Case study: Land condition surveillance using geospatial data

2dRUE approach over Iberia and north-west Africa

Designing and implementing sustainable land-management strategies is intrinsically tied to the availability of objective, repeatable and spatially distributed information on the state of ecosystems. The development of assessment strategies is also in the interest of the United Nations Convention to Combat Desertification and its stakeholders. The related sustainable development goal Target 15.3 'to achieve land degradation neutrality by 2030' requires indicator information on the amount of degrading or degraded land expressed as a percentage of the total land area. The 2dRUE approach addresses such requirements in its assessment and monitoring components that produce data on the state and trend of the land. Furthermore, 2dRUE reports on a full scale of land states other than, but related to, degradation.

From the perspective that land degradation implies a loss or reduction of ecosystem functions (i.e. the ability to provide goods and services), the dynamics and interactions of coinciding socioeconomic and biophysical issues need to be understood at all scales. However, the physical condition of the land is a requisite biophysical aspect. Spatially explicit approaches are needed that aim at characterising ecosystem health, for example in relation to changes of net primary productivity. The condition of a piece of land is defined both by its current state and by its associated trend, best addressed by separate assessment and monitoring procedures. In this sense, 'land condition' is an expression of the ecological maturity of ecosystems, which struggle for equilibrium between the opposing forces of human exploitation and ecological self-organisation. Land-change and ecosystem-adaptation processes can include land degradation. Building on this concept, the 2dREU approach contains separate assessment and monitoring procedures, the results of which are ultimately combined to express the 'land condition'.

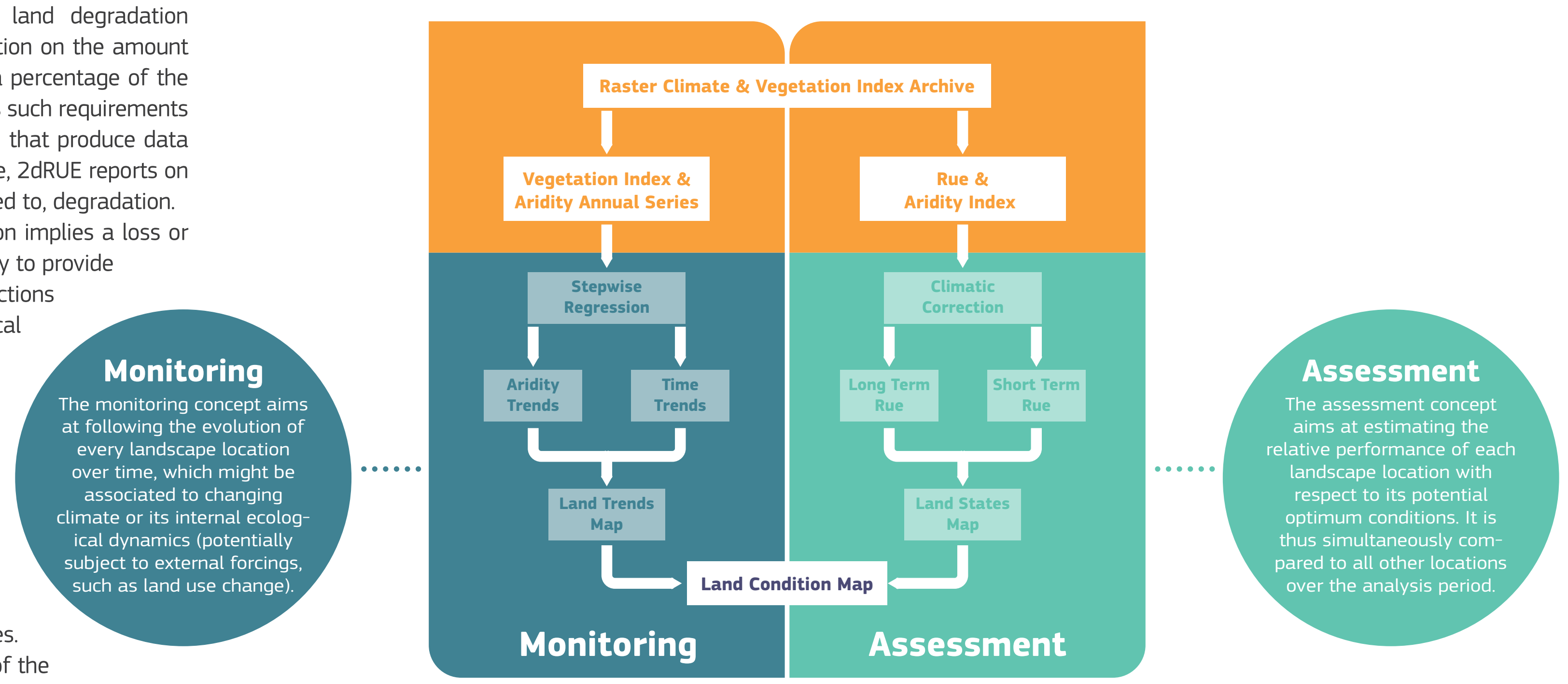
Earth-observation satellites play an important role in assessing vegetation status and changes over time. The characterisation of vegetation productivity alone, however, is rarely enough to produce unbiased assessments on whether an ecosystem is performing at the level of expectation. An option to overcome this conceptual bottleneck is to design assessment frameworks that combine satellite observations of plant productivity with additional spatially explicit data fields. This was the basis of the development of the 2dREU surveillance approach.

