 20 years and applied to the 2000-2015 time period (Mattina et al., 2018). Derivation of SOC stocks changes is carried out following different steps at different levels[3] (fig.3). Data inputs for mapping use LC changes over time converted by carbon change factors, here the FLU coefficient, according to the type of transition. A factor of 1 indicates no changes (appendix 1).
Concerning FMG and FI change factors, no global data are adapted to obtain the information.

Level of detail	SOC stock baseline	SOC stock changes
Tier 1	Apply IPCC Tier 1 methods that relate SOC stock to environmental and management factors, with separate approaches and defaults for mineral and organic soils.	Apply IPCC Tier 1 methods to assess SOC stock change (0-30 cm) after default 20-year period[1]; methods differ for mineral and organic soils.
Tier 2	Two general approaches: a) Apply IPCC Tier 2 method, i.e. update of SOC reference stocks and associated stock change factors with nationally-determined values. SOC reference stocks can be determined from global or national high-resolution, digital soil maps or from measurements (e.g. national soil surveys); b) Where available and robust, apply methods that relate SOC stock to environmental and management factors, using statistical learning methods (e.g. used in state-of-the-art digital soil mapping studies) using best available baseline data for SOC stock and environmental covariates (e.g. land cover) for defined reference period. Where possible, refine established global relationship using national data.	a) Apply IPCC Tier 2 method using stock change factors with nationally-determined values; b) Apply methods derived from baseline data to changed environmental and management conditions observed during the reporting year, i.e. use relationships derived from global or national digital soil mapping products.
Tier 3	Two general approaches: a) As for Tier 2b above, but only using measured soil data for the baseline period; b) Derived from ecosystem (process-based) modelling.	a) As for Tier 2b above, but only using measured soil data for the reporting period; b) Derived from ecosystem modelling, calibrated at points using results from new field measurements/monitoring.

[1]Note: default equations are based on linear relationships that are modified to allow for different reporting periods.

Fig. 4. Conceptual framework to quantify changes in soil organic carbon stocks (Source: Sims et al., 2019, p.353).

As for the LC layers, SOC default data outputs are in geo-tiff (WGS83 coordinates system) format and the distribution of SOC/LC (2000-2015) is provided as numerical values. MODIS sinusoidal equal-area projection (SR-ORG:6842) is selected as the basis of all area calculations.

[3] See Mattina et al., 2018 and Sims et al., 2019 for more information.

2.2.4 Proportion of degraded land over total land area

SDG 15.13.1 complementary sub-indicators are integrated – with a precautional approach – following the principle "one out, all out", meaning that if at least one of the sub-indicators shows a potential degradation or a negative change the location is automatically considered as degraded (fig.5). As explained by Mattina et. al. (2018), this choice reflects the fact that stability or improvements in land conditions cannot in any case compensate for degradation.

In order to represent the *portion of degraded land over total land area*, the total land area is determined by the total surface area of a country, excluding all area covered by inland waters and generally areas permanently inundated by water (i.e. water bodies). The definition of these permanently inundated areas is made by combining different datasets on permanent water classification (i.e. ESA CCI-LC; the European Commission's Joint Research Centre Global Surface Water product; the Global Surface Water).

Productivity	Land Cover	SOC	SDG 15.3.1
Improvement	Improvement	Improvement	Improvement
Improvement	Improvement	Stable	Improvement
Improvement	Improvement	Degradation	Degradation
Improvement	Stable	Improvement	Improvement
Improvement	Stable	Stable	Improvement
Improvement	Stable	Degradation	Degradation
Improvement	Degradation	Improvement	Degradation
Improvement	Degradation	Stable	Degradation
Improvement	Degradation	Degradation	Degradation
Stable	Improvement	Improvement	Improvement
Stable	Improvement	Stable	Improvement
Stable	Improvement	Degradation	Degradation
Stable	Stable	Improvement	Improvement
Stable	Stable	Stable	Stable
Stable	Stable	Degradation	Degradation
Stable	Degradation	Improvement	Degradation
Stable	Degradation	Stable	Degradation
Stable	Degradation	Degradation	Degradation
Degradation	Improvement	Improvement	Degradation
Degradation	Improvement	Stable	Degradation
Degradation	Improvement	Degradation	Degradation
Degradation	Stable	Improvement	Degradation
Degradation	Stable	Stable	Degradation
Degradation	Stable	Degradation	Degradation
Degradation	Degradation	Improvement	Degradation
Degradation	Degradation	Stable	Degradation
Degradation	Degradation	Degradation	Degradation

Fig. 5. Explanation of the aggregation of SDG 15.3.1 sub-indicators on the basis of the 1OAO principle (Conservation Internal, 2019, p.61).

The GPG specified the calculation details too (Sims et al., 2017):

– Degraded area in the monitoring period (t_n) is calculated as follows:

$$A(Degraded)i,\mathrm{n}=\Sigma Arecenti,n+nj=1Apersistenti,n$$

Where:
$A(Degraded)i,n$ = total area degraded in the land cover class *i* in the year of monitoring *n* (ha);
$Arecenti,n$ = area defined as degraded in the current monitoring year following 1OAO assessment of the sub-indicators (ha);
$Apersistenti,n$ = area previously defined as degraded which remains degraded in the monitoring year following the 1OAO assessment of the sub-indicators (ha);

– The proportion of degraded land cover type i is given by:

$$Pi,n=A(degraded)i,\mathrm{n}A(total)i,n$$

Where:
Pi,n = proportion of degraded land in that land cover type *i* in the monitoring period *n*;
$A(Degraded)i$,n = total area degraded in the land cover type *i* in the year of monitoring *n* (ha);
$A(total)i$,n = total area of land cover type *i* within the national boundary (ha);

– The total area of land that is degraded over total land area is given by:

$$A(Degraded)\mathrm{n}=\Sigma A(Degraded)i,\mathrm{n}mi$$

Where:
$A(Degraded)$n = total area degraded in the year of monitoring *n* (ha);
$A(Degraded)i$,n = total area degraded in the land cover type *i* in the year of monitoring *n*.

– The total proportion of land that is degraded over total land area is given by:

$$P\mathrm{n}=A(Degraded)\mathrm{n}\Sigma\mathrm{A(Total)}mi$$

Where:
Pn = proportion of land that is degraded over total land area;
$A(Degraded)$n = total area degraded in the year of monitoring *n* (ha);
A(Total) = total area within the national boundary (ha).

The proportion is then converted to a percentage value by multiplying by 100.

3 Trends.Earth

The Land Degradation Monitoring Toolbox (Trends.Earth) platform – developed by the Conservation International, with collaboration of the Lund University, the National Aeronautics and Space Administration (NASA) and the support of the Global Environment Facility (GEF) – was conceived to monitor land change by using Earth observations. It is based on Python scripts that can be modified by the user. All calculations are processed by Google Earth Engine (GEE). The plug-in is directly available in QGIS 2.18 – or higher versions – for the installation.

3.1 Sub-indicators and Data sources

LC inputs data computed in Trends.Earth come from the UNCCD datasets presented above. Additionally, Trends.Earth is likely to use the same land use coefficients for the calculation the changes in SOC (fig.6.).

LU coefficients	Forest	Grasslands	Croplands	Wetlands	Artifical areas	Bare lands	Water bodies
Forest	1	1	f	1	0.1	0.1	1
Grasslands	1	1	f	1	0.1	0.1	1
Croplands	1/f	1/f	1	1/0.71	0.1	0.1	1
Wetlands	1	1	0.71	1	0.1	0.1	1
Artifical areas	2	2	2	2	1	1	1
Bare lands	2	2	2	2	1	1	1
Water bodies	1	1	1	1	1	1	1

Changes in SOC are better studied for land cover transitions involving agriculture, and for that reason there is a different set of coefficients for each of the main global climatic regions: Temperate Dry ($f = 0.80$), Temperate Moist ($f = 0.69$), Tropical Dry ($f = 0.58$), Tropical Moist ($f = 0.48$), and Tropical Montane ($f = 0.64$).

Fig. 6. Matrix of land use coefficients used in Trends.Earth (Source: Conservation International, 2019, p.60).

3.1.1 Vegetation productivity

The land productivity sub-indicator calculated in Trends.Earth is a combination – as in UNCCD – of three measures obtained from NDVI data: 1) trajectory (corresponding to the UNCCD trend), 2) state and 3) performance. Generally speaking, Trends.Earth uses bi-weekly products from MODIS and AVHRR to compute annual integrals of NDVI (Conservation International, 2019).

The productivity trajectory is obtained by the linear regression of aggregated annual integrals NDVI (2000-2015) at the pixel level in order to identify areas where changes in primary productivity are detected over a long-time scale. These values are then statistically tested (Mann-Kendall): positive or negative significant differences ($p < 0.05$) are interpreted as potential improvement or potential degradation of land respectively.

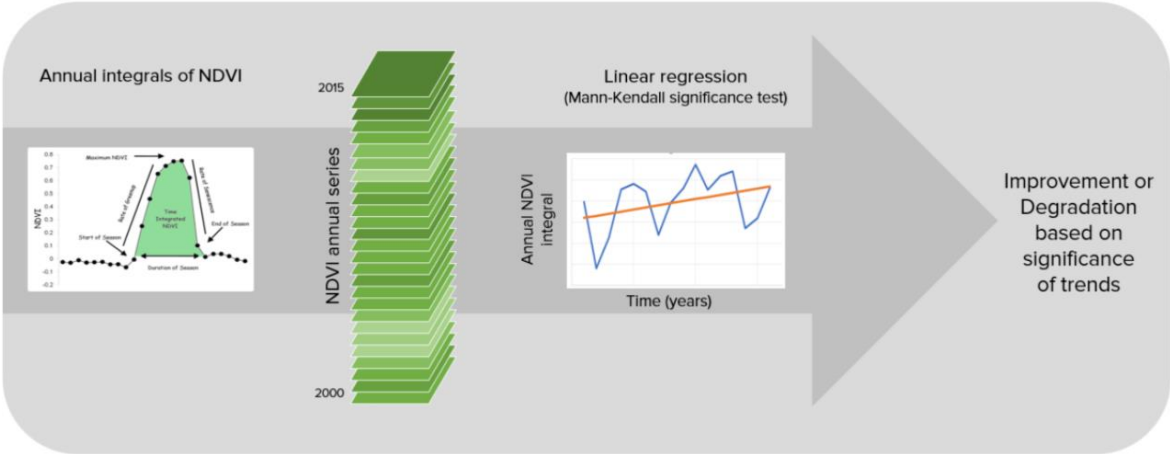


Fig. 7. Schematic summary of the derivation of productivity trajectory of Trends.Earth (Source: Conservation International, 2019, p.55).

As primary productivity is affected by climate conditions, such as temperature, availability of water, light and nutrients, the Trends.Earth plug-in allows the user to perform climatic corrections by using data on soil moisture, precipitation and evapotranspiration from different datasets (fig.8). Three methods are possible to make these corrections (Conservation International, 2019):

- Residual Trend Analysis (RESTREND): represents the prediction of NDVI for a given rainfall amount by linear regression models. Residuals of the predicted NDVI *versus* the observed NDVI are considered as non-climatically related productivity change.
- Rain Use Efficiency (RUE): represents the ratio of annual NPP to annual precipitation. Positive significant RUE trends indicate a potential improvement and degradation is represented by negative significant RUE trends.
- Water Use Efficiency (WUE): WUE trends are calculated by using total annual evapotranspiration (ET) rather than precipitations. ET is given by the difference between precipitations and water lost to surface runoff, recharge to groundwater and changes to soil water storage. Positive and negative significant trends are interpreted in the same way as for RUE.

Variable	Sensor/Dataset	Temporal	Spatial	Extent	Units/Description
NDVI	AVHRR/GIMMS	1982-2015	8 km	Global	Mean annual NDVI * 10000
	MOD13Q1-coll6	2001-2016	250 m	Global	Mean annual NDVI * 10000
Soil moisture	MERRA 2	1980-2016	0.5 ° x 0.625 °	Global	Water root zone m^3m^{-3} * 10000
	ERA I	1979-2016	0.75 ° x 0.75 °	Global	Volumetric Soil Water layer m^3m^{-3} (0-7 cm)
Precipitation	GPCP v2.3 1 month (Global Precipitation Climatology Project)	1979-2016	2.5° x 2.5°	Global	mm/year
	GPCC V7 (Global Precipitation Climatology Centre)	1901-2016	1° x 1°	Global	mm/year
	CHIRPS	1981-2016	5 km	50N-50S	mm/year
	PERSIANN-CDR	1983-2015	25 km	60N-60S	mm/year
Evapotranspiration	MOD16A2	2000-2014	1 km	Global	Annual ET km/m2 (=mm) * 10

Fig. 8. List of the datasets available in Trends.Earth to perform NDVI trend analysis, including datasets for climatic corrections (Source: Conservation International, 2019, p.56).

Coding for the productivity trajectory is defined as follows:

Trend:

- Value -32768 = No data
- Any other value = Linear trend of annually integrated NDVI, scaled by 10 000

Significance:

- -32768 = No data
- -3 = Significant decline (p > 0.99)
- -2 = Significant decline (p > 0.95)
- -1 = Significant decline (p > 0.90)
- 0 = No significant change
- 1 = Significant increase (p > 0.90)
- 2 = Significant increase (p > 0.95)
- 3 = Significant increase (p > 0.99)

The productivity state indicator is at first computed by comparing a baseline period of primary productivity (2000-2012) to a 3-target-year (2013-2015) (fig.9). Then, for each pixel, a frequency distribution is computed by exploiting annual NDVI integrals for the baseline period. 5% is added to each extreme in case of missing extreme values. The resulting distribution curve is used to define a values classification of 10 percentiles. Determination of the percentile class is carried out by computing the mean NDVI for the baseline period. The mean NDVI is added to the comparison period too. Class number difference is obtained by subtracting the baseline classes from the comparison classes. If the result is ≥ +2, the pixel is potentially improved, equally, a class difference of ≤ -2 indicates a degradation of the pixel. Results ranging from -1 to 1 indicate that no changes occurred.

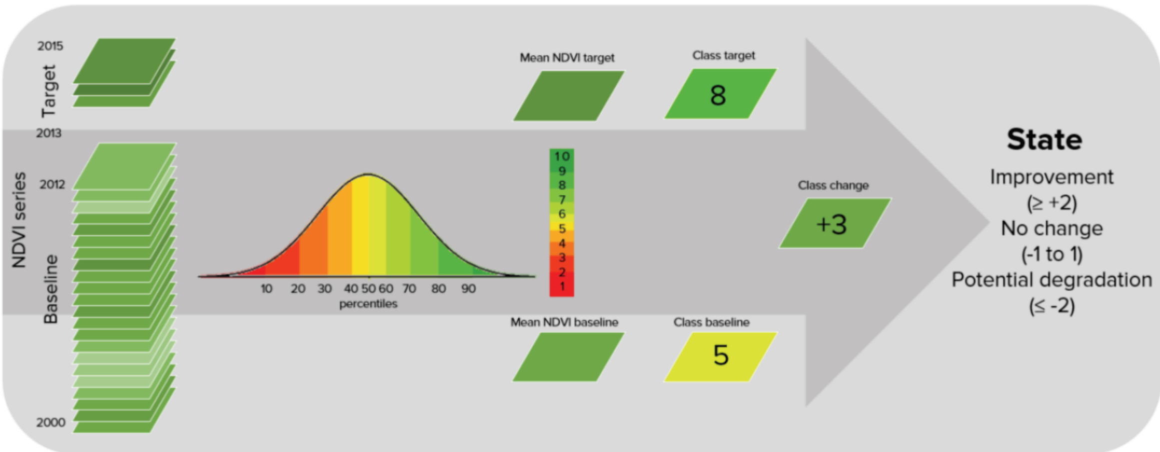


Fig. 9. Schematic summary of the methodology to calculate productivity state indicator in Trends.Earth (Source: Conservation International, 2019, p.56).

Coding for the productivity state is defined as follows:

Degradation:

- -32768 = No data
- Any other value = Change in productivity state classes between baseline and target period, calculated as the rank in the target period minus the rank in the baseline period. Positive values indicate improvement, negative values indicate decline.

Productivity state classes:

- -32768 = No data
- Any other value = Percentile class for productivity state.

Productivity state NDVI mean:

- -32768 = No data
- Any other value = Mean annually integrated NDVI for the baseline period chosen for productivity state, scaled by 10 000.

The productivity performance is a combination of soil taxonomic units (SoilGrids-USDA, fig.10) and LC layers (fig.11). NDVI mean is computed for each pixel (for a defined analysis period) in order to determine ecologically similar units, represented by the intersection of the two types of layer. All mean NDVI values of each intersection are extracted to create a frequency distribution. This step allows to obtain the maximum productivity for the unit analysed by considering the value which represent the 90th percentile. Land condition is defined by the ratio of mean NDVI (observed) and maximum productivity: all pixels with a result lower than 50% are considered as degraded.

Variable	Sensor/Dataset	Temporal	Spatial	Extent	Units/Description
NDVI	AVHRR/GIMMS	1982-2015	8 km	Global	Mean anual NDVI * 10000
	MOD13Q1-coll6	2001-2016	250 m	Global	Mean anual NDVI * 10000
Land cover	ESA CCI	1992-2015	300 m	Global	Land cover classes
Soil taxonomic units	SoilGrids - USDA	Static	250 m	Global	Soil units

Fig. 10. List of the datasets available in Trends.Earth to compute the productivity state indicator (Source: Conservation International, 2019, p. 57).

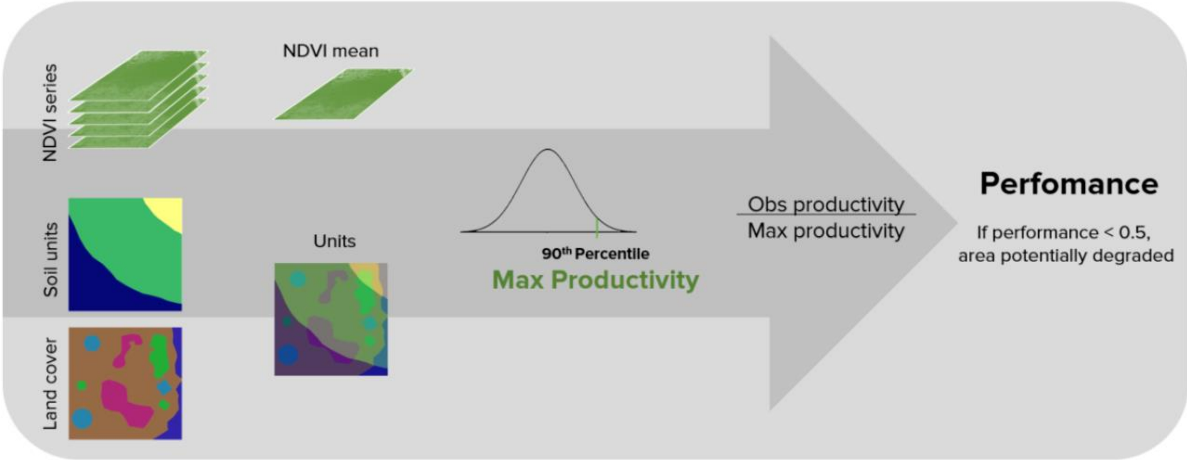


Fig. 11. Schematic summary of the calculation of the productivity performance indicator (Source: Conservation International, 2019, p.57).

