Convergence of Global Change Issues

Convergence of evidence: Where the evidence leads

The six most frequent combinations of 9 coinciding GCIs.
There are 13 327 different combinations of the 14 GCIs behind the map above. Some cover large areas, other just a few pixels. The table presents the 6 most frequent combinations of 9 GCIs.
Source: WAD3-JRC, 2018.

The occurrence of multiple global change issues (GCIs) at a location suggests a potential for land degradation (at least in some form).

Limitations of global assessments

The assessment and mapping of land degradation at different spatial scales (global, local) is highly desirable. However, numerous limitations make it all but impossible to directly apply, and scale, global assessments to local conditions. For example, (i) some data simply do not exist for all places on Earth (e.g. household income); (ii) while specific data may be widely available, it is often collected and reported using different methods, diverse standards, and/or using incompatible scales; and (iii) some data are wholly site-specific and thus not amenable to global assessments. Limitations such as these encumbered past attempts to produce global maps of desertification[1, 2], including previous editions of the *World Atlas of Desertification* (WAD1-WAD2)[3-5].

Desertification maps were controversial for a variety of interrelated reasons. First, their scientific value was circumspect because of the multifaceted nature of land degradation and the inability to unambiguously define what was actually being mapped. Second, the use of global maps to represent a dynamic, complex issue like land degradation created false equivalencies. For example, red zones on a map – used to indicate severe land degradation – cannot capture the nuances, and different manifestations, of land degradation in any two areas (e.g. soil erosion, decreased production, loss of vegetation cover, salinity, water scarcity, pollution, disruption of chemical cycles, loss of biodiversity), its underlying causes (e.g. overgrazing, poor land management, population growth, climate change), and its consequences of interest to humans (e.g. loss of livelihoods, loss of ecosystem services, economic impacts, dust production)[6]. Such false equivalencies hindered organisations and institutions who attempted to use these maps to prescribe specific types of interventions to ameliorate problem areas[7, 8]. Third, desertification maps suffer from a lack of "context", that is, the ability to understand and portray actual conditions on the ground (as exemplified by the red zones described above). Only local context can provide insight into why a particular land degradation issue came to be, how significant it might be, what the range of potential solutions might be available, and whether the potential social, cultural, economic, environmental costs and benefits might warrant intervention[9] (see Case Studies).

New data, new opportunities

Since the publication of WAD in 1992[4], there have been a host of scientific and technical advancements that have contributed to the development of a new framework to study environmental problems. These advancements include the emergence of new, comprehensive global data, improved understanding of underlying processes, and technological innovations in analytical tools. As a result, global change issues (e.g. spread of urbanisation, deforestation, ground water depletion) are more readily characterised with increased spatial accuracy, which has led to novel insights of global-scale dynamics, as well as the ability to rapidly disseminate these products to a worldwide audience.

Earlier global mapping attempts relied solely on data obtained from a few satellites that often could not be processed systematically, had few corroborating data, and lacked ample ground observations. Today, the monitoring of the state of the Earth is multi-sourced: the number of Earth-observing satellite systems has increased from about 20 (in 1992) to more than 90 (in 2013)[10]; there are global networks of long- and short-term land and sea based observations gathered by ground stations and aircraft[11]; and basic geo-referenced data provide social and economic conditions not directly observable but essential to understanding local context. This multi-sourced theme is illustrated by the Global Earth Observing System of Systems, which is a set of coordinated, independent Earth observation and processing systems that provide information to a broad range of public and private users[12, 13].