Assessment

The assessment concept aims at estimating the relative performance of each landscape location with respect to its potential optimum conditions. It is thus simultaneously compared to all other locations over the analysis period.

Monitoring

The monitoring concept aims at following the evolution of every landscape location over time that might be associated with a changing climate or its internal ecological dynamics (potentially subject to external forces, such as land-use change).

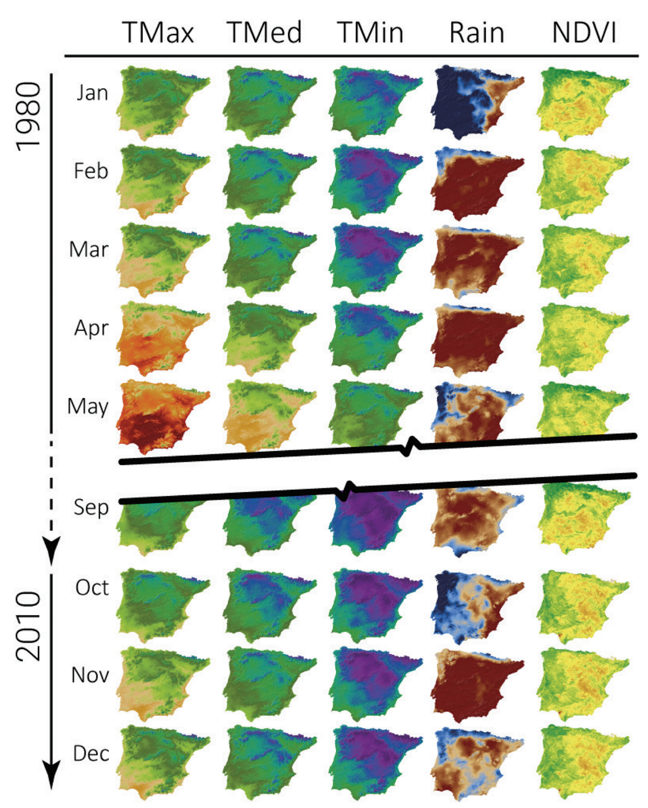


The 2dRUE Surveillance Approach.
Source: Del Barrio, G., based on Del Barrio, G. et al., 2010[7].

2dRUE data requirements: raster archives of climate recordings and vegetation properties

The data required for assessment and monitoring concepts such as 2dRUE here include archived time series of satellite observations of vegetation properties and corresponding spatially interpolated climate data. Vegetation indices (derived from multi-spectral satellite observations) represent an excellent proxy for characterising vegetation in terms of biomass or net primary productivity (the amount of biomass produced per unit of time). The normalised difference vegetation index (NDVI) is a suitable choice because its integral over the course of the year is a proxy for net primary productivity[1, 2]. Archived time series (for example the SPOT Vegetation S10, MODIS/Terra MOD13Q1) are made available through various geo-portals. Climate-station data can be accessed through national or international data repositories, but may need to be gridded over a given study area and period based on spatial interpolation algorithms[3, 4]. The assessment period should be compliant with global-change-type events, but long enough to capture a representative range of vegetation responses to climate. Temporal resolution must capture seasonal climate variations. Spatial resolution should be as fine as possible without entering into the scale domain where topographic variability may mask broader trends. Bearing those constraints in mind, an observation period of 10 years at monthly intervals with a spatial resolution of 1 km is a recommended choice.