Coding for the productivity performance is defined as follows:

Degradation:
- -32768 = No data
- -1 = Degradation
- 0 = No change

Ratio:
- -32768 = No data
- 0 = Ratio of mean NDVI and maximum productivity.

Units:
- -32768 = No data
- Any other value = ID number of units used to calculate performance.

The final vegetation productivity is defined by aggregating the results of the three metrics (fig.12). Compared to UNCCD reporting – which requires 3 classes (improvement, stable and degradation) – Trends.Earth provides 2 additional classes based on the productivity state indicator informing on the type of degradation (stable but stressed; early signs of decline).

Trajectory	State	Performance
Improvement	Improvement	Stable
Improvement	Improvement	Degradation
Improvement	Stable	Stable
Improvement	Stable	Degradation
Improvement	Degradation	Stable
Improvement	Degradation	Degradation
Stable	Improvement	Stable
Stable	Improvement	Degradation
Stable	Stable	Stable
Stable	Stable	Degradation
Stable	Degradation	Stable
Stable	Degradation	Degradation
Degradation	Improvement	Stable
Degradation	Improvement	Degradation
Degradation	Stable	Stable
Degradation	Stable	Degradation
Degradation	Degradation	Stable
Degradation	Degradation	Degradation

3 Classes	5 Classes
Improvement	Improving
Improvement	Improving
Improvement	Improving
Improvement	Improving
Improvement	Improving
Degradation	Stable
Stable	Stable
Stable	Stable
Stable	Stable
Degradation	Stable but stressed
Degradation	Early signs of decline
Degradation	Declining
Degradation	Declining
Degradation	Declining
Degradation	Declining
Degradation	Declining
Degradation	Declining
Degradation	Declining

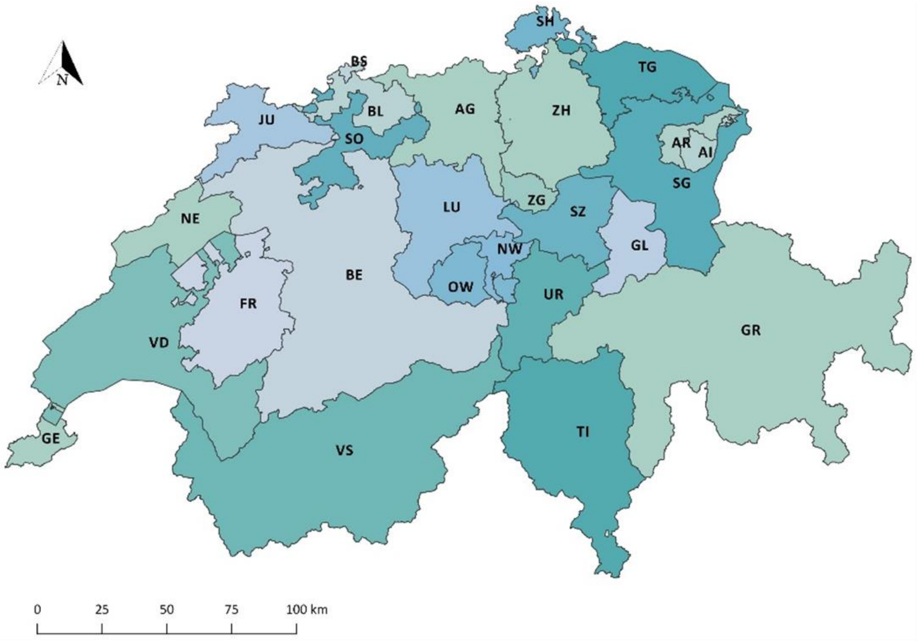
Fig. 12. Aggregation of the productivity sub-indicators into 5 classes (Source: Conservation International, 2019, p.58).

Coding for the SDG 15.3.1 productivity is defined as follows:

- -32768 = No data
- 1 = Declining
- 2 = Early signs of decline
- 3 = Stable but stressed
- 4 = Stable
- 5 = Increasing.

4 Land Degradation in Switzerland: an application of Trends.Earth plug-in

As mentioned in the introduction, this study focuses on the land degradation in Switzerland. The country has a federal system subdivided into 26 cantons (fig.13) and three main geographic regions (fig.14): The Alps, the Swiss Plateau and the Jura.



Acronym	Name of the canton
AG	Aarau
AR	Appenzell Ausserrhoden
AI	Appenzell Innerrhoden
BS	Basel-Stadt
BL	Basel-Landschaft
BE	Bern
FR	Fribourg
GE	Geneva
GL	Glarus
GR	Graubünden
JU	Jura
LU	Luzern
NE	Neuchâtel
NW	Nidwalden
OW	Obwalden
SH	Schaffhausen
SZ	Schwyz
SO	Solothurn
SG	St. Gallen
TG	Thurgau
TI	Ticino
UR	Uri
VD	Valais
VS	Vaud
ZG	Zug
ZH	Zürich

Fig. 13. Switzerland subdivided in cantons with the acronyms and the name in the table on the right. The map was create in QGIS with opendata.swiss data (SwissBOUNDARIES3D cantonal limits).

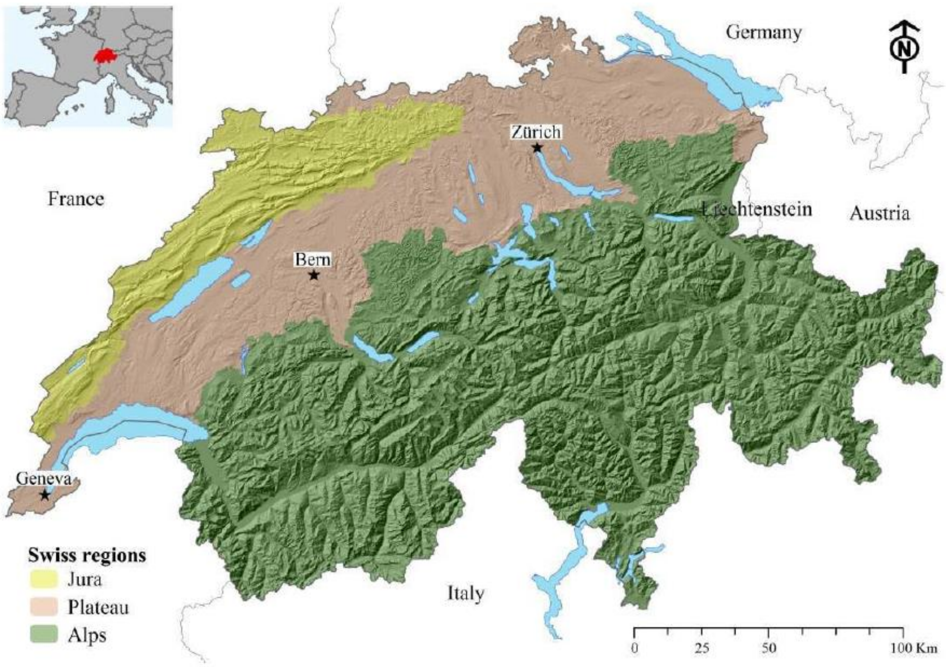


Fig. 14. Geographic location of the three Swiss regions (Source: Vega Orozco et al., 2015, p.3)

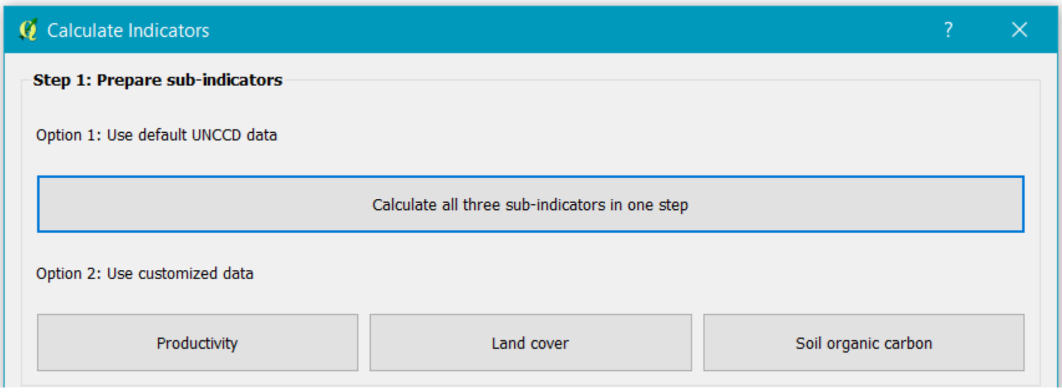
4.1 Methodology

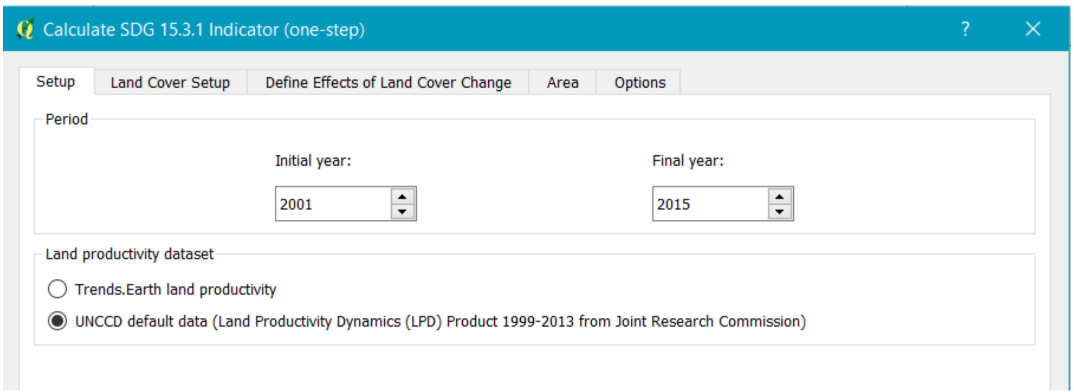
The application of the Trend.Earth plug-in was carried out following the Conservation International documentation (release 0.67): run 1-step sub-indicators; task status and download of sub-indicators layers; computation of the final SDG 15.3.1 indicator; interpretation of summary tables (Excel). Described step are accompanied by screenshots taken during the use of the plug-in. The entirety of the process was carried out for Switzerland at the national level, once with UNCCD datasets and once with Trends.Earth datasets. The same application was made for the cantonal level.

Administrative boundaries are provided by the Natural Earth Administrative Boundaries.

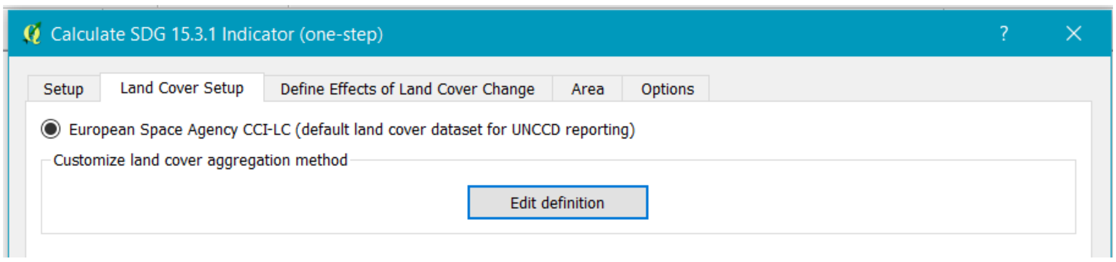
4.1.1 Sub-indicators preparation and final SDG 15.3.1 indicator calculation

The first step is the calculation of the three sub-indicators, made by using the default UNCCD dataset and with the one step option (time period: 2001-2015). LPD of UNCCD default data are from JRC dataset (1999-2013).





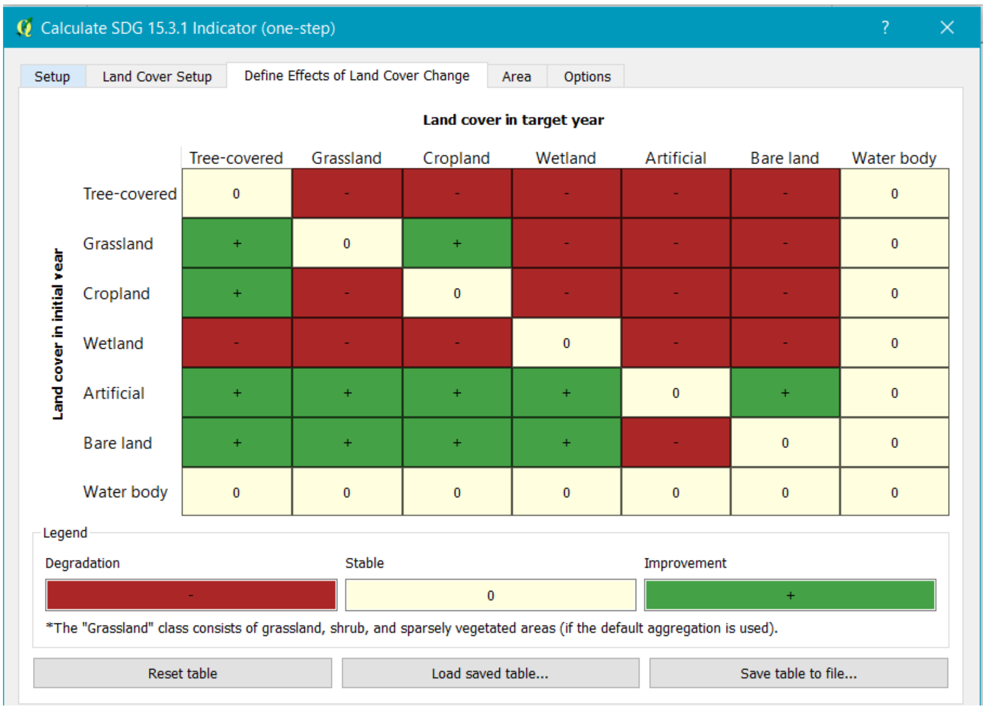
The user can customize land cover aggregation method by editing definition of output classes depending on the input ESA class. In this study the default land cover dataset for UNCCD reporting was chosen (7 classes).



The matrix of land cover change was not changed:

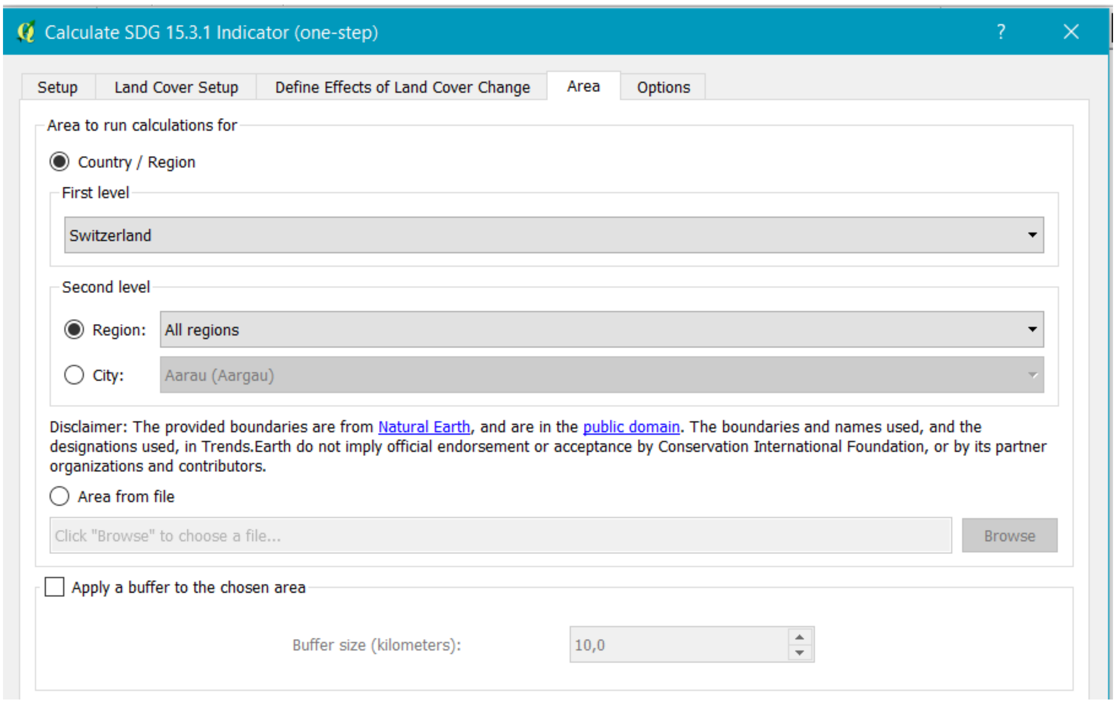
- three-covered transition to grassland; cropland; wetland; artificial or bare land is defined as a degradation, while changes from other classes to tree-covered land cover is considered as an improvement;
- grassland changing in cropland is considered as improvement and a decline inversely;
- any changes in wetland area are signs of degradation, whereas any transitions of artificial land are defined as positive;
- changes in bare land are also positive, except for the transition from bare land to artificial.

The matrix can be modified if information on the field are available.