In addition, open access, innovative analytical tools, and significant advancements in information technology (e.g. cloud computing, the Internet of Things, social networking) have facilitated an era of "big data" where new avenues of research (both within and outside the traditional Earth observation community) are flourishing[14, 15]. This mixture of disciplinary expertise has led to the realisation that a consideration of social and economic processes is necessary to quantify environmental change that matters to humans[11, 16, 17]. Moreover, there are economic and political contexts in which all local conditions are bounded, and these complex relationships help better explain previously underappreciated telecoupling between environmental, economic and social drivers in one place, and their sometimes surprising outcomes elsewhere, often far-removed[11, 17-19] (see Environmental Globalisation, page 40).
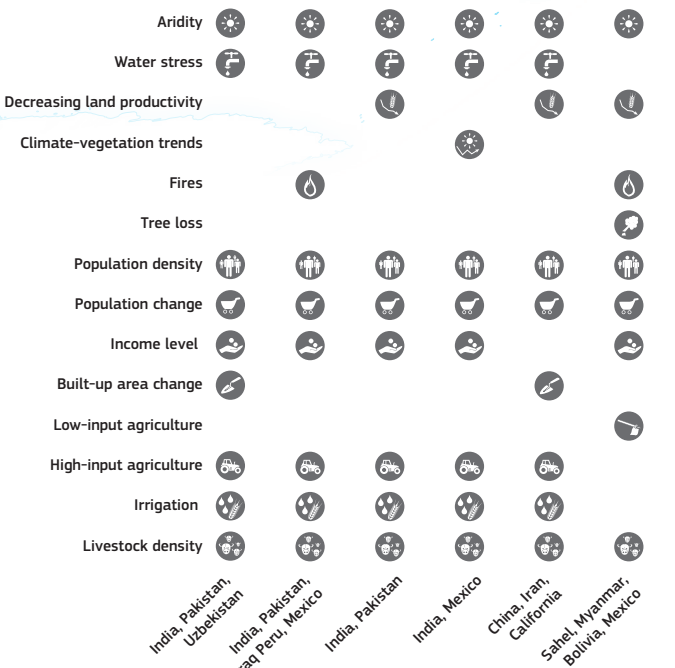
Constructing convergence of evidence maps

The map illustrates the concept of convergence of evidence. It depicts where global change issues (GCIs) relevant to land degradation coincide at a global scale. The map is constructed using two basic kinds of global data: land cover/land use and global change issues (GCIs):

First, land cover/land use data: Total global land mass is stratified into broad classes based on their share of cropland[22], rangeland[22], and forest[23] (the term 'forest' is used to indicate the 'tree cover extent' mapped in the dataset). Depending on specific interests, the availability of data, region and scale of investigation, other stratifications, e.g. climate, soil, and ecosystem services, could be used.

Second, global change issues: 14 global change issues (GCIs) were selected. These GCIs are a mixture of biophysical and socio-economic drivers, and were selected because of their availability as global data and their usefulness as factors associated with land degradation[24]. Based on whether its value at a particular spatial location is above or below a certain threshold, each GCI is classified as being either a concern for land degradation (e.g. declining productivity) or not (e.g. stable productivity). A GCI threshold is calculated based on the per class distribution of the dataset within each of the broad land classes. At this global scale, for most GCIs the median value is considered (except for agriculture input and land productivity - see table on GCIs for details).

The global map shown here does not represent land degradation. Rather, it illustrates the convergence of evidence of GCIs relevant to land degradation. As noted previously, the correct interpretation of the map must consider contextual information on regional and local conditions, as per individual user's knowledge. See text for details and following pages for theme maps that illustrate possible stakeholder's interests.

Opportunity to Explore: Web Access to Global Data

WAD1 and WAD2 were limited by their reliance on the printed page. Once compiled and printed, the information contained in assessment maps could not be probed more deeply. For example, there was no obvious way to examine the data or model that went into designating the Cholistan desert in Pakistan as having severely-degraded soils. This limited the ability of users to understand how land degradation processes at local sites related to other locations or regions. Furthermore, there was no opportunity for systematic feedback, which would permit users to share their knowledge of local conditions. To overcome this, this atlas provides access to the global data that have been assembled at the Joint Research Centre of the European Commission (http://WAD.jrc.ec.europa. eu). The intent is to allow users who have interest in a particular thematic topic (e.g. irrigation, overgrazing, land use change) or specific geographic location to visit the website to explore the co-occurrence of two or more of the global change issues presented here and, utilising contextual knowledge of a particular location, perhaps combine these data with other global data to explore various drivers and consequences of land degradation processes[20].

Convergence of evidence approach

Heeding the lessons learned regarding "limitations of global assessments" and benefiting from "new opportunities, new data" (described above), this atlas explicitly decouples global and local assessments and employs a scale-independent approach. This is accomplished by using a convergence of evidence mapping approach, which facilitates the exploration of land degradation – in its various forms and complexities – in lieu of global "maps of desertification".