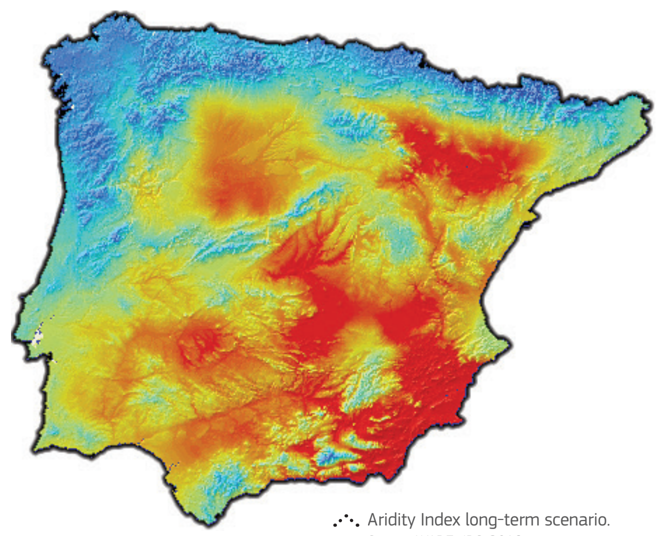
2dRUE diagnostically maps the land condition over large territories for a given time period.



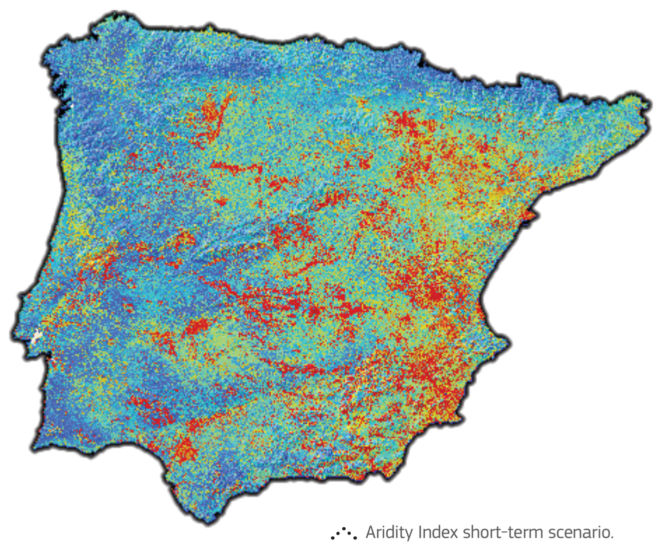
Gridded Climate Archives.
Source: WAD3-JRC, 2018.

Aridity index

The mean UN Food and Agriculture Organisation–UN Environmental Programme aridity index over the analysis period is a by-product of 2dRUE. This index is derived from the ratio of mean annual precipitation to potential evapotranspiration and expresses the portion of atmospheric water demand that is met by precipitation[5]. The United Nations Convention to Combat Desertification considers areas where the aridity index ranges from 0.03 to 0.65 to be susceptible to desertification. The data required to compute the aridity index are part of the climate archive.



Aridity Index long-term scenario.
Source: WAD3-JRC, 2018.



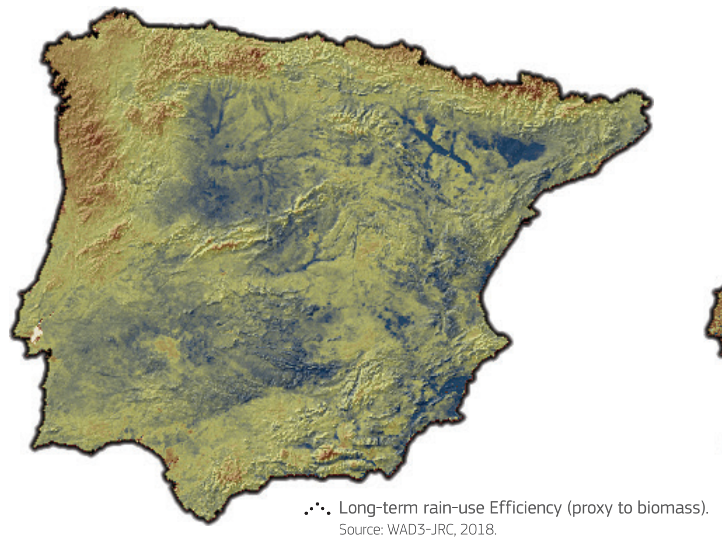
Aridity Index short-term scenario.
Source: Del Barrio, G. WAD3-JRC, 2018.