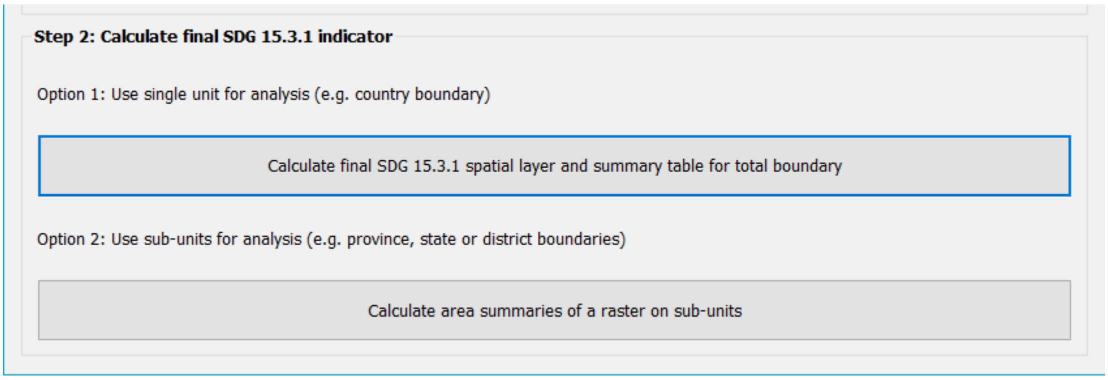


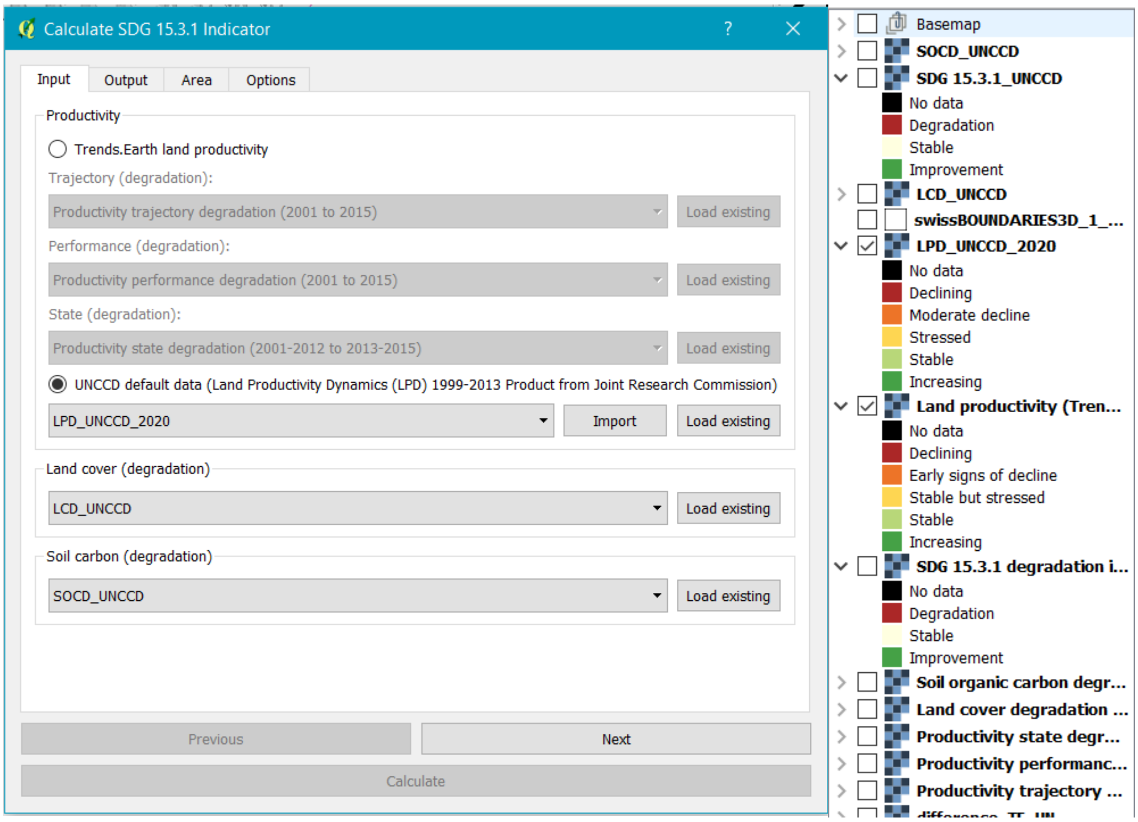
	Tree-covered	Grassland	Cropland	Wetland	Artificial	Bare land	Water body
Tree-covered	0	-	-	-	-	-	0
Grassland	+	0	+	-	-	-	0
Cropland	+	-	0	-	-	-	0
Wetland	-	-	-	0	-	-	0
Artificial	+	+	+	+	0	+	0
Bare land	+	+	+	+	-	0	0
Water body	0	0	0	0	0	0	0

The study area was then defined: analysis was firstly performed at the national level and in a second time by cantons (total: 26). Calculation task was submitted to Google Earth Engine for computing, once finished, results were downloaded and saved. The layers were then automatically loaded into the QGIS project.



The second step is to compute productivity, land cover and soil carbon layers previously prepared to calculate the final SDG 15.3.1 indicator spatial layer. Calculation was run by the user computer and once completed SDG 15.3.1 layer was automatically uploaded into the QGIS map. Downloaded results also provided Excel files with summarized information on SDG 15.3.1, the productivity, the soil organic carbon, the land cover for the selected area of study and summary tables in UNCCD reporting format.





4.1.2 Data processing

Data treatment was directly carried out in QGIS 2.18 (i.e. raster calculator) and in Excel for basic arithmetical calculations and creation of graphics.

All output layers were transformed in the in Swiss coordinate reference system (CRS): CH/1903 / LV03; authority ID = EPSG:21781. A clip mask was created to better represent Switzerland boundaries.

5 Results

The presentation of the results is separated into 1) the sub-indicators results; 2) the final SDG 15.3.1 results; and 3) vegetation productivity and SDG 15.3.1 indicator results by cantons.

5.1 Sub-indicators' results

In Switzerland, for the period 2001-2015, there were not considerable changes in LC: 96.7% of the total land area was considered as stable, while 3% presented a negative transition (table 2). Only 0.26% (105.2 km^2) of the country showed a positive class change, these positive transitions were mostly located in the Swiss Alps (canton Uri and Valais) and the Jura (fig.15).

Table 2. Qualification of the land cover change by km2 and in (%).

Land cover	Area (km^2)	Total land area (%)
Total land area	39 995.9	100.00%
Improved	105.2	0.26%
Stable	38 681.5	96.71%
Degraded	1 209.2	3.02%
No data	0.0	0.00%

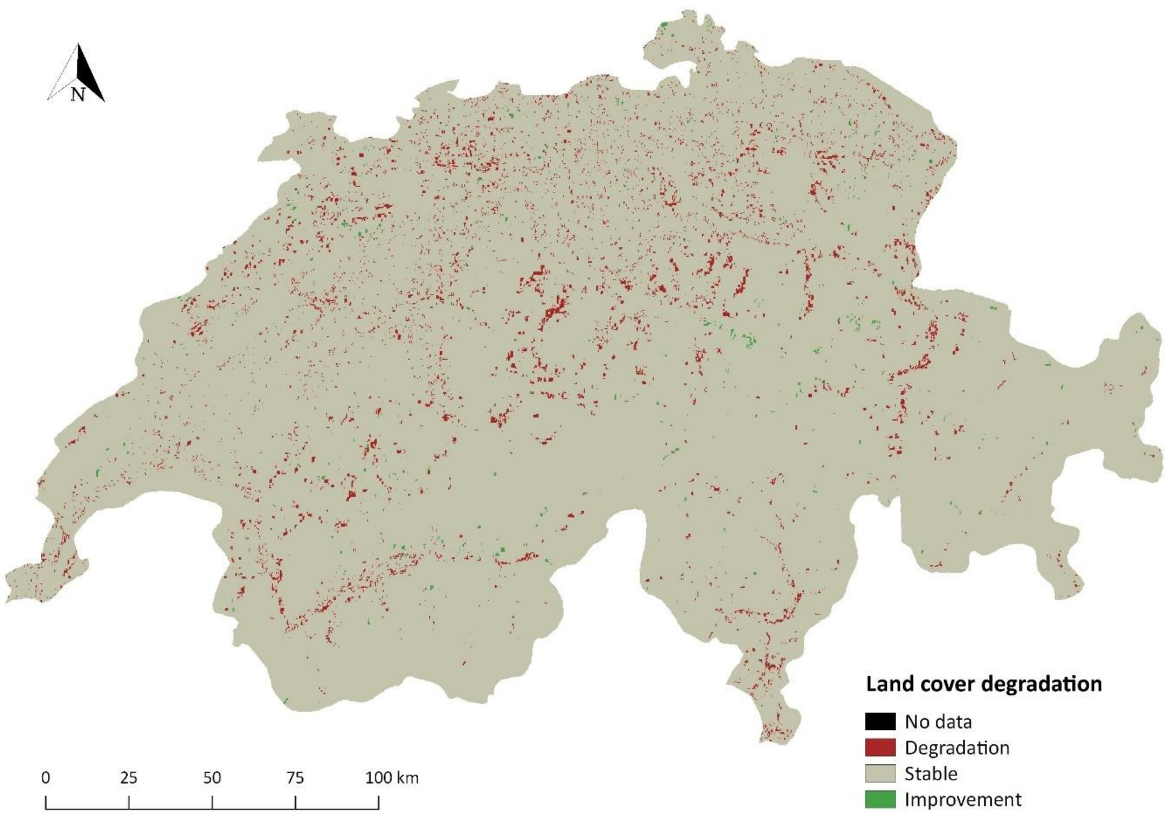


Fig. 15. Land cover degradation indicator in Switzerland.

During this period, three LC classes out of seven incurred area losses: tree-covered areas and croplands decreased by 4%, while losses in “other land” were of 0.18% (fig .16). On a practical level, tree-covered area in the baseline year was of 16 127 km^2 and of 15 490 km^2 in the target year, whilst cropland lost about 257 km^2 of land (from 6 272 to 6 015 km^2) (appendix 2). Inversely, artificial areas increased by almost 50%, growing up from 1 232 to 1 804 km2. LC transitions to wetlands increased by 4.7%, of 2.4% for grasslands and of 1.5% for water bodies.

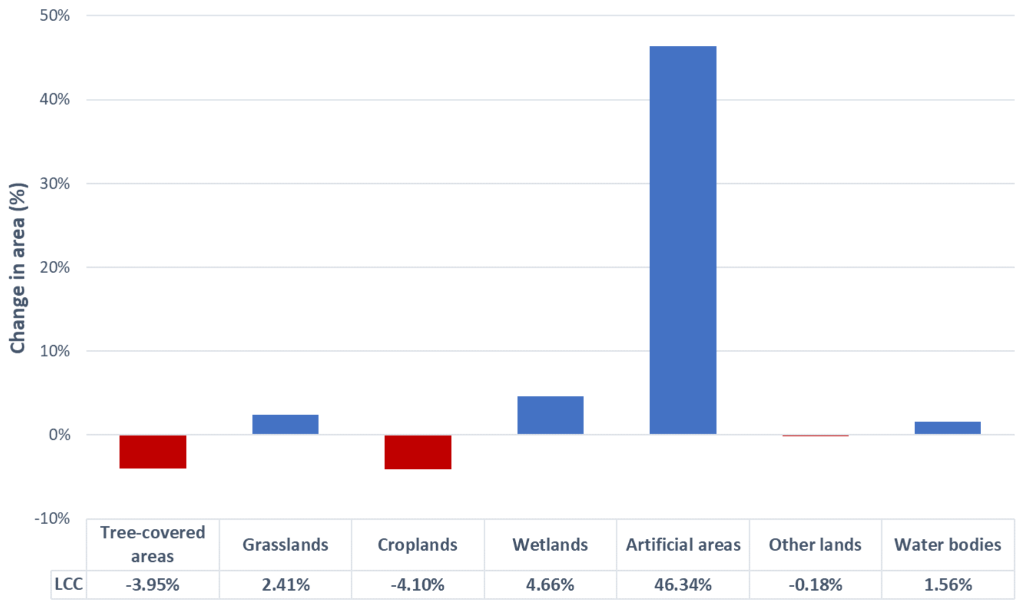


Fig. 16. Graphic change in area (%) of the 7 classes. Blue bars indicate a growth and red bars indicate a decreased area.

According to the UNCCD reporting, tree-covered areas, grasslands, croplands and other land transited to the artificial area class (fig.17). In the case of croplands, the most considerable transition was to artificial area. Croplands partly became tree-covered areas and grassland too. Additionally, tree-covered areas transformed in grassland, cropland, artificial areas, other land and wetlands; while other types of land which turned into tree-covered areas originally were grasslands and other land.

Land cover type in baseline year	Land cover in target year: Tree-covered areas	Grasslands	Croplands	Wetlands	Artificial areas	Other land	Total
Tree-covered areas	15 399.25	478.57	153.66	1.32	66.19	2.70	16 101.70
Grasslands	78.13	12 522.46	8.32	0.00	95.47	0.04	12 704.42
Croplands	10.83	4.03	5 853.03	0.00	403.25	1.24	6 272.38
Wetlands	0.04	0.00	0.00	17.76	0.04	0.00	17.85
Artificial areas	0.00	0.00	0.00	0.00	1 232.88	0.00	1 232.88
Other land	1.98	5.95	0.00	0.00	2.67	3 651.67	3 662.27
Total	15 490.24	13 011.01	6 015.01	19.08	1 800.49	3 655.66	

Fig. 17. Land cover change in area (sq. km) providing details on the type of transition.

Concerning the SOC sub-indicator, changes in SOC storage from baseline to target year was of -0.82%. Generally speaking, 94.2% of the total land area showed stable SOC; while land area with degraded SOC represented 1.6% of the country, which was mainly caused by the artificial surface growth (appendix 3). Land area with no data for SOC represented 4% of total the land area and no land area with improved SOC was detected (table 3, fig.18).

Table 3. Soil organic carbon stocks classification (improved, stable, degraded and no data) in km2 and %.

Soil organic carbon	Area (km^2)	Total land area (%)
Total land area	39 995.9	100.00%
Improved	9.2	0.02%
Stable	37 693.0	94.24%
Degraded	624.6	1.56%
No data	1 669.1	4.17%

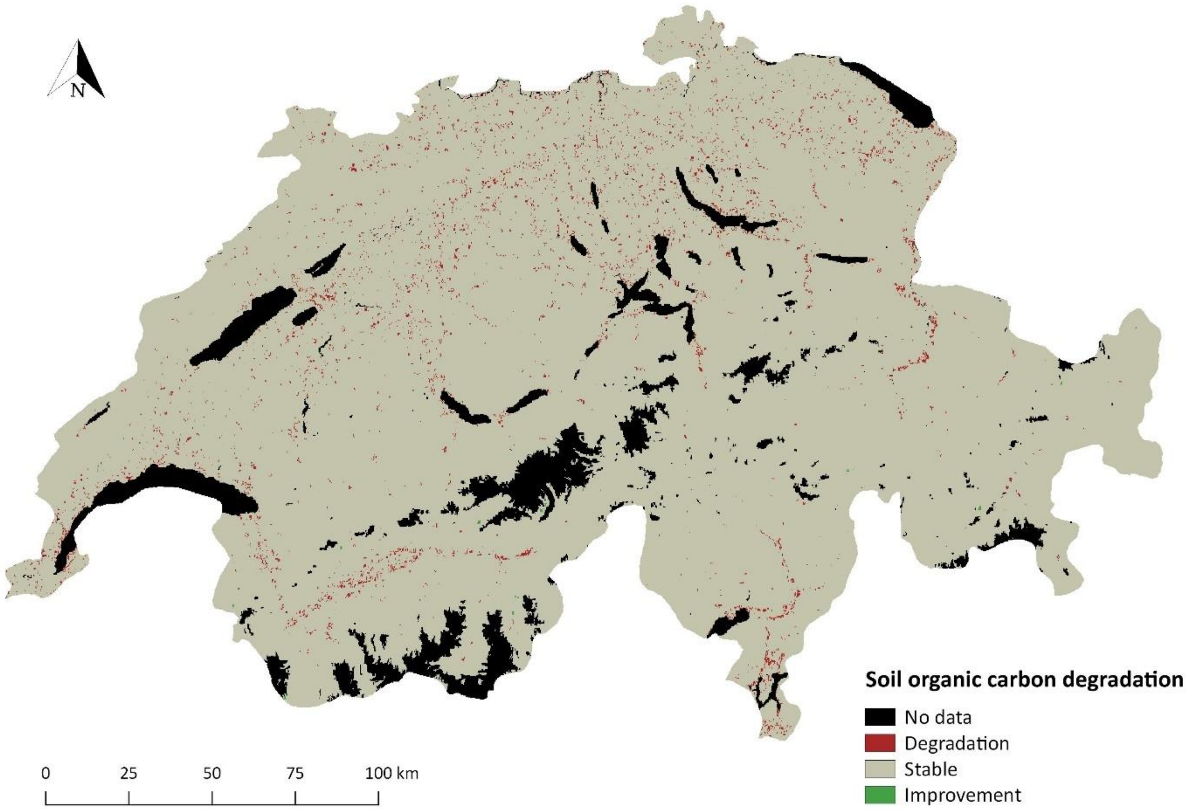


Fig. 18. Soil organic carbon degradation in Switzerland. Classification of pixels in no data, degradation, stable and improvement.

As shown by the graphic below (fig. 19), the most significant change in SOC took place in artificial areas, with a change of 42.5% in 15 years. Decreasing amounts of SOC were observed for tree-covered areas, croplands and “other lands”.

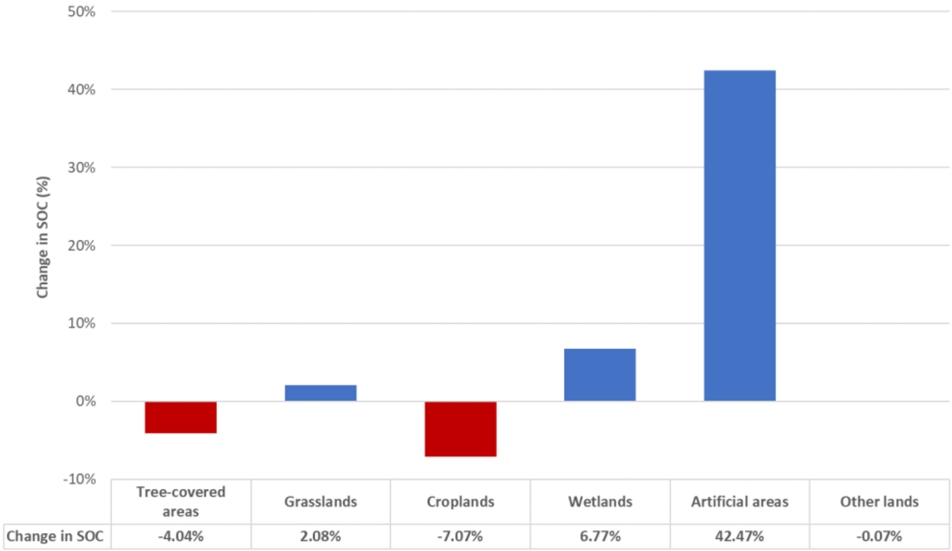


Fig. 19. Change in soil organic carbon (%) for each type of land cover. Blue bars indicate an increase, while red bars indicate a decrease. Details are in appendix 3.

The two methodologies to calculate vegetation productivity generated slightly different results (fig. 20, appendix 4): LP of the Trends.Earth plug-in estimated about 13% – percentage of total land area – of improved vegetation productivity less than the percentage of LPD of the JRC used by the UNCCD model. In contrast, results of land area with stable, degraded or no data productivity were higher in the case of the Trends.Earth model, with differences of respectively -7.4%; -2.6% and -3.2%. Trends.Earth calculated a percentage of land with no data for productivity four times the percentage of UNCCD model.