Convergence of evidence refers to the existence of multiple, independent sources of evidence that, when taken together, point towards the same conclusion, inference and/or decision. For these reasons, convergence of evidence analyses are suggestive rather than diagnostic. Importantly, the conclusion can be very strong even if each of the individual sources of evidence by themselves are not sufficient to reach this conclusion. For example, the scientific consensus that the Earth is warming stems from a convergence of evidence of multiple lines of inquiry, such as pollen records, tree rings, ice cores, glacial ice-cap melt, sea-level rise, ecological data, atmospheric carbon dioxide increases, and annual rates of temperature increase. When combined, this evidence converges to a singular, irrefutable conclusion that the globe is warming[21].

Global change issues (GCIs) used in convergence maps (see also box on 'Constructing convergence of evidence maps')

	Condition	Reference to atlas page reference year and dataset
BIO-PHYSICAL GCI		
Aridity	Aridity Index < 0.65 (Dryland). Aridity is a measure of 'dryness' of the climate expressed as the ratio of precipitation to evapotranspiration; the lower the ratio the drier the climate.	See page 72 CGIAR-CSI Global-Aridity[25, 25b, 26]
Water stress	Total water withdrawal is > 40% of the total surface water plus groundwater available (per year). Total water withdrawals refer to water use from the agriculture, domestic, and industrial sectors. Water stress is a measure for chronic human induced stress, rather than drought stress.	See page 84 Baseline year 2010 Aqueduct 2.1[27]
Decreasing land productivity	Severe or Moderate decline in land productivity. Classes 1-3 in the land productivity dynamics map (LPD). Land productivity, here calculated as the annual growing season accumulation of the above ground biomass production is a proxy for NPP. The dynamics, observed by satellite and derived from phenological analyses of a 15-year time series (1999-2013), point to long term alterations of the health and productive capacity of the land.	See page 114 period 1999-2013 Copernicus Global Land 1km SPOT VGT derived LPD[28, 29]
Climate-vegetation trends	Below-average biomass productivity due to drought conditions. Decline in annual plant biomass productivity (as derived from Fraction of Absorbed Photosynthetically Active Radiation –fAPAR) due to drought conditions (here, based on negative deviations from the 1901-2010 average Standardized Precipitation and Evaporation Index). Expresses the response of plant productivity to climate fluctuations.	See page 122 period 1981 and 2010 fAPAR3g (1981-2010) and SPEI (1901-2010)[30]
Fires	At least one fire over the period. The number of fires observed over the period on satellite iimages with 1 km grid cells.	See page 124 period 2000-2013 MODIS buried area product[31]
Tree loss	Decline in tree cover, if observed in any 30 m² pixel contained within each 1 km² pixel. The change in tree cover is derived from satellite observations at 30m resolution (per year).	See page 36 period 2000-2014 GFC v1.2[23]
SOCIO-ECONOMIC GCI		
Population density	Population density > broad land cover class median. Population density (number of people per km²) is derived from census data.	See page 26 2015 Gridded Population of the World, Version 4, CIESIN[32]
Population change	Change in population density > broad land cover class median. Reflects the dynamics of increasing number of people in a certain area.	See page 26 difference between 2000 and 2015 Gridded Population of the World, Version 4, CIESIN[32]
Income level	Average income of a country's citizens > broad land cover class median. Computed based on the Gross National Income (the value of a country's annual income – domestic plus net income received from abroad) divided by size of its population.	See page 64 2014 World Bank[33]
Built-up area change	Increase in built-up area > broad land cover class median. Built up is expressed as percent of pixel (1 km²) that is observed to be covered by building construction. This is derived from high resolution satellite observations, augmented by ancillary information.	See page 32 change between 2000 and 2014 Global Human Settlement layer[34]
Low-input agriculture	Nitrogen deficit exists. Calculated based on the N balance level remained below the first quantile. The nitrogen balance indicates the level at which the crop(s) uses the applied nitrogen according to local conditions. Values in the first quantile mean that there is less nitrogen than the crop needs. (quantiles are calculated per broad land class).	See page 54 period pre-2014[35]
High-input agriculture	Nitrogen surplus exists. Calculated based on the N balance level remained above the fourth quantile. The nitrogen balance indicates the level at which the crop(s) uses the applied nitrogen according to local conditions. Values in the fourth quantile mean that there is more nitrogen than the crop needs. (quantiles are calculated per broad land class).	See page 54 period pre-2014[35]
Irrigation	Irrigation occurs > 10% of grid cell. Area equipped for irrigation, expressed as percent of total 10 × 10km area. Obtained by combining sub-national irrigation statistics with geospatial and satellite information on the position and extend of irrigation schemes. This layer does not map the area that is actually irrigated.	See page 56 Around 2005 Global map of irrigation areas (Version 5)[36, 37]
Livestock density	Livestock density > class median. Livestock density is calculated in terms of livestock 'units' (LSU). This allows to accumulate the various types of livestock (cattle equal 0.8 LSU, sheep 0.1, pigs 0.1, goats 0.4, chicken 0.01LSU). The layer is compiled with the 2007 FAO GLW data that is improved with current statistics and the use of higher resolution predictor variables. The density of livestock is related to environmental pressures from livestock related land use change, grazing lands and fodder production, and greenhouse gas emissions. Within the broad land classes an additional subdivision between dryland and non-dryland was introduced for calculating the GCI thresholds.	See page 60 2014 Global distribution of livestock[38]