FAO-UNEP Aridity Index

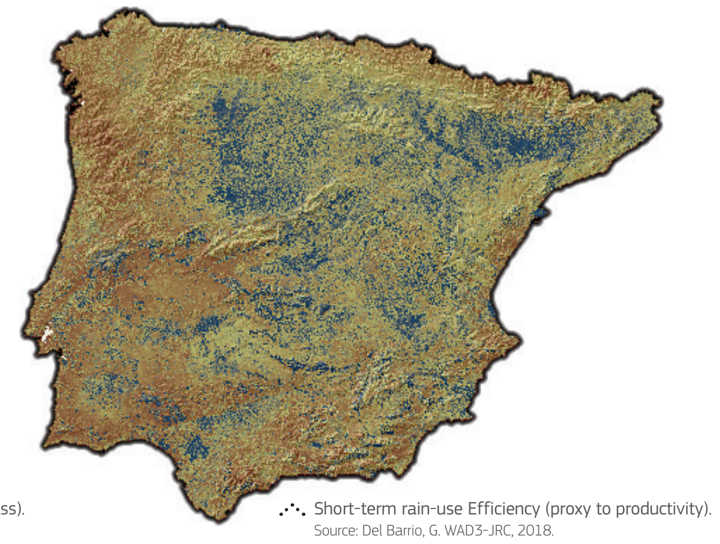
- Arid (0.03 - 0.2)
- Semi-arid (0.2 - 0.5)
- Dry sub-humid (0.5 - 0.65)
- Wet sub-humid (0.65 - 0.75)

Rain-use efficiency

Land-condition assessment must depend on ecological functions, which change proportionally to prevailing processes of self-organisation or degradation. Rain-use efficiency (RUE) is an efficiency ratio that describes output net primary productivity in relation to input rainfall[6]. Large values represent well-developed soil-plant systems that support vegetation functions over a time span greater than intervals between rainfall events. High RUE also implies that most of the water leaves the ecosystem through evapotranspiration rather than through run-off.



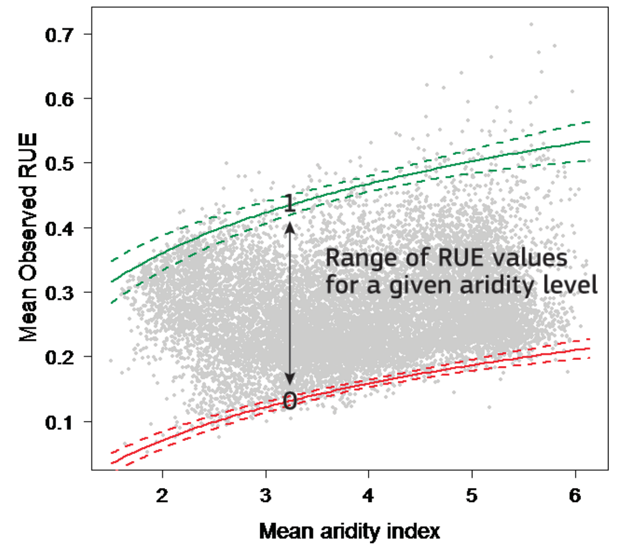
Long-term rain-use Efficiency (proxy to biomass).
Source: WAD3-JRC, 2018.



Short-term rain-use Efficiency (proxy to productivity).
Source: Del Barrio, G. WAD3-JRC, 2018.