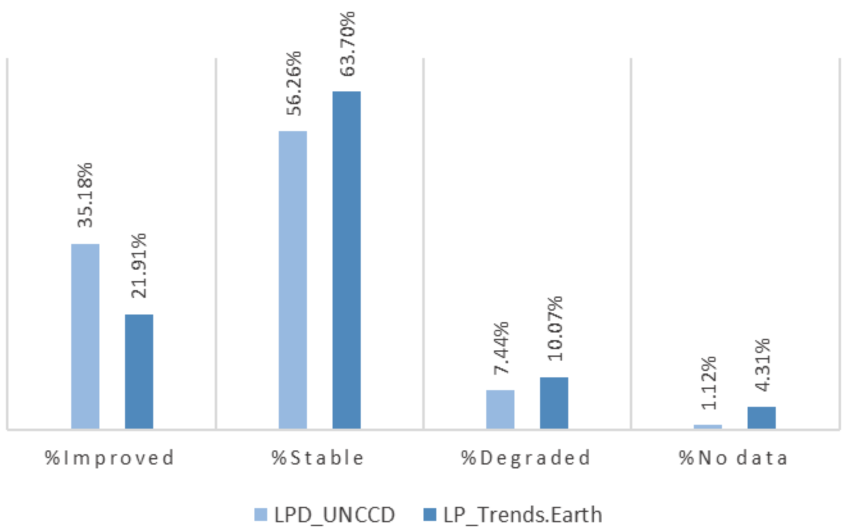


Fig. 20. Differences (UNCCD minus Trends.Earth model) in vegetation productivity between the two models. In absolute percentages, the detected differences were lower than 10%.

Focusing on LPD, land areas with increasing vegetation productivity are mostly located in the Swiss Plateau and the valley floors of different regions, namely in the cantons of Ticino and Valais (fig. 21). 22 502 km^2 of land with stable productivity are homogeneously distributed all over the country. Surfaces with degraded productivity are mainly concentrated in alpine regions.

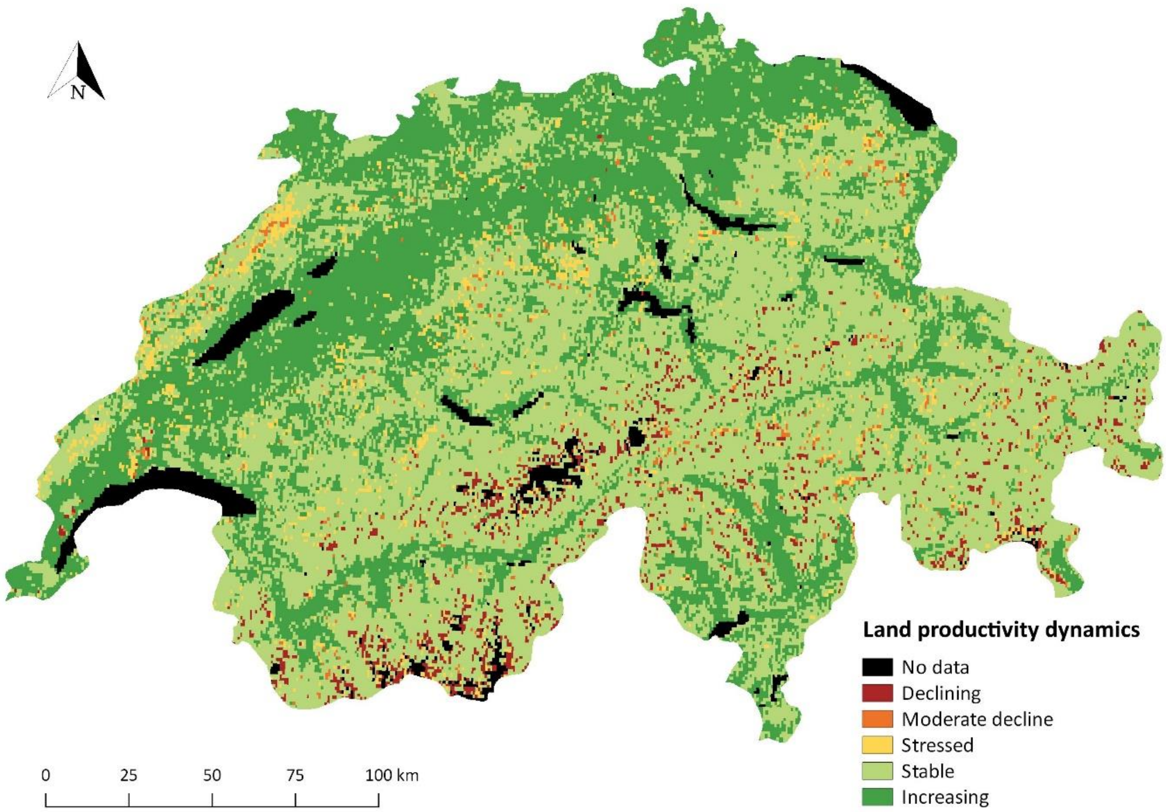


Fig. 21. Land productivity dynamics in Switzerland based on the Joint Research Centre dataset used by the UNCCD model.

When analysing the vegetation productivity by type of LC transition, it was observed that the “other land” class showed a very small percentage improvement in productivity compared to the other LC classes (fig. 22), highlighting a stable productivity instead. About 20% of grasslands are considered as improved and this percentage doubled in the case of tree-covered areas. Moreover, artificial areas and croplands achieved similar percentages of increase land productivity (over 60%). Generally speaking, the different type of LC revealed a stable productivity.

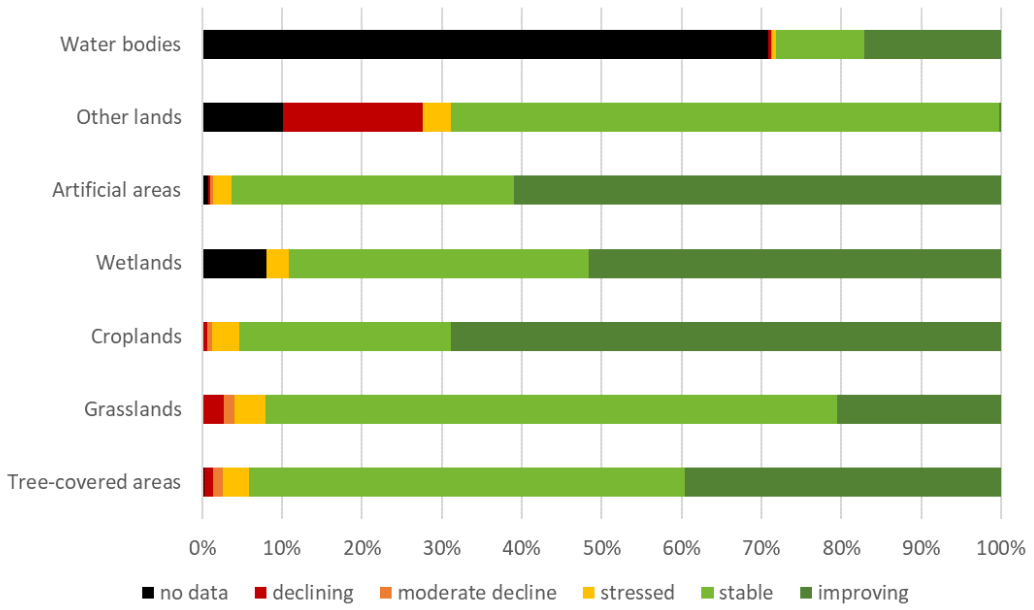


Fig. 22. Details on the conditions of the vegetation productivity (JRC, UNCCD) of each land cover, provided with the percentage of no data, declining, moderate declining, stressed, stable, and improving productivity.

As for the LPD, LP[4] of the Trends.Earth model was mostly stable (63.7% of total land area; fig.20). In contrast to the UNCCD model, in this case pixels showing land with degraded productivity are more homogeneously distributed across the country (fig.23). Nonetheless, increasing land productivity was principally located in the Swiss Plateau and in some regions of the Swiss Alps (i.e. Ticino and Valais valley floors).

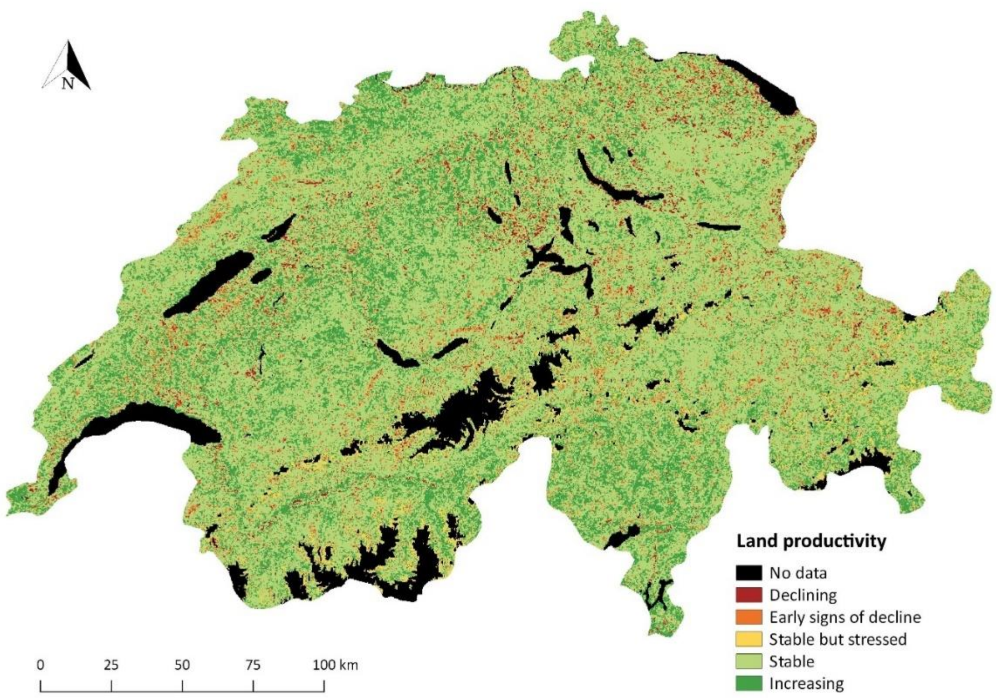


Fig. 23. Land productivity in Switzerland based on the Trends.Earth dataset.

[4] Results of the productivity sub-indicators are provided in appendix 5.

With a focus on the LP by type of LC, it was noticed that all LC types presented a more significant percentage of land with stable productivity (fig. 24). Furthermore, compared to the UNCCD model, percentages of land with improving productivity are lower in all the classes. Additionally, it was observed that the percentage of decreasing productivity was mainly due to the declining productivity of the artificial areas class. Trends.Earth also detected higher percentages of moderate declining productivity.

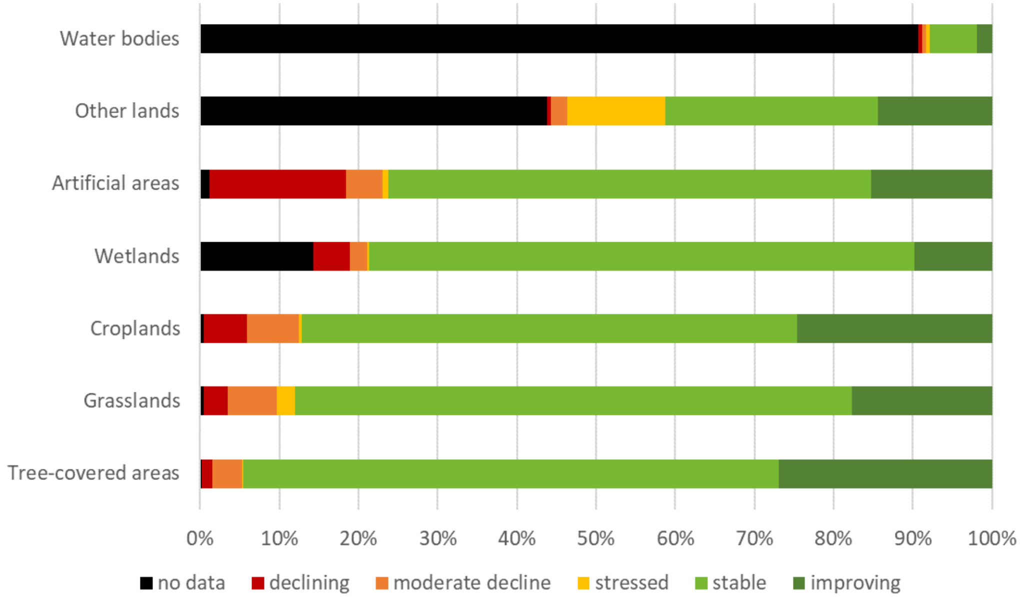


Fig. 24. Details on the conditions of the vegetation productivity (Trends.Earth) of each land cover, provided with the percentage of no data, declining, moderate declining, stressed, stable, and improving productivity.

5.2 Final SDG 15.3.1 indicator

The combination of the three metrics allowed to estimate the land degradation in Switzerland on the basis of the time series 2001-2015 (appendix 6): SDG 15.3.1 of the UNCCD assumed that 33.4% of the total land was improved, half of the total Swiss land was stable and less than 10% was degraded. Concerning the land degradation indicator calculated by Trends.Earth, the percentage of stable land area was of 61% (8.6% higher than the UNCCD), about three times the percentage of improved land (21.5%). Degraded land represented 13% of the total land area of the country, 3.2% more than UNCCD results. Overall, Trends.Earth estimated higher percentage of stable and degraded lands and underestimated – compared to the UNCCD model – the amount of improved land (difference of about 12%) (fig. 25).

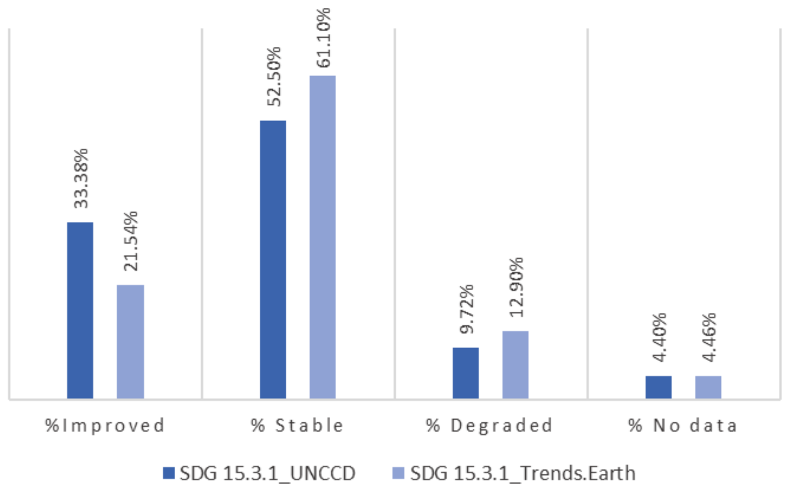


Fig. 25. Differences (UNCCD minus Trends.Earth model) of SDG 15.3.1 between the two models. In absolute percentages, the detected differences were about 10%.

These differences are mostly located in the Swiss Alps and around the lakes (fig.26).

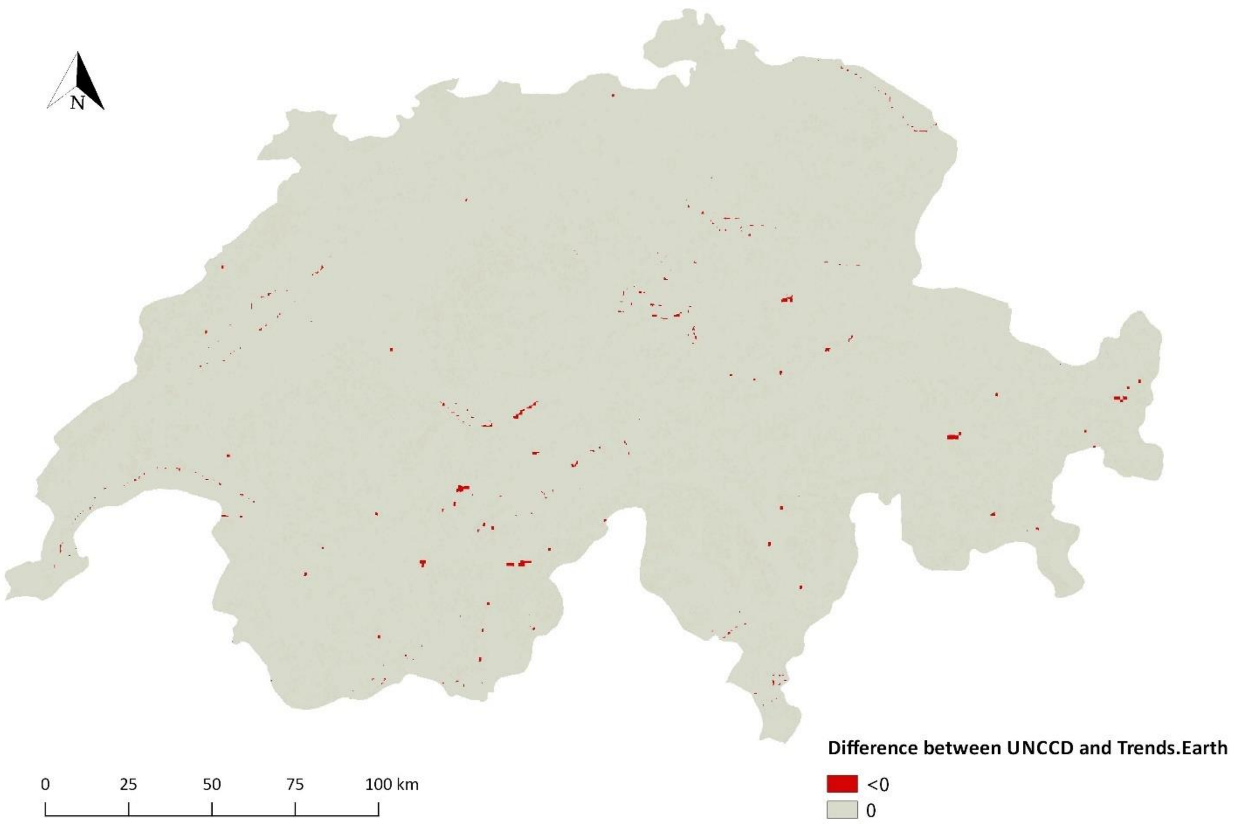


Fig. 26. Visual presentation of differences between the two models (UNCCD - Trends.Earth) for the SDG 15.3.1 indicator. Red pixels indicate areas where Trends.Earth SDG 15.3.1 values were higher than UNCCD values.