Convergence of evidence: Where the evidence leads (cont'd)

Interpreting maps

The goal of convergence of evidence mapping (see box 'Constructing convergence of evidence maps on previous page) is to pinpoint areas on the globe where GCIs coincide. The weight of this evidence (kind and/or number of GCIs) can lead to conclusions on where land degradation may exist. Contextual knowledge and additional information will strengthen such conclusions and warrant further investigation.

A convergence of evidence map does not signify land degradation; rather, as per the convergence of evidence principle described above, no GCI by itself is sufficient to infer land degradation. While the occurrence of multiple GCIs at any location suggests the potential for land degradation (at least in some form), the correct interpretation ultimately must consider contextual information (regarding regional and/or local biophysical and socio-economic conditions). For example, the co-occurrence of high livestock density, water stress and population change in the smallholder coffee region of Kilimanjaro (Tanzania) will most probably have a very different connotation than their co-occurrence in the Panhandle region of Oklahoma (United States). Similarly, the total number of coincident GCIs (e.g. two versus six) per se can only be interpreted with context: that is, a single GCI in one location may have serious consequences in terms of land degradation while six coincident GCIs in another location may have little or no consequences (see following pages).

Thematic maps

To guide the reader, convergence of evidence maps are presented on the following pages for 13 themes or topics (see Table on this page). The various themes – high density cropland, smallholders, protected areas, etc. – are examples of subject matter selected by a stakeholder who has that particular interest. A theme provides a broad context in which to weigh the evidence of coinciding GCIs and, hence, each map, and accompanying statistics, are limited to the specific area of the globe and continents that are specific for the theme.

Limitations of maps

As with all methodologies, there are some limitations:

The land cover/land use (based on the cropland, rangeland and forest share of the land) are very broad and other stratifications could be used;

The thresholds used to classify the GCIs (as being either a concern for land degradation or not) are statistically defined, but the choice for e.g. the 'median' is subjective. They can, however, be fine-tuned to fit empirical data and expert knowledge if available;

In some parts of the world, specific land cover types – such as rainforests in South America and cropland in North America – encompass vast and largely continuous areas. Nevertheless, they are rarely homogeneous, often containing a mixture of information such as open versus closed canopies (the former supporting livestock grazing) and are interspersed with fallow fields, roads, remnant woodlands, and human settlements;

While the 14 GCIs are important, they are only a representative subset of potentially-relevant issues. There is currently a lack of dynamic data but as more global data becomes available, other GCIs will be identified, which will strengthen the approach;

Maps of a single theme and coinciding GCIs poses some limits. For example, a map of high livestock density will have a different meaning if it occurs in a high-input cropping system versus a rangeland, which illustrates the necessity of context; and

Global data for many important aspects of land degradation are not available. This includes both biophysical data (e.g. biomass loss, biodiversity, soil organic carbon dynamics, soil erosion, plant encroachment) and social-economic data (household income, literacy rates, gender mix, etc.). Such joint data are necessary to elucidate and interpret the complexity of factors that govern land degradation in dynamic human-environmental systems[17]. This is illustrated in a number of case studies (see page 188, onward).