Climate correction of rain-use efficiency

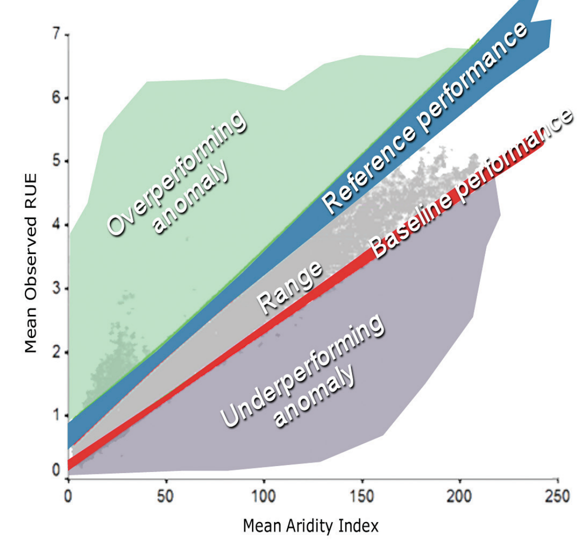
Observed RUE needs adjustments to enable comparisons between all locations across climates[7]. This correction builds on combining the observed RUE for each landscape location with their respective aridity index values (below). The relative performance of a location is then derived from comparing its individual RUE to the range of all RUE values at the same aridity level. Relative (or 'climate-detrended') RUE (either long- or short-term) rescales ecosystem performance to a standardised value range between 0 and 1. Prepared in this way, a map of relative RUE scores represents a measure of 'land condition', which is corrected for varying aridity levels across the study area.



Observed rain-use efficiency plotted against the aridity index.
Source: Del Barrio, G. et al., 2016[9].

Temporal scales

Two temporal aspects of RUE are implemented in 2dRUE. A long-term performance score builds on using the average annual RUE over a multi-year observation period; it represents a suitable proxy to biomass. The short-term RUE is computed for a specific 6-month period during which the maximum vegetation index (e.g. NDVI) of the time-series is detected; it is considered a suitable proxy for productivity.

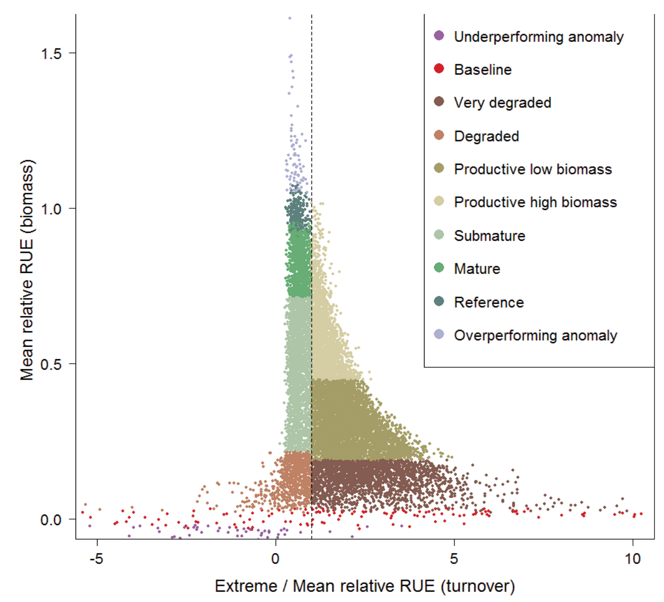


Classification of location using the RUE — aridity index scatterplot.
Source: Del Barrio, G.

Understanding land states

Both biomass and productivity are expected to decrease as land degradation proceeds, but peak turnover rate (i.e. the ratio of productivity to biomass) is found at intermediate stages of exploitation[8]. The states legend follows such a rationale[9]. First, the long-term RUE-AI scatterplot boundary functions and their confidence intervals are used to detect reference and baseline performances, along with their respective anomalies (bottom left). Second, the range central class is further subdivided according to empirical thresholds of both biomass (long-term RUE) and turnover rate (the ratio of short-term to long-term RUE) to yield a sequence of increasing exploitation intensity: mature, submature, productive with high biomass, productive with low biomass, degraded and very degraded (below).

Land exploitation in Iberian Peninsula.
Source: Del Barrio, G.

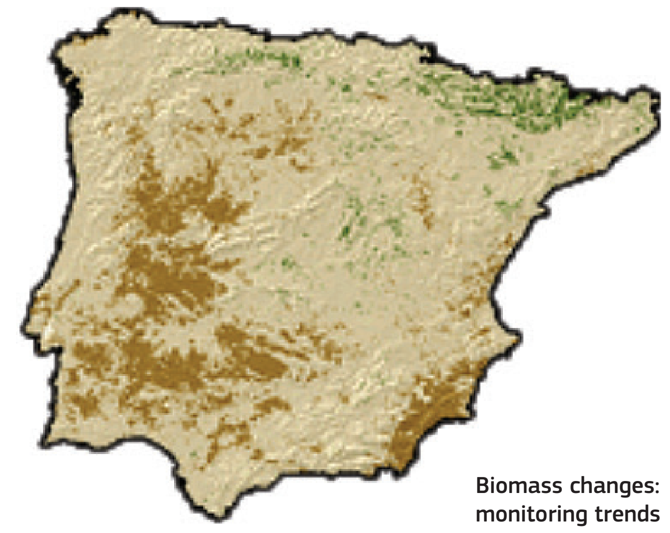


Change in mean relative RUE with turnover.
Source: Del Barrio, G., 2016[9].