As the vegetation productivity reflects the condition of the land, SDG 15.3.1 indicator results followed a similar pattern (fig. 27 and fig.28). Thus, improved land areas were mostly located in the Swiss Plateau, in part of the Jura region and in the valley floors of the Swiss Alps. In contrast to the vegetation productivity sub-indicator, the two models had the same percentage of no data, represented by water bodies and alpine regions (snow).

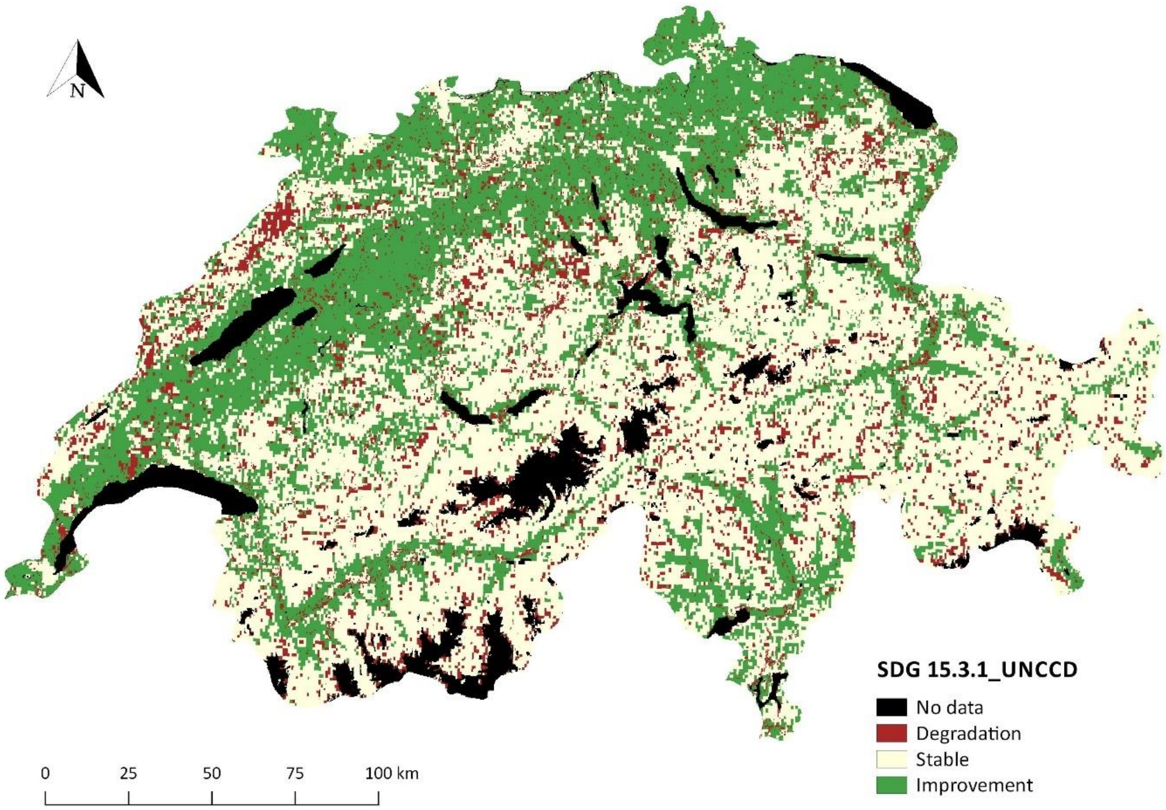


Fig. 27. Land degradation in Switzerland based on the UNCCD dataset.

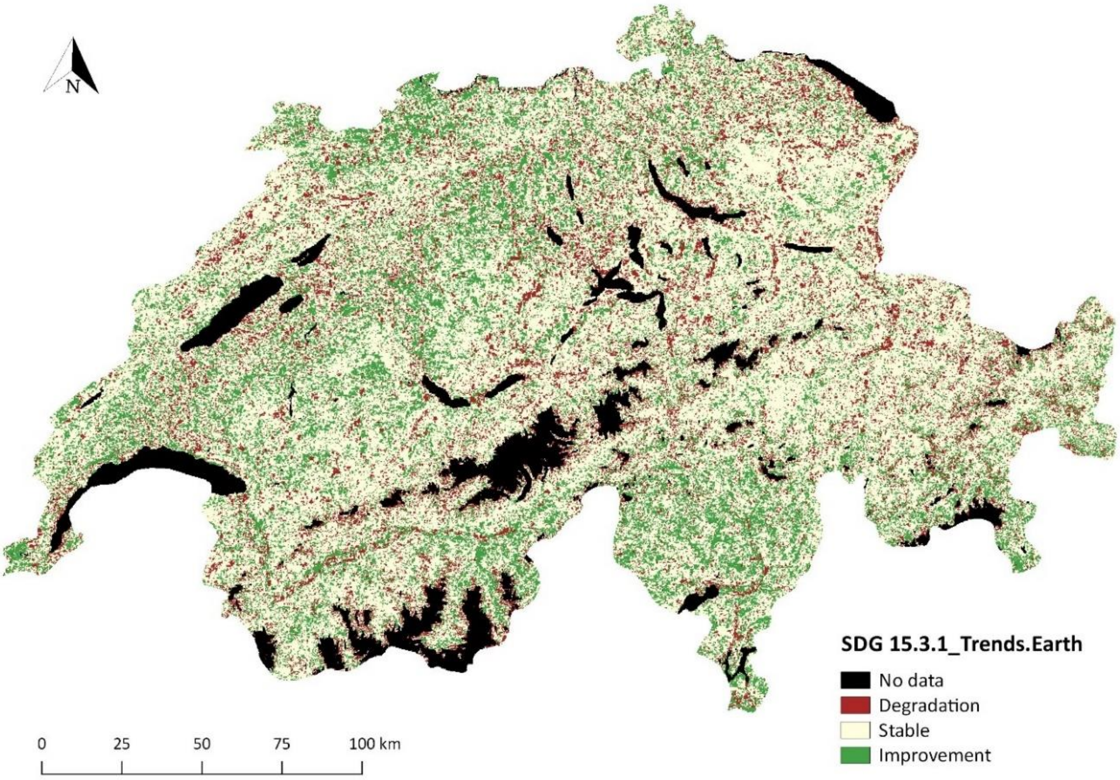


Fig. 28. Land degradation in Switzerland based on the Trends.Earth dataset.

5.3 Vegetation productivity and SDG 15.3.1 indicator by Swiss cantons

Land productivity results (%) of UNCCD and Trends.Earth were compared by Swiss cantons and by classification (improved, stable and decreasing productivity). “No data” class was not treated as no significant differences were detected.

Concerning the improved productivity class, differences in percentage (UNCCD minus Trends.Earth) between the two models ranged from -37% to 58% (fig. 29). In terms of proportions (Trends.Earth/UNCCD), improved productivity calculated by Trends.Earth, 13 cantons (AI, BE, BL, FR, GL, GR, LU, NW, OW, SZ, TI, UR, VS) out of 26 represented 60%-110% of the UNCCD percentages (appendix 7). 7 cantons (AR, GE, JU, NE, SG, VD, ZG) achieved about half of the UNCCD percentages (40%-50%) and 5 only between 20% and 30%. Only Basel Stadt (BS) obtained a percentage of more than twice the UNCCD result: improved land productivity was 66.3% for the Trends.Earth model versus 29.3% of the LPD used by the UNCCD model.

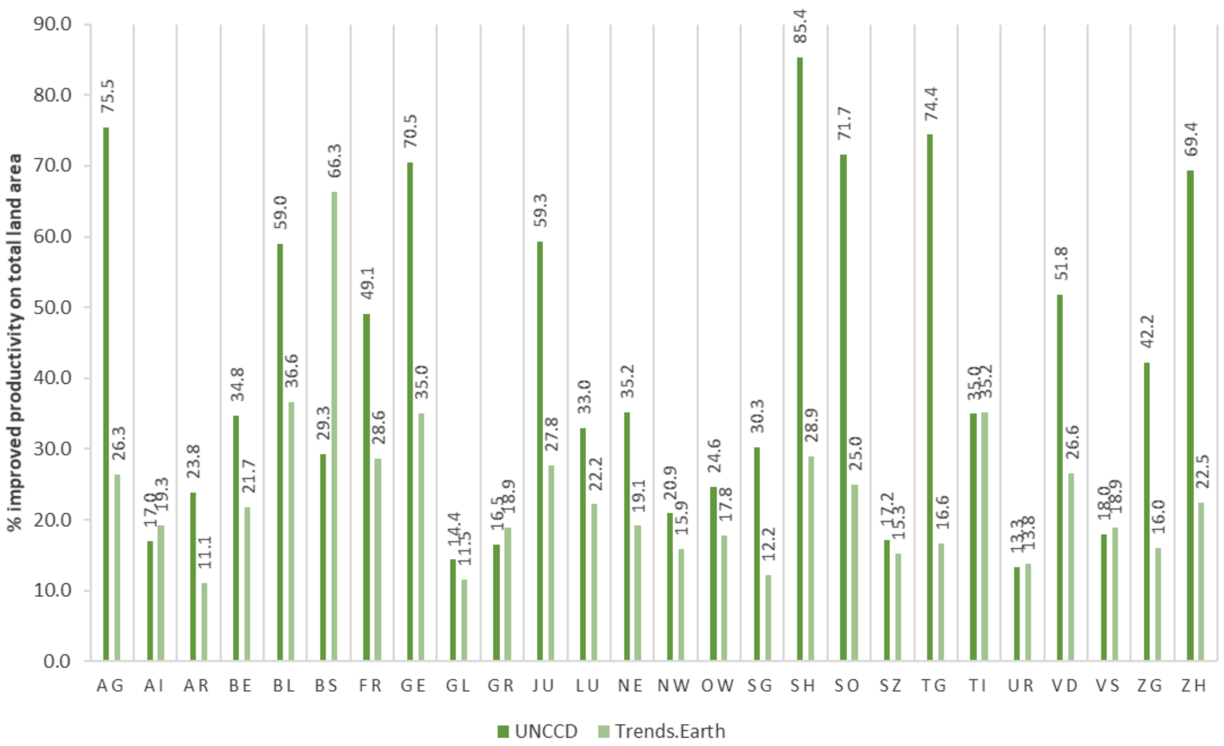


Fig. 29. Comparison between UNCCD and Trends.Earth improved productivity on total land area.

In general terms, percentages of stable productivity by cantons were higher in the Trends.Earth model, specifically for 20 cantons, excepted for BS, GL, GR, SZ, UR and VS (fig.30). The percentages of land with stable productivity between the two models were generally similar for 13 cantons (AI, AR, BE, GL, GR, LU, NW, OW, SG, SZ, TI, UR and VS), ranging from 80% to 120%. 5 cantons (BL, FR, NE, VD and ZG) reached percentages that were about one and a half times the UNCCD percentages, and Geneva, Jura and Zurich results were more or less two times more significant. In total, 4 cantons (AG, SH, SO and TG) presented percentages that were about three times the UNCCD results, in the case of Schaffhausen this percentage was more than four times higher. Basel Stadt achieved only ½ of the percentage obtained by the UNCCD.

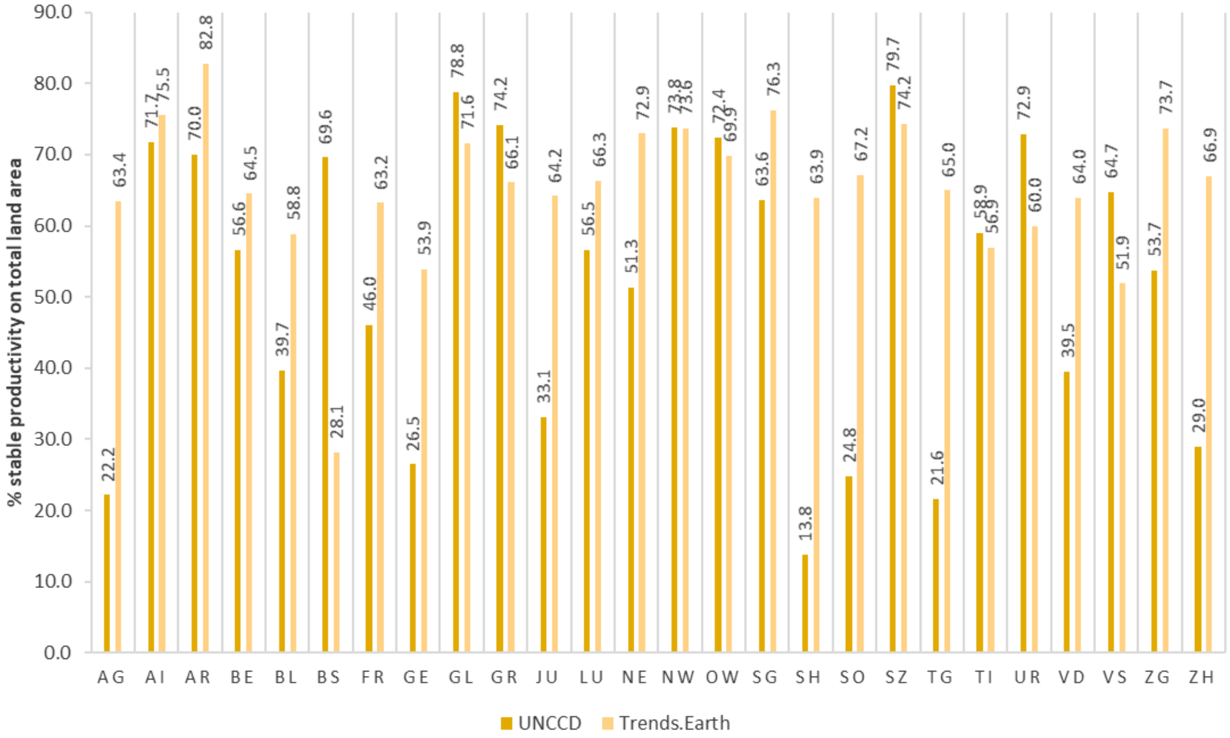


Fig. 30. Comparison between UNCCD and Trends.Earth stable productivity on total land area.

Results for percentages of decreasing productivity were variable and, except for Appenzell Innerrhoden (AI), Neuchâtel (NE) and Valais (VS), UNCCD percentages were lower than the Trends.Earth model. Similar results were obtained by 9 cantons (AR, BE, GR, JU, LU, TI, UR, VD and VS). 5 cantons that had percentages twice as high as the UNCCD ratios (200%-250%) or more: GL, NW, SG, SO and ZG. 10 had percentages tree times higher or more: AG (x4.2), BL (x3.2), BS (x4.1), GE (x4.1), OW (x3.5), SH (x8.0), SZ (x3.3), TG (x4.9) and ZH (x6.9).

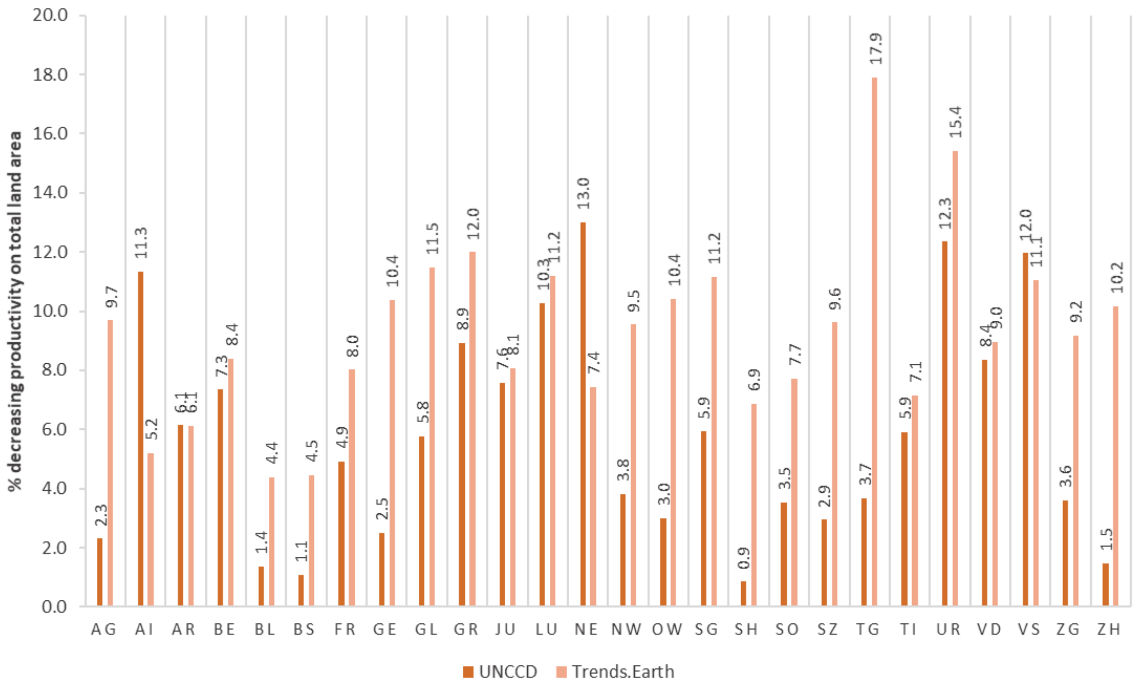


Fig. 31. Comparison between UNCCD and Trends.Earth decreasing productivity on total land area.

Estimated percentage values of improved land of the different cantons were almost the same in the case of 10 cantons: AI, GL, GR, LU, NW, OW, SZ, TI, UR and VS (fig.31). 12 cantons represented 40-60% of the UNCCD results (AG, AR, BE, BL, FR, JU, NE, SG, SH, SO, VD and ZG), while Thurgau and Zurich achieved only 20-30% of the UNCCD percentages. The ratio for Basel Stadt was of 2.3, more than two times the UNCCD result for this canton (appendix 8).