How to read the maps

Accompanying each convergence of evidence map are summaries of the coinciding global change issues (GCIs). The GCIs are classified as occurring in either dryland or non-dryland (based on Aridity, see Table of GCIs).

The GCIs are shown in relation to the land productivity dynamics map (LPD) (for details, see page 114). LPD is global in scope, derived from multi-temporal and long-term time series of remotely-sensed land productivity measures equivalent to NPP, at medium spatial resolution (1 km or better). Briefly, land productivity reflects the overall quality of land and soil, so persistent decreases in land productivity dynamics (LPD) is evidence of a long-term alteration of the health and productive capacity of the land. The LPD map depicts the persistent trajectory of land productivity dynamics during 15 years, from 1999 to 2013, which are summarised by five qualitative classes (see Table below). These five classes represent the intensity and persistence of negative or positive trends and changes of vegetation cover. Note that the first three classes (severe decline, moderate decline and stressed) are used to define the GCI "Decreasing land productivity" (see table of GCIs).

Class value	Description
1	Persistent severe 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

Hypothetically, if the spatial occurrence of drought conditions (see "Climate and vegetation trends", page 122), decreasing land productivity, decreasing population density, and decreasing livestock density were to coincide in rangelands of central Botswana, the collective weight of these GCIs – that is, a convergence of evidence – would strongly suggest that land degradation may exist in this area, or at least that the conditions and current dynamics are present to be potentially susceptible to land degradation. Ultimately, the level of concern and subsequent action (social, cultural, economic, environmental) must be determined by stakeholders who have local context and knowledge[9].

Disclaimer: Statistics, map descriptions and interpretations are based on the 14 biophysical and socio-economic global change issues used in the WAD3 example of convergence of evidence. These 14 global change issues are a representative, not exhaustive, collection of potential drivers or outcomes of land degradation. Statistics and area estimates may differ from those reported elsewhere due to various factors, including differences in methodologies, choice of thematic datasets, and disparities in the base maps used to measure terrestrial areas.

Theme/topic	Definition	Reference	Page
High density cropland	> 50% of each grid cell (1 km²) is under cultivation	GLC-Share v1.0[39]	148
Low density cropland	between 10 - 50% of each grid cell (1 km²) is under cultivation	GLC-Share v1.0[39]	152
High density – high input cropland	> 50% of each grid cell (1 km²) is under cultivation and where there is a high rate of nitrogen fertiliser application (corresponding to the global change issue "High-input agriculture"; see Table p. 145)	GLC-Share v1.0[39] and Nitrogen balance on landscape[35]	154
High density – low input cropland	> 50% of each grid cell (1 km²) is under cultivation and where there is a low rate of nitrogen fertiliser application (corresponding to the global change issue "Low-input agriculture"; see p. 145)	GLC-Share v1.0[39] and Nitrogen balance on landscape[35]	158
Low density – low input cropland	between 10 - 50% of each grid cell (1 km²) is under cultivation and where there is a low rate of nitrogen fertiliser application (corresponding to the global change issue "Low-input agriculture"; see table p. 145)	GLC-Share v1.0[39] and Nitrogen balance on landscape[35]	160
High density – rainfed cropland	> 50% of each grid cell (1 km²) is under cultivation and the only source of water is rainfall	GLC-Share v1.0[39] and GMIA v5.0[36, 37]	164
Low density – rainfed cropland	between 10 - 50% of each grid cell (1 km²) is under cultivation and the only source of water is rainfall	GLC-Share v1.0[39] and GMIA v5.0[36, 37]	166
Smallholder cropland	> 10% of each grid cell (1 km²) is occupied by farms, the medium-size of which is <2 ha	GLC-Share v1.0[39] Field size[40]	170
Irrigated cropland	each grid cell (1 km²) has > 50% under cultivation, of which >10% equipped for irrigation	GLC-Share v1.0[39] and GMIA v5.0[36, 37]	172
Cropland with yield gaps	> 10% of each grid cell (1 km²) has yields less than the median values for 17 major crops (see Closing Yield Gaps, page 52)	GLC-Share v1.0[39] and Yield gaps for major crops[41, 42]	176
Rangeland	natural or semi-natural vegetation that provides a habitat suitable for wild or domestic ungulates	GLC-Share v1.0[39] and Livestock distribution[38]	178
Forest	areas where > 40% of each grid cell (1 km²) is covered with trees	GFC v1.2[23]	182
Protected areas	areas mapped by the World Database on Protected Areas[59]	WDPA[43]	184