Monitoring

Monitoring aims to track trends of change. It is a flow-type variable, which complements the state determination made by the assessment component. The rate of change of biomass per year is an accepted indicator of ecosystem change trends, and NDVI is used as a surrogate. In simplified terms, biomass changes can be attributed either to interannual climate oscillations or to intrinsic ecological dynamics[10, 11]. Whilst the former are useful to evaluate climate effects (including climate change), the latter suggest gradual ecosystem changes in terms of land degradation (negative trends) or ecological succession (positive trends).

Several techniques are available to discriminate climate from human effects, most of them involving regression-based statistical analysis[12]. In 2dRUE, a stepwise regression is applied, which uses annual values of mean NDVI as the dependent variable, and time and aridity index as predictors. Because these predictors are intercorrelated, a procedure is implemented such that the second predictor is incorporated to the regression model only if it makes a significant contribution to the determination fixed by the first predictor alone[7]. The result is a robust, albeit conservative estimation, which frames any combination of climate and human effects.



Effects of between-year variations in aridity (in terms of PET/P) on vegetation.
Source: based on Del Barrio, G. et al., 2010[7].

Biomass changes: monitoring trends

- Decrease
- No relationship
- Increase

Effects of time on vegetation: the map reveals long-term vegetation trends after short-term climate drivers are removed.
Source: based on Del Barrio, G. et al., 2010[7].

Case study: Land condition surveillance using geospatial data (cont'd)

2dRUE approach over Iberia and north-west Africa (cont'd)

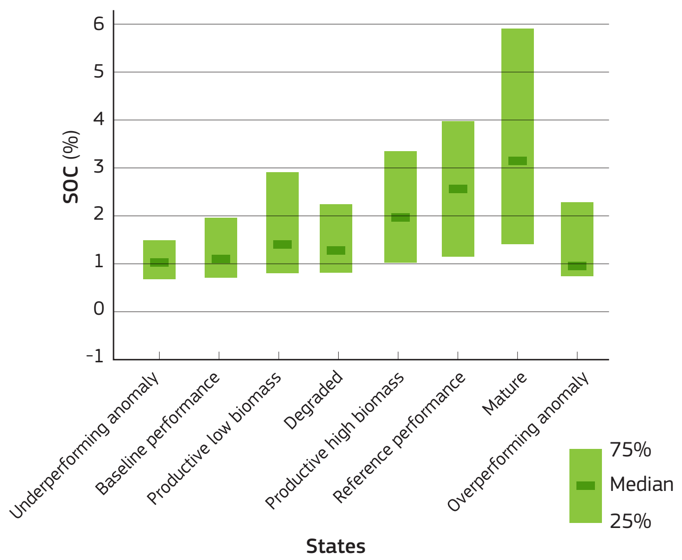
Desertification and land uses

Changing conditions within land-use systems are an expression of ecosystem functions and performance, and therefore provide a proxy for land degradation[16]. In the Iberian peninsula, statistical analysis of land-condition trends and changes based on the 2dRUE approach reveals two opposing dynamics[14,15].

On the one hand, biomass production in large areas of agriculture remained static or has fluctuated with the climate, but has never increased over time. This could suggest a sustainable exploitation of net primary production in both rainfed and irrigated agricultural systems. However, some agricultural ecosystems exhibit clear signs of active degradation processes, which could drive them towards terminal stages in which exhausted and unproductive systems are ultimately abandoned. What will remain are simplified (degraded) ecosystems with low productivity and poor vegetation cover. Areas of increasing intensification, particularly where marginal lands are under irrigation, appear as prominent hotspots.

On the other hand, in comparison, there are there are similarly large regions of higher ecosystem maturity that reveal increasing productivity. These regions mostly consist of natural and semi-natural vegetation under ecological succession after phases of economically triggered land abandonment, such as the rural exodus in the middle of the 20th century, or the accession of Spain and Portugal to the European Union.