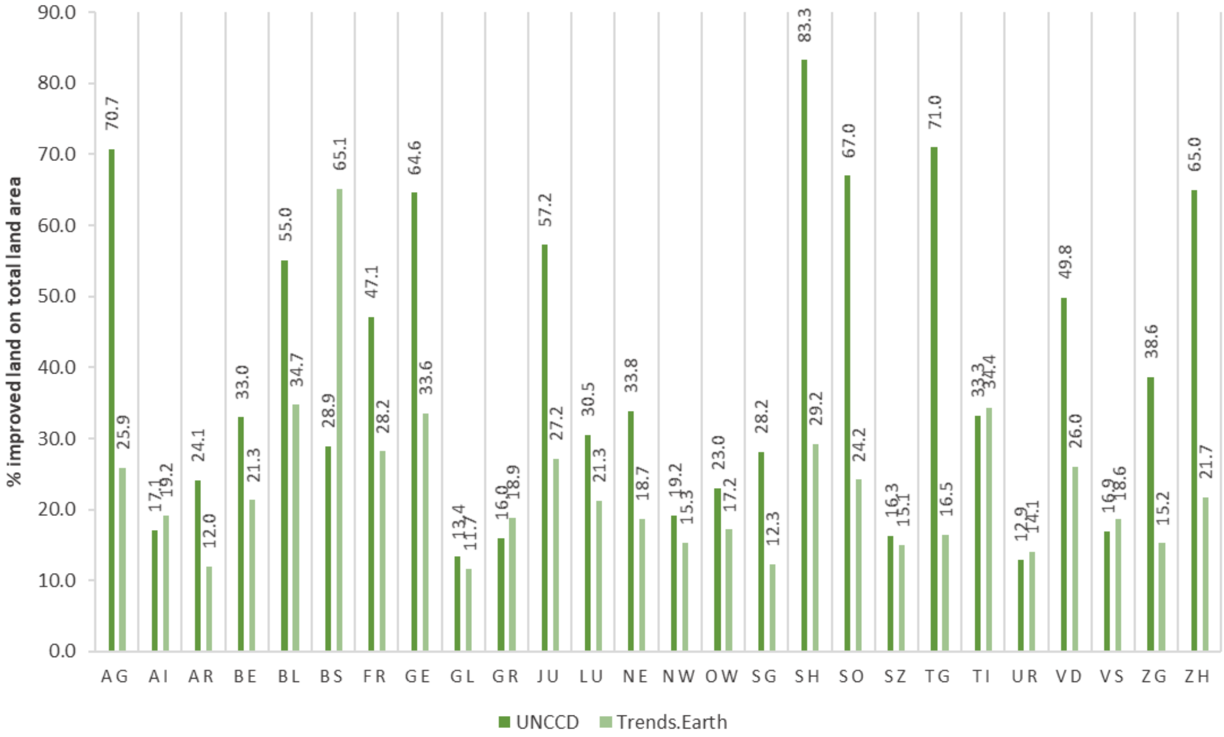


Fig. 32. Comparison between UNCCD and Trends.Earth improved land on total land area.

Concerning the portion of stable land, no important variations were observed between the two models, namely for cantons 13: AI, AR, BE, GL, GR, LU, NW, OW, SG, SZ, TI, UR and VS (fig.33). Ratios varying from 1.4 to 1.6 were observed in 5 cantons: BL, FR, NE, VD and ZG. In addition, 7 cantons achieved ratios of 2.0 or more: AG, GE, JU, SH, SO, TG and ZH. The percentage of improved land calculated by Trends.Earth was less than half the UNCCD result.

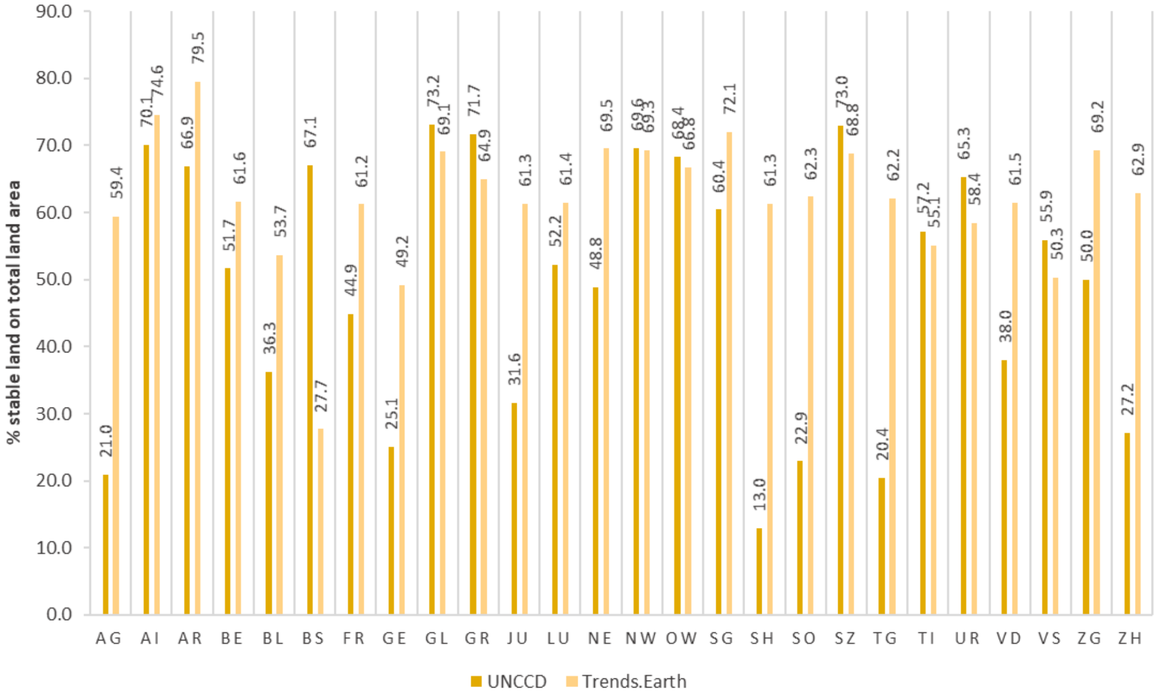


Fig. 33. Comparison between UNCCD and Trends.Earth stable land on total land area.

Regarding portions of degraded land, the UNCCD results showed lower percentages of degraded land (fig.34), with the exception of Appenzell Innerhoden (ratio: 0.5) and Neuchatêl (ratio: 0.7). In some cases, these ratios were a half or less than a half of the estimation of Trends.Earth: AG, BS, GE, GL, OW, SH, TG and ZH. Cantons with similar percentages were 8 in total: AR, BE, BL, JU, LU, SO, TI and VD. Furthermore FR, GR, NW, SG, SZ, UR, VS and ZG showed percentages of 130-160% of the UNCCD model.

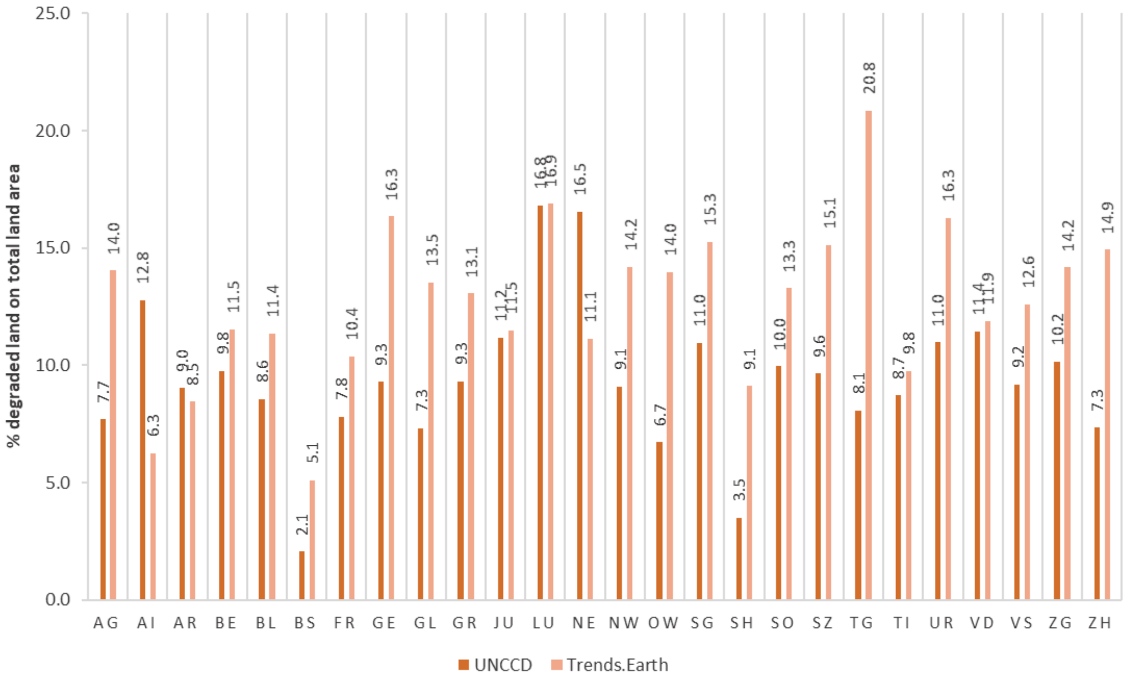


Fig. 34. Comparison between UNCCD and Trends.Earth degraded land on total land area.

6 Discussion

This section, devoted to the comments on the results presented above, is divided in sub-sections in order to separate the discussion strictly related to the two models from the comments on the general conditions of the land in Switzerland. The discussion on Swiss land degradation is based on the results of Trends.Earth as the study tests this model.

6.1 Differences between the two models

The comparison of the vegetation productivity and the SDG 15.3.1 indicator results between the UNCCD model and Trends.Earth does not show important differences. The significance of these differences cannot be statistically tested (n=2 for each indicator). Despite this, a difference of 10% is considered as acceptable by this study. Differences in the "no data" class regarding plant productivity can be explained by the exclusion of high mountain regions, where the vegetation is rare, in the Trends.Earth model.

Moreover, one of the first thing that were noticed is the differences at the visual level: output layers by using UNCCD datasets have a lower resolution than Trends.Earth (fig. 35). In general, the plug-in provides output layers in a coarse resolution. Although the UNCCD map has a worse resolution, it is easier to read and interpret. Large regions with an improved or degraded land are easier to identify at the national/cantonal scale.

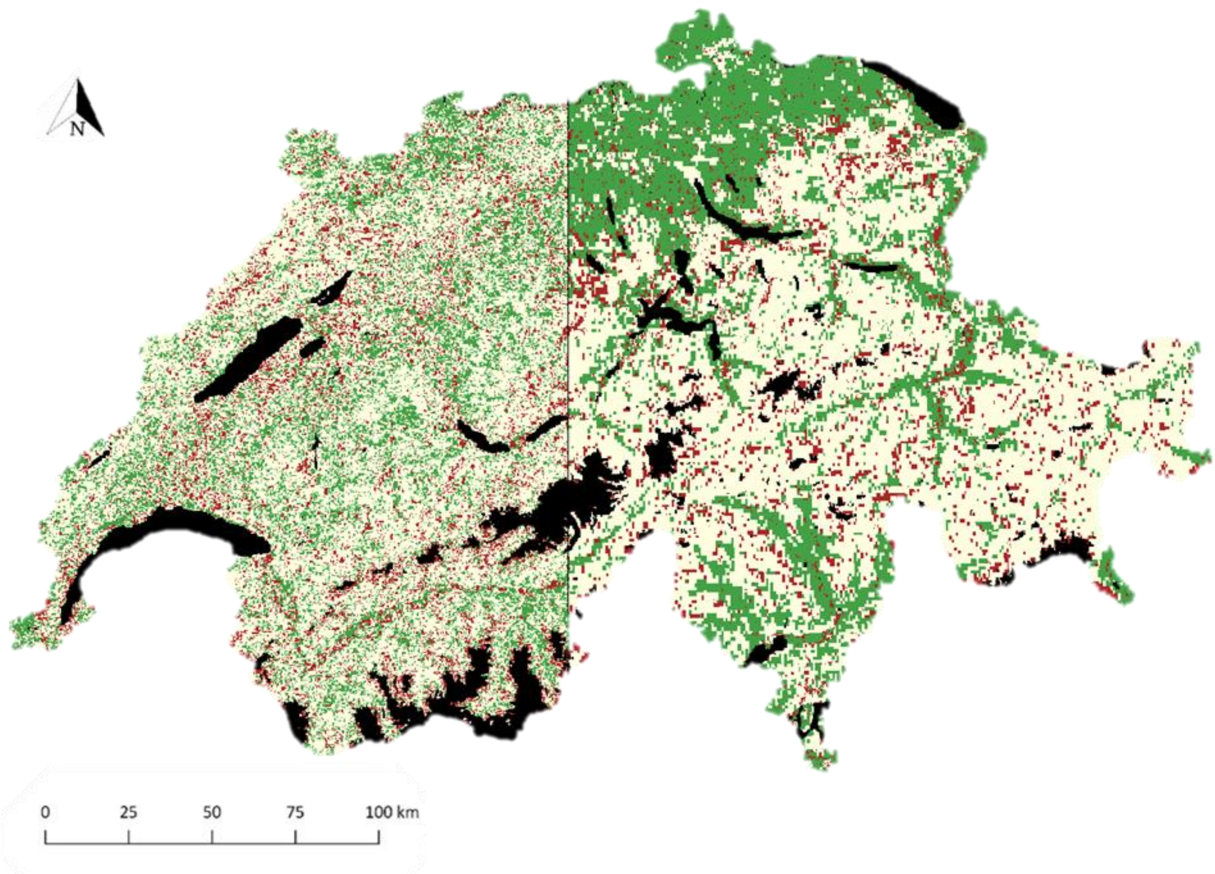


Fig. 35. Swipe-map of the two SDG 15.3.1 indicators showing the different resolution. Trends.Earth on the left and UNCCD model on the right.

As Trends.Earth recurs to regional or global datasets, it is suitable and helpful for a global/international analysis (fig. 36).

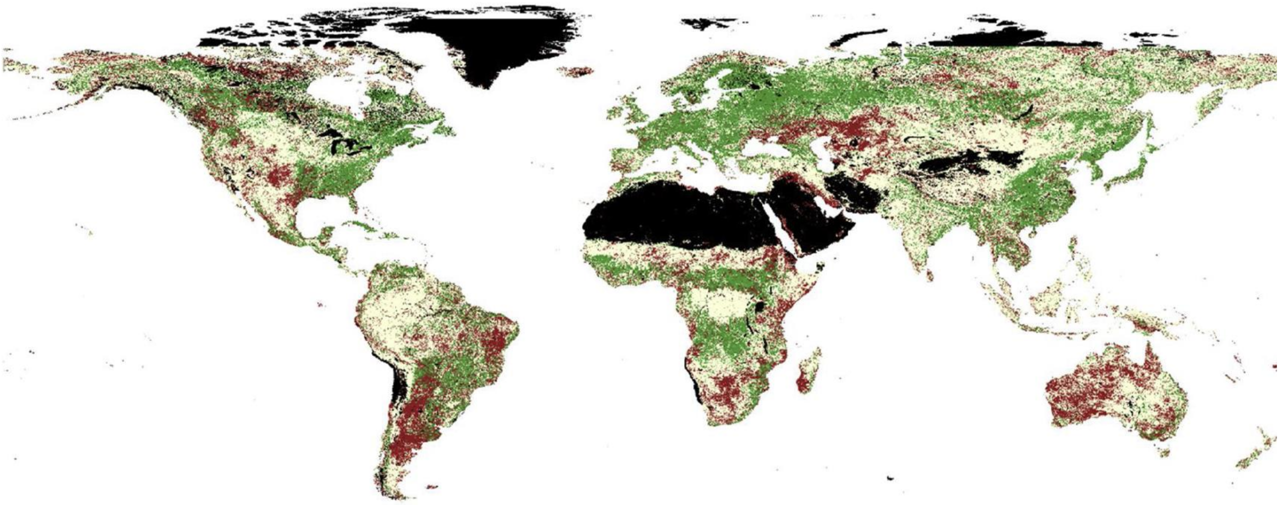


Fig. 36. Global land degradation using Trends.Earth plug-in (Source: Giuliani et al., 2020, p.6).

6.2 The general state of Switzerland's land

According to the Federal Statistical Office (FSO), artificial surfaces increased by 584 km^2 from 1985 to 2009 (FOEN, 2017a). Sealed surfaces are susceptible to degrade soil, which eventually loses its natural functions. In 2009, the urbanised areas covered 7.5% of Switzerland's territory (FOEN, 2017b). Moreover, in 2017, it was estimated that 60% of the urbanized land was sealed and that sealing land reaches a percentage of 10% in the Swiss Plateau (FOEN, 2017c)

Concerning the most productive soils, the Observation of Swiss Landscape program (OPS: Observation du Paysage Suisse), with collaboration of the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), reported that 32% of the habitat areas were previously cropland surfaces (transition from 1985 to 2009), 33% were grasslands, 13% were agricultural lands (i.e. orchards, horticultural lands, vineyards, etc.), and 9% were pasturelands (FOEN, 2017b).

For the period 2001-2015, Trends.Earth observed a similar trend: transitions of LC to the artificial areas class increased by 46%. During this period, losses in tree-covered areas and croplands were of 4% each. Instead, grasslands gained 2% of other types of LC. The growth of artificial areas is linked to croplands loss, as about 22% of artificial areas were represented by this type of land use/LC. Transition of tree-covered areas (4%) and grasslands (5%) also contributed to artificial areas growth. Geographically speaking, degraded LCC surfaces are specifically located in urban areas (i.e. cities and around the lakes) and in croplands (fig.37).

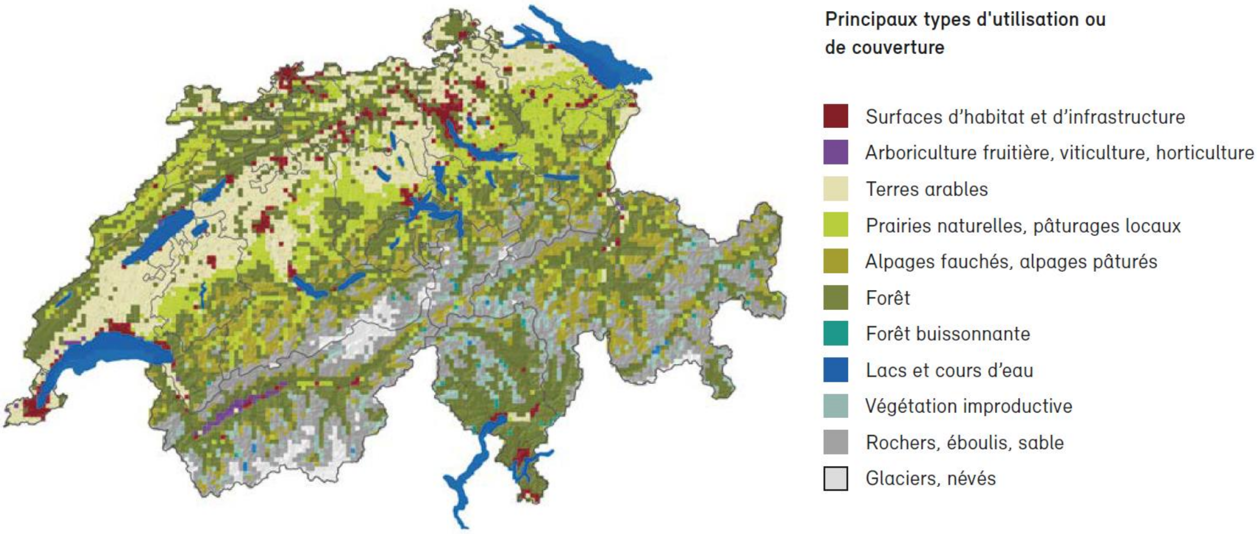


Fig. 37. Main land uses in Switzerland. Red = habitat areas; violet = orchard and other agricultural lands; beige = croplands; light green = grasslands and local pastures; green-brown = mowed and grazed alpine pasture; dark green = forests; green-blue = bushy forests; blue = lakes and water streams; light blue = unproductive vegetation; grey = rocks, screes and sand; white = glaciers, snow (Source: FOEN, 2017b, p.17)

Nevertheless, areas certifying a degraded LCC are – partly – overlapped by areas presenting an improved plant productivity. Yet, this assumption is not visually easy to confirm by looking at the maps (fig. 23 and 28), but the UNCCD reporting provided by the plug-in shows that the net land productivity dynamics increased between 2000 and 2010 for croplands (appendix 9). This improvement is in contrast with the results of the SDG 15.3.1 indicator of Trends.Earth, which indicates both improved and degraded land in croplands. It is important to note that the model does not provide further information on the quality of the soil, namely on the biodiversity loss, the soil eutrophication/acidification, the soil erosion, etc. Thus, it is difficult and complex to clearly identify the factors of a local change in land conditions and field work knowledges are then required. Another explanation to the high LP in some areas could be the methodology: the plug-in considers the transition of grasslands to croplands as positive, while it could be negative in Switzerland. By changing the land cover change matrix in the Trends.Earth model, LP results could be different.