13 thematic topics used to represent the convergence of evidence map.
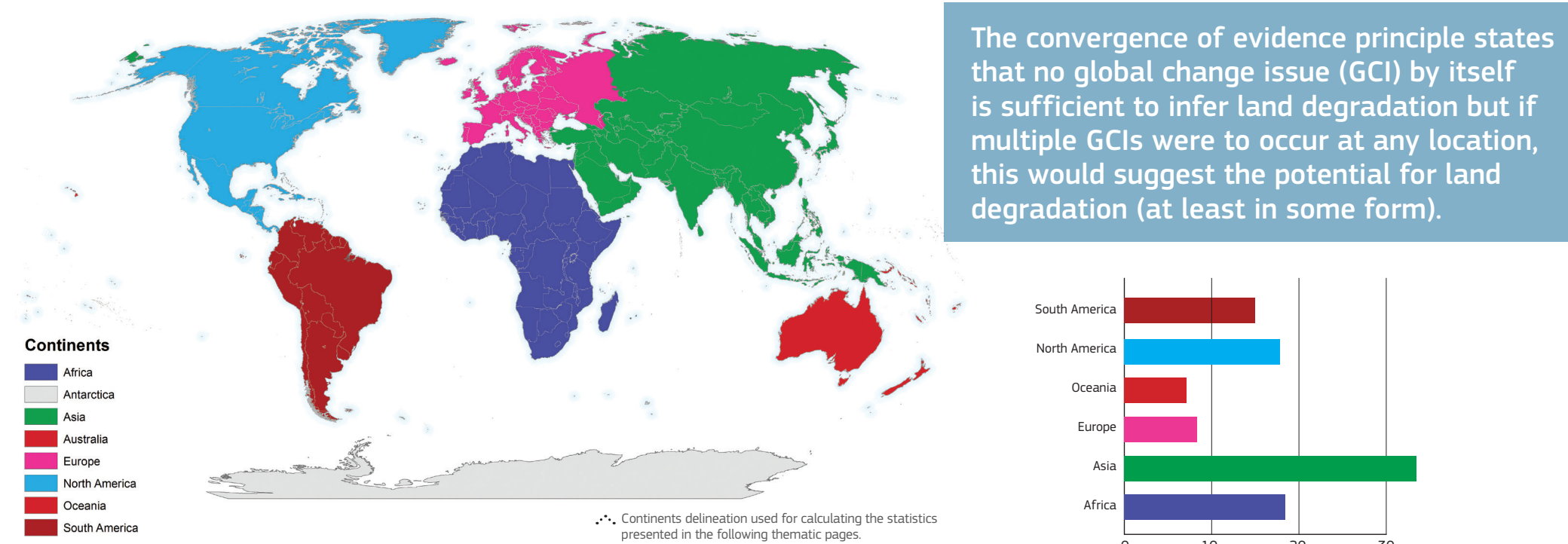
The convergence of evidence principle states that no global change issue (GCI) by itself is sufficient to infer land degradation but if multiple GCIs were to occur at any location, this would suggest the potential for land degradation (at least in some form).

Continents
- Africa
- Antarctica
- Asia
- Australia
- Europe
- North America
- Oceania
- South America

Continents delineation used for calculating the statistics presented in the following thematic pages.