An important question is whether these dynamics are connected. In the past, usable lands went through alternating cycles of production and fallow. Marginal lands served as an important buffer by being brought into production 'as needed' (less so in Portugal, where maintaining overall land condition is a priority). Exploitation and self-organisation were thus sequentially linked in this scenario. Nowadays, increasingly driven by global policies and market mechanisms, the traditional system seems to fall into separate development pathways for agricultural and marginal land, the former being intensified until exhaustion and the latter left to succession beyond practical recovery. The associated risk is that pathways of interconversion become irreversible, therefore pressure on degrading ecosystems can no longer be buffered by reactivating reserves in marginal lands.



Validation
Validation of land condition assessments is difficult, owing to the limited availability of ecological functional data (e.g. suboptimal production or biomass for the climate potential) suitable for describing complex problems such as land degradation. Most of existing assessments of degradation are expert-based, thus largely subjective. They may be useful at the interpretation stage, but not for proper validation where the objective is to accept or reject an assessment product. It is therefore necessary to fall back on spatial data which describe key elements of ecosystems. One option is to compare land states derived with 2dRUE to the percentage of Soil Organic Carbon (SOC), available through the Map of Organic Carbon in Topsoils in Europe[17]. We found that the SOC distributions change proportionally to states of increasing ecosystem maturity. Moreover, the threshold of 2% SOC discriminates states where a change of management or direct input of organic matter seems appropriate.
Source: Del Barrio, G. (AP).

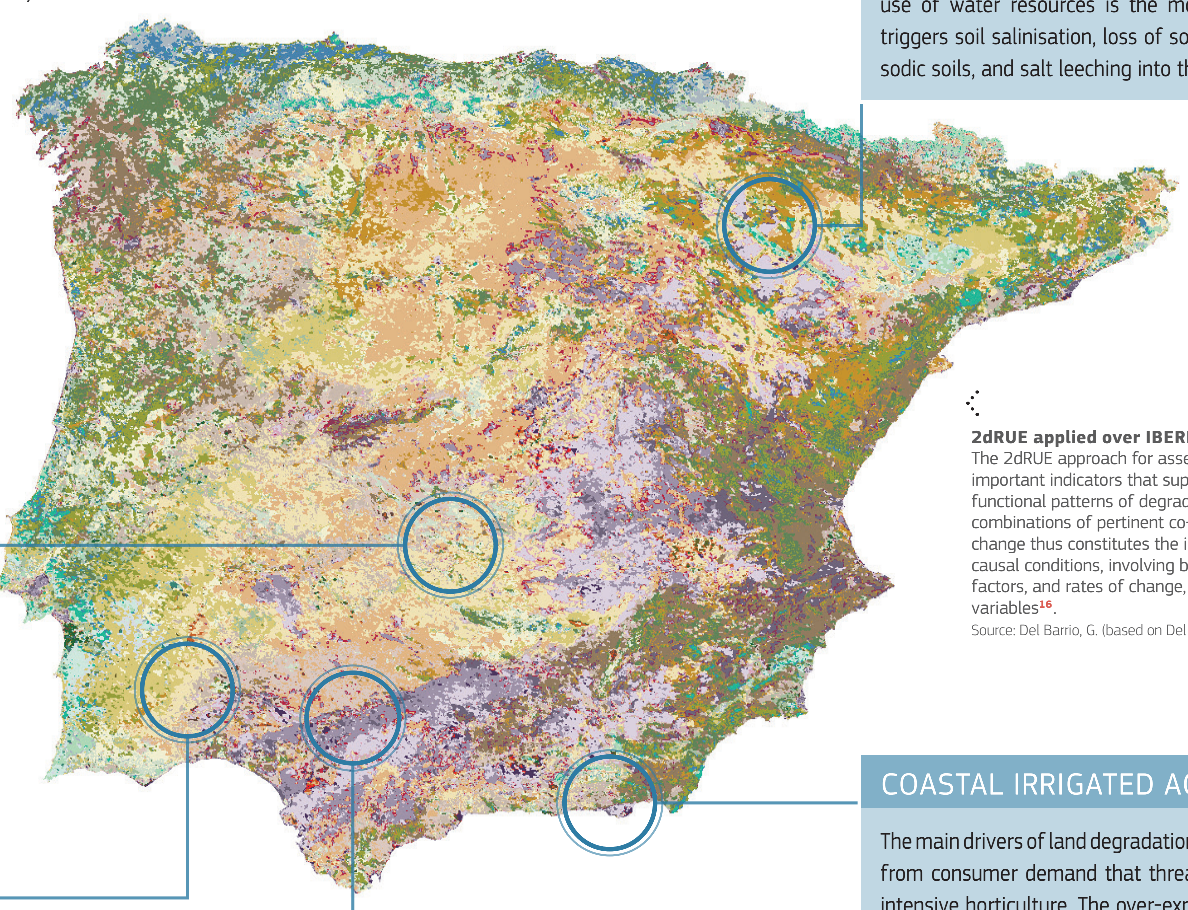
Traveling sprinklers in Meseta plateau.
Source: Hill, J.