Vegetation productivity in the Swiss Alps, namely in the case of the cantons of Valais and Ticino, seems to increase in some areas. This growth can be explained by the presence of forest in these regions and its surface expansion. Nonetheless, at the same time and in the same areas, the land shows some signs of stressed productivity and degraded soil. We can hypothesize that the forestry sector in Switzerland still does not achieve the target 15.3 and that more measures to protect forests and ensure their sustainable management need to be implemented (Swiss Confederation, 2018). This hypothesis is supported by the fact that in some forest areas the SOC is degraded: reductions in carbon sinks can be caused by deforestation (Olsson et al., 2019). In addition, the presence of orchards and other type of agricultural practices in the "Bas-Valais" (Low Valais) – west of Valais – and the "Valais Central" (Central Valais) can also have an influence on land degradation. In facts, the conversion of tree-covered areas in croplands – that is a desertification – is considered as a negative transition.

Furthermore, the Trends.Earth model identifies decreasing land quality in mountainous areas. This result can be interpreted as an early sign of climate change effects. Mountains have a specific ecosystem and their diversity and complexity make them one of the most sensitive ecosystems to climatic disturbances (Fort, 2015). Climate change exacerbates land degradation and slows down the achievement of LDN by increasing the frequency of extreme events such as floods as well as droughts, fire, etc. (IUCN, 2015). These events can also involve soil erosion and reduce carbon reserves, consequently CO_2 emissions increase. Biodiversity loss is concerned too (fig. 38).

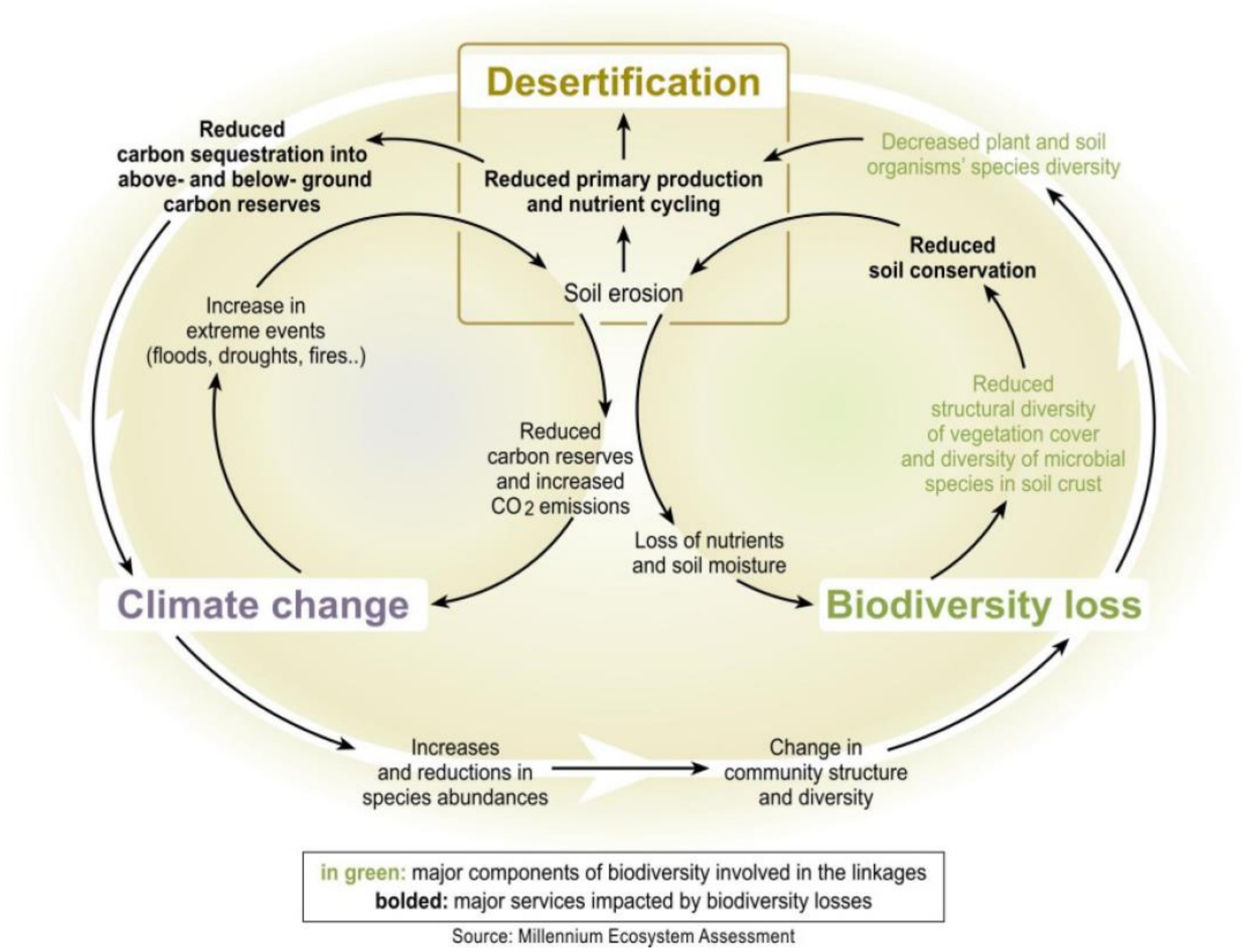


Fig. 38. Feedback loop between desertification, biodiversity loss and climate change dynamics (Source: IUCN, 2015, p.3).

In the light of what was mentioned above, the overlap of increasing vegetation productivity and degraded lands in some regions, more specifically in Valais and Ticino, can be the result of two processes: conversion of land in crop agriculture surfaces or in artificial area in the valley floors and, at the same time and with the influence of climate change, the extension of tree-covered areas in Switzerland's mountain. Actually, between 1985 and 2013, forest surfaces evolved differently depending on the region: the forest extent in the Jura and the Plateau was stable, while it expanded in the Alps, increasing by 8 to 28% (FOEN, 2019). The abandonment of cropland in mountainous regions can also promote this kind of expansion.

However, the results of this study are incongruous with the official publications of the Swiss Confederation. In fact, Trends.Earth observed a decrease in both tree-covered areas and croplands at the national and cantonal levels. This contrast can be linked to the method used to define the type of

LC. Different or better results can be obtained by customizing input data in the model with local dataset (i.e. two LC datasets to compare changes over time).

Beyond all these assumptions, Trends.Earth shows that land degradation is still a challenge in Switzerland. According to the Swiss soil sealing indicator – as a percentage of total land area – the target 15.3 has an increasing trend (observed development based on the trend) and a negative assessment (Swiss Confederation, 2018). In numbers, it was observed that in 2009, 4.7% of the Swiss territory was sealed with impermeable material. For the period 1979/85 that percentage was 3.6% and in the census years 1992/1997 it was of 4.2% (fig. 39).

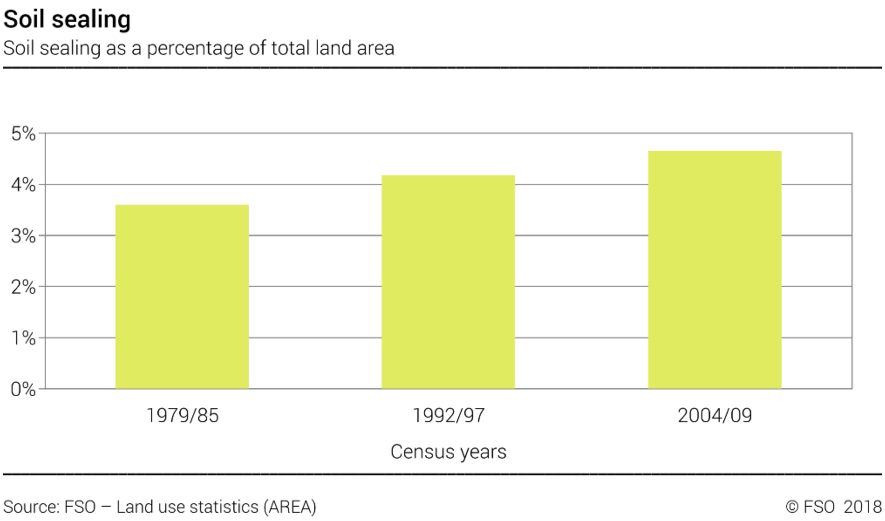


Fig. 39. Soil sealing indicator (% on total land area) (FSO, 2020).

In 24 years (1984-2009), the proportion of sealed soil increased by 29% in Switzerland (FOEN, 2017b). The growth of artificial areas plays an important role in the land degradation. Despite the fact that about 40% of residential and infrastructure surfaces are represented by green spaces, such as parks, vegetized roadsides, gardens, etc., the soil is degraded or transformed because of the effects of construction (i.e. displacement of materials) (FOEN, 2017b).

7 Conclusion

In spite of some differences with the UNCCD model – mainly due to different methodologies to derive the vegetation productivity – Trends.Earth is a robust model that is able to provide valid information on land degradation. Moreover, the plug-in is a powerful tool and it can produce results for both models. Concerning the plug-in itself, Trends.Earth presents several advantages:

- It is an open source plug-in;
- It has a simple interface;
- It is straightforward and the documentation guide the user step by step;
- It is not time consuming (although it depends on GEE);
- It is applicable to all the countries;
- It provides ready-to-use output layers;
- It is internationally comparable and the output Excel files furnish data in the UNCCD reporting format;
- It allows the users to customize the input data
- Results are in Geo-Tiff format which can be read by other GIS software.

However, it has some inconveniences too. As detailed in the discussion section, the plug-in default datasets use global datasets that do not provide further information on the local context. It can give an idea of the land conditions, but the interpretation of the results needs to be contextualized with additional knowledge on the region (i.e. national official publications) and field-based measurements. For instance, the transition from LC/LU type to another class can be positive or negative depending on the area taken into account. The expansion of tree-covered areas can be positive in one country and negative in another. The type of vegetation can also have an influence on the derivation of the vegetation productivity. Giuliani et al. (2020, p.4) pointed out the same problem: “It translates EO data into useful information. However, it does not provide any knowledge”. Moreover, policy-makers need this knowledge to correctly and successfully implement measures to combat land degradation.

In addition, it was observed that in the case of the model run at the cantonal level the differences between the UNCCD model and Trends.Earth were larger. This suggests that the model may improve its scalability. Thus, the disadvantages are:

- The lack of local knowledge for the interpretation;
- Need for an improved methodology to derive the vegetation productivity;
- Need for an improved scalability;
- Need for more available remote sensing imagery of high-resolution;
- Need to facilitate the access to datasets used in the analysis in order to allow the user to carry out statistical tests.

SDG 15.3.1 indicating degraded land in Switzerland confirmed that LDN remains a challenging issue for the country. The extent of degraded land is not wide-ranging, but Switzerland, despite the implementation of various measures, still does not have an appropriate and sustainable use of the soil and does not guarantee the conservation of its functions. As soil represents a fundamental natural resource that provides food, is the habitat for plants and animals, serves as water and carbon reservoir, plays a role in the regulation of global cycles, and so on; it is imperative to not neglect it and to protect it instead.

The application of Trends.Earth to analyse the land degradation in Switzerland is pertinent and useful as the Swiss Confederation does not have an internationally comparable indicator. Actually, Trends.Earth allows to compare the soil quality with others neighbouring countries and at the international scale. Furthermore, it is complementary to the Swiss soil sealing indicator. The combination of the two indicators, in addition to the local knowledge (i.e. extreme events, disease of the vegetation, etc.) and data (i.e. Copernicus data, Swiss Data Cube, etc.), can help Switzerland to have a global view on soil conditions across the country. Without additional costs, the results can be improved by using Swiss LC datasets, or Swiss meteorological data (precipitations, cloud conditions, etc.). Moreover, the target 15.3, as well as all the target of the 2030 Agenda, is managed at different levels: federal, cantonal and communal. Thus, it is important to coordinate all the parties and promote the dialogue between the cantons. A platform to centralize the information could be developed exploiting Trends.Earth: it will allow all the cantons to have access to data on land degradation in order to conceive a national strategy to protect and restore soil in Switzerland.

LDN is a catalyst that potentially accelerate the achievement of other SDGs (Trowbridge, 2018; UNCCD-GM, 2016). This study – with the example of land degradation – shows that part of SDGs indicators can be measured through geospatial data. Nevertheless, as Arnold et al. (2019, p.3) stated: "*The way in which the 2030 SDG indicators will be implemented will depend on the individual countries' data availability, policy and developmental priorities, capacity, available data infrastructure and institutional arrangements, among other factors*". The GPG should assist countries which have poor geospatial data availability. On one hand local data are more reliable, on the other hand global data might help some countries that do not have national capacities to process GIS data. The Trends.Earth plug-in has the potential to solve this challenge.

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9 Appendix

Appendix 1. For all land cover change that occurred one or more times between 2000-2015 a default change factors (FLU) were applied. A factor of 1 means no changes applied (Source: Mattina et al., 2018, p.22).

From Land Cover Class	To Land Cover Class	Climate	Default FLU	Notes
Wetlands	*Any other class*	all	0.04	1,a
Any other class	Other Land	all	0.1	b
Any other class	Artificial surfaces	all	0.32	2,c
Tree covered areas	Cropland	Temperate Dry/Boreal Dry	0.8	3
	Cropland	Temperate Wet/Boreal Moist/ Boreal Wet	0.69	d
	Cropland	Tropical Dry	0.58	d
	Cropland	Tropical Moist/Wet	0.48	d
Grassland	Cropland	Temperate Dry/Boreal Dry	0.8	4
	Cropland	Temperate Wet/Boreal Moist/ Boreal Wet	0.69	d
	Cropland	Tropical Dry	0.58	d
	Cropland	Tropical Moist/Wet	0.48	d
Other land, subclass 'permanent snow & ice'	*Any other class*	all applicable	0.7	e
Any other class	Other land, subclass 'permanent snow & ice'	all applicable	1	e
Water bodies	*Any other class*	all	1	f
Grassland	Forest	all	1	f
Forest	Grassland	all	1	f
Cropland	Tree-covered areas	Temperate Dry/Boreal Dry	1.25	g
	Tree-covered areas	Temperate Wet/Boreal Moist/ Boreal Wet	1.45	g
	Tree-covered areas	Tropical Dry	1.72	g
	Tree-covered areas	Tropical Moist/Wet	2.08	g
Cropland	Grassland	Temperate Dry/Boreal Dry	1.25	4,g
	Grassland	Temperate Wet/Boreal Moist/ Boreal Wet	1.45	g
	Grassland	Tropical Dry	1.72	g
	Grassland	Tropical Moist/Wet	2.08	g
Any other class	Wetlands	all	2	5,g
Other land	*Any other class*	all	2	5,g
Artificial surfaces	*Any other class*	all	2	5,g

1) except transition to ESA sub-class "permanent snow/ice" where FLU = 1
2) except any transition from Wetlands to Artificial where CFLU=0.04 and any other transition to ESA sub-class "permanent snow/ice" where CFLU = 1
3) except Wetlands to Croplands CFLU = 0.04 and any other transition from ESA sub-class "permanent snow/ice" where CFLU = 0.7
4) Grassland is treated the same as Tree covered areas in regards to SOC
5) capped at 2 due to lack of data for restoration case after catastrophic SOC losses (<60%)

a) All but refractory carbon is considered oxidised IPCC 2013 Wetlands Supplement (Mangrove soils)
b) Catastrophic loss of SOC due to loss of all vegetation inputs and subsequent erosion vulnerability, except permanent snow and ice = no change
c) Average loss 68% for soil sealing (Wei *et al* 2014)
d) Adapted from Table 5.5 IPCC (GPG 2006)
e) Assuming thawing permafrost leading to 30% loss of SOC (Zimov *et al* 2006). The inverse case assumes no change in SOC.
f) Assumes no change in SOC levels.
g) Restoration cases are assumed as the inverse of the opposite land use conversion and FLU is capped at 2 for 'previous losses' of SOC greater than 60%/FLU < 0.4.

Appendix 2. Land cover change by land cover class: details on the total area in the baseline year, the target year and the changed area (km2).

LCC	Baseline area (km^2)	Target area (km^2)	Change in area (km^2)
Tree-covered areas	16 127.13	15 490.88	-636.25
Grasslands	12 705.02	13 011.01	305.99
Croplands	6 272.38	6 015.01	-257.37
Wetlands	18.32	19.17	0.85
Artificial areas	1 232.88	1 804.16	571.29
Other lands	3 662.27	3 655.66	-6.61
Water bodies	1 418.30	1 440.39	22.09

Appendix 3. Summary of change in soil organic carbon: changes from baseline to target and by type of LC transition. SOC losses principally concern artificial areas.