South America / North America / Oceania / Europe / Asia / Africa
0 — 10 — 20 — 30

Examples of coincident global change issues at one specific 1 km² grid cell. The examples on each map represent some key situations. Similar information queries are possible for all grid cells on the interactive web site (see BOX 'Opportunity to Explore: Web Access to Global Data' on page 145).

1 Continental distributions of **coincident global change issues** (GCIs)
Y-axis: number of coinciding GCIs (from 1 to 13; the GCIs high or low fertiliser use are mutually exclusive)
X-axis: % of area occupied per number of GCIs the area always refers to the specific area of the globe and continents that are specific for the theme– e.g. High density cropland; (in brackets the total area per continent of this theme is given).
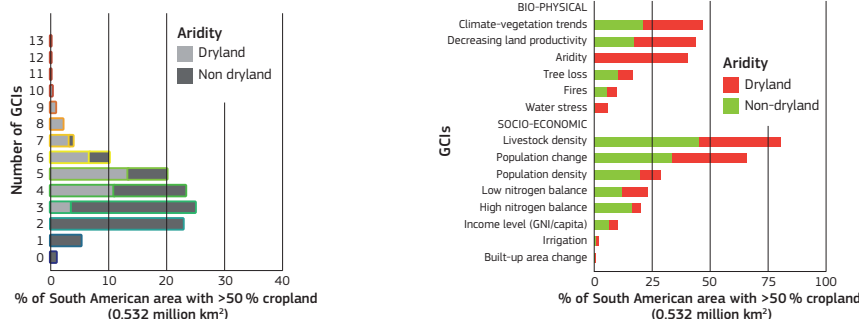
Example illustrating the distribution of the number of coinciding global change issues (GCIs) in High Density cropland in South America. The most common number of coinciding GCIs is 3 (most of which are in non dryland regions).

2 Continental distribution of **predominant global change issues** (GCIs) according to percent area occupied specific for the presented theme top of the map – e.g. High density cropland.

Example illustrating the percent occurrence of each of the global change issues (GCIs) in High Density cropland in South America.

3 Land productivity dynamics (in five classes – Y-axis) according to the number of coincident GCIs (in three groups – few (<4) in blue, several (4-7) in yellow, many (>7) in red) expressed as absolute area occupied (in km²) within the theme.
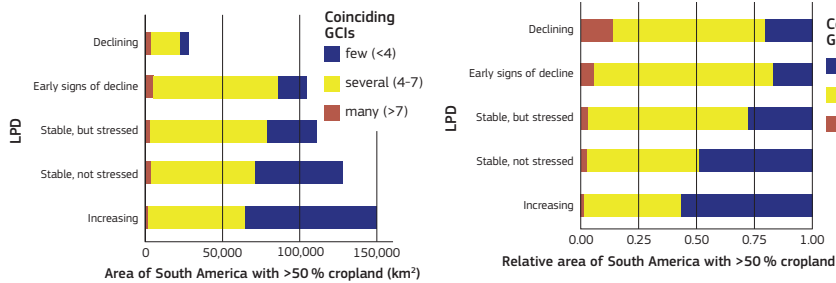
Example showing the number of coinciding global change issues (GCIs) in relation to LPD (in absolute area) in High Density cropland in South America.

4 Land productivity dynamics (in five classes – Y-axis) according to the number of coincident issues (in three groups – few (<4) in blue, several (4-7) in yellow, many (>7) in red) expressed as relative area occupied within the theme (which represent 100%).

Example showing the number of coinciding global change issues (GCIs) in relation to LPD (in relative area) in High Density cropland in South America.

Distributions of predominant issues in NORTH AMERICA

Distributions of predominant issues in EUROPE

GLOBAL distributions of predominant issues

Distributions of predominant issues in ASIA

Distributions of predominant issues in SOUTH AMERICA

Distributions of predominant issues in OCEANIA

Distributions of predominant issues in AFRICA

Convergence of Evidence: High Density Cropland
High density cropland are areas where > 50% of each grid cell (1 km²) is under cultivation

Proportion of the continents' land covered by the thematic topic represented on the map.

The maps have grid cells of 1 km². Statistics are in total area (km²) or percentage of total area of the presented theme and are given for both global and/or continental scales.