Summary of change in soil organic carbon

	Area (sq km)	Percent of total land area
Total land area:	39 995.9	100.00%
Land area with improved soil organic carbon:	9.2	0.02%
Land area with stable soil organic carbon:	37 693.0	94.24%
Land area with degraded soil organic carbon:	624.6	1.56%
Land area with no data for soil organic carbon:	1 669.1	4.17%

Percent change in soil organic carbon storage from baseline to target: ***-0.82%***

Soil organic carbon change from baseline to target

	Baseline soil organic carbon (tonnes / ha)	Target soil organic carbon (tonnes / ha)	Baseline area (sq. km)	Target area (sq. km)	Baseline soil organic carbon (tonnes)	Target soil organic carbon (tonnes)	Change in soil organic carbon (tonnes)	Change in SOC
Tree-covered areas	158.25	157.85	16 101.70	15 490.24	254 812 304.32	244 517 732.29	-10 294 572.03	-4.04%
Grasslands	176.42	175.84	12 704.42	13 011.01	224 130 335.85	228 787 906.28	4 657 570.42	2.08%
Croplands	121.96	118.18	6 272.38	6 015.01	76 495 205.66	71 087 864.54	-5 407 341.12	-7.07%
Wetlands	139.20	139.01	17.85	19.08	248 466.54	265 293.60	16 827.07	6.77%
Artificial areas	115.50	112.68	1 232.88	1 800.49	14 240 288.92	20 288 327.34	6 048 038.42	42.47%
Other lands	117.60	117.73	3 662.27	3 655.66	43 067 555.49	43 036 934.00	-30 621.48	-0.07%
		Total:	*39 991.51*	*39 991.51*	*612 994 156.77*	*607 984 058.05*	*-5 010 098.72*	

Soil organic carbon change from baseline to target by type of land cover transition (as percentage of initial stock)

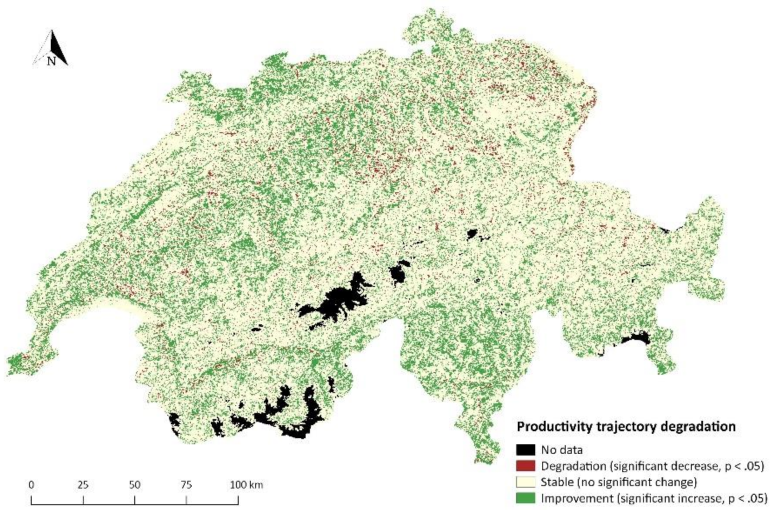
Land cover type in baseline year	Land cover type in target year: Tree-covered areas	Grasslands	Croplands	Wetlands	Artificial areas	Other lands
Tree-covered areas	-0.06%	-0.40%	-6.14%	-0.17%	-36.95%	-31.03%
Grasslands	-0.05%	-0.12%	-8.69%		-35.99%	-22.51%
Croplands	4.13%	3.81%	-0.79%		-38.42%	-11.85%
Wetlands	0.00%			-0.14%	0.00%	
Artificial areas					-2.44%	
Other lands	25.98%	32.47%			-1.24%	0.00%

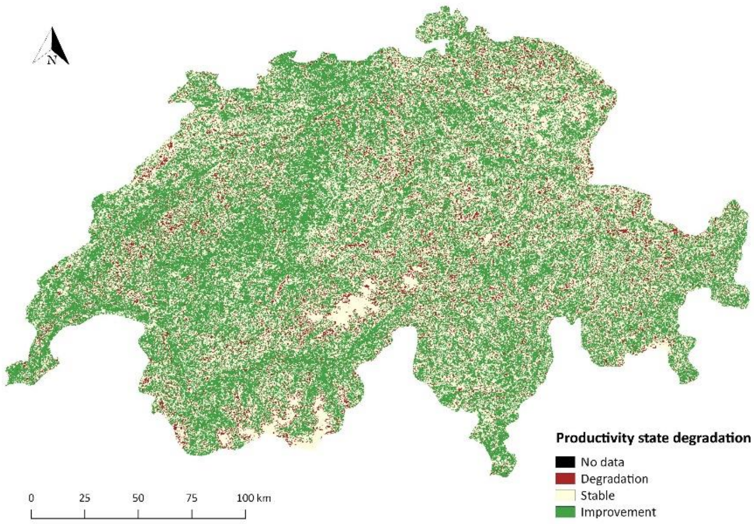
Appendix 4. Details on differences in vegetation productivity between UNCCD and Trends.Earth.

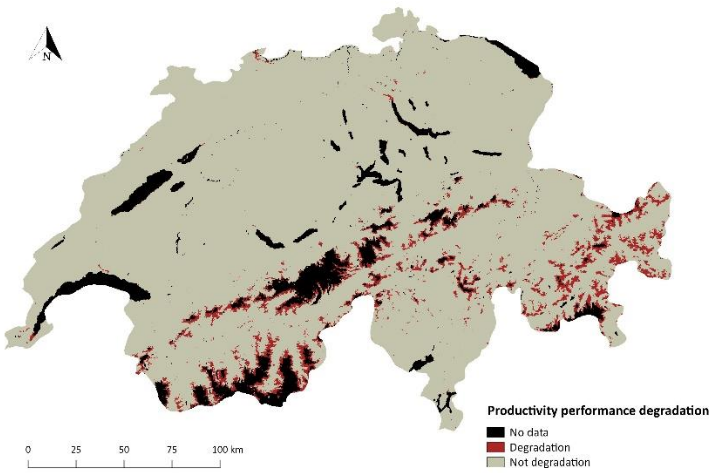
	Total land area	Land area with improved productivity	Land area with stable productivity	Land area with degraded productivity	Land area with no data for productivity
CH_Trends.Earth	39 995.9	8 764.4	25 478.6	4 027.2	1 725.7
CH_UNCCD	39 995.9	14 070.1	22 502.6	2 975.3	447.9
Difference		5 305.7	-2 976.1	-1 051.9	-1 277.8

	%Total land area	%Land area with improved productivity	%Land area with stable productivity	%Land area with degraded productivity	%Land area with no data for productivity
CH_Trends.Earth	1.0	22%	64%	10%	4%
CH_UNCCD	1.0	35%	56%	7%	1%
Difference		13%	-7%	-3%	-3%

Appendix 5. Maps of the three productivity sub-indicators of Trends.Earth: trajectory, state and performance.







Appendix 6. Differences in SDG 15.3.1 between the two models (km2 and % of total land area).

	Total land area	Land area improved	Land area stable	Land area degraded	Land area with no data
CH_UNCCD	39 995.9	13 351.3	20 998.7	3 886.8	1 759.1
CH_Trends.Earth	39 995.9	8 615.3	24 438.0	5 159.9	1 782.7

	% improved	**% stable**	**% degraded**	**% no data**
SDG_UNCCD	33.38	52.50	9.72	4.40
SDG_Trends.Earth	21.54	61.10	12.90	4.46
Difference	11.84	-8.60	-3.18	-0.06

Appendix 7. Details on productivity indicator by canton: km2; differences and proportions of the two models.

Km2

	Trends.Earth					UNCCD				
	Total land area	Land area improved	Land area stable	Land area degraded	Land area with no data	Total land area	Land area improved	Land area stable	Land area degraded	Land area with no data
AG	1 399.4	368.7	887.3	135.5	7.9	1 399.4	1 056.1	310.5	32.3	0.5
AI	166.3	32.1	125.6	8.6	0.0	166.3	28.2	119.3	18.9	0.0
AR	238.7	26.6	197.5	14.6	0.0	238.7	56.9	167.2	14.7	0.0
BE	5 786.7	1 257.6	3 731.8	485.1	312.2	5 786.7	2 011.5	3 277.2	424.8	73.2
BL	547.1	200.2	321.8	24.0	1.2	547.1	322.5	217.0	7.5	0.0
BS	38.9	25.8	10.9	1.7	0.4	38.9	11.4	27.1	0.4	0.0
FR	1 570.5	449.2	993.0	126.0	2.4	1 570.5	770.6	722.7	77.1	0.1
GE	240.9	84.4	129.9	25.0	1.6	240.9	169.9	63.8	6.1	1.1
GL	663.3	76.4	475.0	76.2	35.7	663.3	95.3	522.4	38.3	7.3
GR	6 997.2	1 325.9	4 623.8	839.0	208.5	6 997.2	1 154.6	5 189.0	624.4	29.2
JU	848.0	235.3	544.2	68.4	0.0	848.0	502.6	281.1	64.3	0.0
LU	1 392.7	308.9	922.9	155.9	5.0	1 392.7	459.4	787.2	143.1	2.9
NE	742.1	142.0	541.3	55.2	3.5	742.1	260.9	380.5	96.5	4.1
NW	237.5	37.7	174.8	22.7	2.3	237.5	49.6	175.3	9.1	3.5
OW	470.3	83.6	328.7	49.0	9.1	470.3	115.7	340.5	14.1	0.0
SG	1 974.9	241.7	1 506.2	220.3	6.7	1 974.9	597.6	1 257.0	117.1	3.2
SH	328.2	95.0	209.8	22.6	0.8	328.2	280.2	45.2	2.8	0.0
SO	772.0	192.9	518.5	59.6	1.0	772.0	553.2	191.5	27.3	0.0
SZ	836.3	127.6	621.0	80.5	7.3	836.3	143.5	666.6	24.6	1.6
TG	811.1	135.0	526.9	145.2	4.0	811.1	603.4	175.1	29.8	2.8
TI	2 831.5	997.4	1 612.2	202.4	19.5	2 831.5	989.9	1 668.3	167.1	6.3
UR	1 049.3	144.6	629.3	161.7	113.7	1 049.3	140.0	765.1	129.5	14.7
VD	2 905.0	771.9	1 858.1	260.6	14.3	2 905.0	1 505.9	1 146.9	242.7	9.5
VS	5 275.9	996.7	2 737.0	583.5	958.6	5 275.9	947.4	3 413.4	630.7	284.3
ZG	204.6	32.7	150.8	18.7	2.4	204.6	86.4	109.9	7.4	0.9
ZH	1 667.7	374.8	1 115.9	169.6	7.4	1 667.7	1 157.2	483.0	24.7	2.8

	UNCCD - Trends.Earth				Trends.Earth/UNCCD			
	Land area improved %	Land area stable	Land area degraded	Land area with no data	Land area improved %	Land area stable	Land area degraded	Land area with no data
AG	49%	-41%	-7%	-1%	0.3	2.9	4.2	15.6
AI	-2%	-4%	6%	0%	1.1	1.1	0.5	0.0
AR	13%	-13%	0%	0%	0.5	1.2	1.0	0.0
BE	13%	-8%	-1%	-4%	0.6	1.1	1.1	4.3
BL	22%	-19%	-3%	0%	0.6	1.5	3.2	0.0
BS	-37%	41%	-3%	-1%	2.3	0.4	4.1	0.0
FR	20%	-17%	-3%	0%	0.6	1.4	1.6	19.0
GE	35%	-27%	-8%	0%	0.5	2.0	4.1	1.5
GL	3%	7%	-6%	-4%	0.8	0.9	2.0	4.9
GR	-2%	8%	-3%	-3%	1.1	0.9	1.3	7.1
JU	32%	-31%	0%	0%	0.5	1.9	1.1	0.0
LU	11%	-10%	-1%	0%	0.7	1.2	1.1	1.7
NE	16%	-22%	6%	0%	0.5	1.4	0.6	0.9
NW	5%	0%	-6%	1%	0.8	1.0	2.5	0.6
OW	7%	3%	-7%	-2%	0.7	1.0	3.5	0.0
SG	18%	-13%	-5%	0%	0.4	1.2	1.9	2.1
SH	56%	-50%	-6%	0%	0.3	4.6	8.0	0.0
SO	47%	-42%	-4%	0%	0.3	2.7	2.2	0.0
SZ	2%	5%	-7%	-1%	0.9	0.9	3.3	4.5
TG	58%	-43%	-14%	0%	0.2	3.0	4.9	1.4
TI	0%	2%	-1%	0%	1.0	1.0	1.2	3.1
UR	0%	13%	-3%	-9%	1.0	0.8	1.2	7.8
VD	25%	-24%	-1%	0%	0.5	1.6	1.1	1.5
VS	-1%	13%	1%	-13%	1.1	0.8	0.9	3.4
ZG	26%	-20%	-6%	-1%	0.4	1.4	2.5	2.5
ZH	47%	-38%	-9%	0%	0.3	2.3	6.9	2.6

Appendix 8. Details on SDG 15.3.1 indicator by canton: %area; differences and proportions of the two models.

	Trends.Earth						UNCCD				
	Total land area %	Land area improved	Land area stable	Land area degraded	Land area with no data		Total land area %	Land area improved	Land area stable	Land area degraded	Land area with no data
AG	100	25.9	59.4	14.0	0.7	AG	100	70.7	21.0	7.7	0.6
AI	100	19.2	74.6	6.3	0.0	AI	100	17.1	70.1	12.8	0.0
AR	100	12.0	79.5	8.5	0.0	AR	100	24.1	66.9	9.0	0.0
BE	100	21.3	61.6	11.5	5.5	BE	100	33.0	51.7	9.8	5.6
BL	100	34.7	53.7	11.4	0.2	BL	100	55.0	36.3	8.6	0.1
BS	100	65.1	27.7	5.1	2.1	BS	100	28.9	67.1	2.1	2.0
FR	100	28.2	61.2	10.4	0.2	FR	100	47.1	44.9	7.8	0.2
GE	100	33.6	49.2	16.3	0.9	GE	100	64.6	25.1	9.3	1.0
GL	100	11.7	69.1	13.5	5.7	GL	100	13.4	73.2	7.3	6.1
GR	100	18.9	64.9	13.1	3.1	GR	100	16.0	71.7	9.3	3.0
JU	100	27.2	61.3	11.5	0.0	JU	100	57.2	31.6	11.2	0.0
LU	100	21.3	61.4	16.9	0.4	LU	100	30.5	52.2	16.8	0.4
NE	100	18.7	69.5	11.1	0.6	NE	100	33.8	48.8	16.5	0.8
NW	100	15.3	69.3	14.2	1.2	NW	100	19.2	69.6	9.1	2.1
OW	100	17.2	66.8	14.0	2.1	OW	100	23.0	68.4	6.7	1.9
SG	100	12.3	72.1	15.3	0.4	SG	100	28.2	60.4	11.0	0.5
SH	100	29.2	61.3	9.1	0.3	SH	100	83.3	13.0	3.5	0.3
SO	100	24.2	62.3	13.3	0.2	SO	100	67.0	22.9	10.0	0.1
SZ	100	15.1	68.8	15.1	1.0	SZ	100	16.3	73.0	9.6	1.0
TG	100	16.5	62.2	20.8	0.5	TG	100	71.0	20.4	8.1	0.5
TI	100	34.4	55.1	9.8	0.8	TI	100	33.3	57.2	8.7	0.8
UR	100	14.1	58.4	16.3	11.3	UR	100	12.9	65.3	11.0	10.8
VD	100	26.0	61.5	11.9	0.6	VD	100	49.8	38.0	11.4	0.8
VS	100	18.6	50.3	12.6	18.5	VS	100	16.9	55.9	9.2	18.0
ZG	100	15.2	69.2	14.2	1.4	ZG	100	38.6	50.0	10.2	1.2
ZH	100	21.7	62.9	14.9	0.5	ZH	100	65.0	27.2	7.3	0.5

	UNCCD - Trends.Earth (%)					Trends.Earth/UNCCD			
	Land area improved %	Land area stable	Land area degraded	Land area with no data		Land area improved	Land area stable	Land area degraded	Land area with no data
AG	44.8	-38.4	-6.3	-0.1	AG	0.4	2.8	1.8	1.1
AI	-2.0	-4.5	6.5	0.0	AI	1.1	1.1	0.5	0.0
AR	12.0	-12.6	0.6	0.0	AR	0.5	1.2	0.9	0.0
BE	11.6	-9.9	-1.8	0.1	BE	0.6	1.2	1.2	1.0
BL	20.3	-17.4	-2.8	-0.1	BL	0.6	1.5	1.3	2.5
BS	-36.3	39.4	-3.0	-0.1	BS	2.3	0.4	2.5	1.1
FR	18.9	-16.3	-2.6	0.0	FR	0.6	1.4	1.3	1.2
GE	31.0	-24.1	-7.0	0.1	GE	0.5	2.0	1.8	0.9
GL	1.7	4.1	-6.2	0.4	GL	0.9	0.9	1.8	0.9
GR	-2.9	6.8	-3.7	-0.1	GR	1.2	0.9	1.4	1.0
JU	30.0	-29.7	-0.3	0.0	JU	0.5	1.9	1.0	0.0
LU	9.3	-9.2	-0.1	0.0	LU	0.7	1.2	1.0	1.0
NE	15.1	-20.7	5.4	0.2	NE	0.6	1.4	0.7	0.7
NW	3.9	0.3	-5.1	0.9	NW	0.8	1.0	1.6	0.6
OW	5.8	1.6	-7.3	-0.2	OW	0.7	1.0	2.1	1.1
SG	15.9	-11.6	-4.3	0.0	SG	0.4	1.2	1.4	0.9
SH	54.0	-48.3	-5.6	-0.1	SH	0.4	4.7	2.6	1.3
SO	42.8	-39.4	-3.3	0.0	SO	0.4	2.7	1.3	1.2
SZ	1.2	4.2	-5.5	0.0	SZ	0.9	0.9	1.6	1.0
TG	54.5	-41.7	-12.8	0.0	TG	0.2	3.0	2.6	1.0
TI	-1.1	2.1	-1.0	0.1	TI	1.0	1.0	1.1	0.9
UR	-1.2	6.9	-5.3	-0.5	UR	1.1	0.9	1.5	1.0
VD	23.8	-23.5	-0.5	0.1	VD	0.5	1.6	1.0	0.8
VS	-1.7	5.6	-3.4	-0.5	VS	1.1	0.9	1.4	1.0
ZG	23.4	-19.3	-4.0	-0.1	ZG	0.4	1.4	1.4	1.1
ZH	43.3	-35.7	-7.6	0.0	ZH	0.3	2.3	2.0	1.0

Appendix 9. UNCCD reporting format for the trends in land productivity.

		Net land productivity dynamics (2000-2010 sq. km)					
	Land cover class	Declining	Moderate decline	Stressed	Stable	Increasing	No data
Land cover type	Tree-covered areas	158.47	195.69	498.43	8 400.11	6 100.89	45.66
	Grasslands	338.12	169.97	477.99	9 013.45	2 514.27	8.65
	Croplands	32.69	32.89	199.27	1 535.88	4 043.03	9.26
	Wetlands	0.00	0.00	0.47	6.72	9.04	1.53
	Artificial areas	1.93	4.51	22.60	450.64	743.00	10.20
	Other land	639.08	2.24	127.83	2 503.99	10.55	367.98