NORTHERN CONTINENTAL IRRIGATED AGRICULTURE

The northern margin of the semi-arid Ebro basin is characterised by rocks formed by the evaporation of water (evaporites, such as gypsum, anhydrite and halite (common salt)). The development of large irrigation schemes that use surface run-off from the Pyrenees has transformed traditional mixed agriculture into alfalfa-maize crop complexes and stock breeding (sheep and beef). A consequence of the unlimited use of water resources is the mobilisation of salts, which triggers soil salinisation, loss of soil structure and erosion of sodic soils, and salt leeching into the drainage network.

Land states

- UNDERPERFORMING - degrading
- UNDERPERFORMING - fluctuating
- UNDERPERFORMING - increasing
- UNDERPERFORMING - static
- BASELINE - degrading
- BASELINE - fluctuating
- BASELINE - increasing
- BASELINE - static
- DEGRADED - degrading
- DEGRADED - fluctuating
- DEGRADED - increasing
- DEGRADED - static
- PRODUCTIVE DEGRADED - degrading
- PRODUCTIVE DEGRADED - fluctuating
- PRODUCTIVE DEGRADED - increasing
- PRODUCTIVE DEGRADED - static
- PRODUCTIVE - degrading
- PRODUCTIVE - fluctuating
- PRODUCTIVE - increasing
- PRODUCTIVE - static
- MATURE - degrading
- MATURE - fluctuating
- MATURE - increasing
- MATURE - static
- REFERENCE - degrading
- REFERENCE - fluctuating
- REFERENCE - increasing
- REFERENCE - static
- OVERPERFORMING - degrading
- OVERPERFORMING - fluctuating
- OVERPERFORMING - increasing
- OVERPERFORMING - static



2dRUE applied over IBERIA
The 2dRUE approach for assessing land condition provides important indicators that support the framing of the complex functional patterns of degradation as 'syndromes', i.e. typical combinations of pertinent co-factors. A syndrome of land change thus constitutes the interaction between specific causal conditions, involving both proximate and underlying factors, and rates of change, i.e. slow and fast causative variables[16].
Source: Del Barrio, G. (based on Del Barrio, G. et al., 2010[7]) (AP).

SOUTHERN CONTINENTAL IRRIGATED AGRICULTURE

Traditional agriculture in the south-eastern part of the central Iberian uplands combined olive groves, vineyards and grain crops. Over the past 40 years, this system has evolved to produce forage crops (alfalfa and maize) associated with sheep breeding, together with industrial crops (sunflower) and grapes, most under irrigation with groundwater. However, lower temperatures in the upland areas limit the quality and competitiveness of these crops on the market. Economic gains have thus been moderate, while the over-exploitation of aquifers and subsequent degradation of wetlands pose major environmental problems.

DEHESA AND *MONTADO* AGROFORESTRY AND STOCKBREEDING

It affects the whole south-west quadrant of Iberia. This land-use system is complex and integrates agroforestry and stock breeding (sheep, beef and pigs). Its survival under current economic trends faces several difficulties. One is the small amount of circulating capital in relation to the fixed one. Landowners are little interested in sustainable management. They usually stock their holdings above carrying capacity by supplying feed from outside. The resulting soil compaction by trampling diminishes infiltration and increases run-off and soil erosion.

OLIVE TREE AGRICULTURE

The central part of the Guadalquivir basin and adjacent rangelands traditionally support rainfed olive orchards with large, widely spaced trees. These old groves are increasingly replaced by smaller (young) trees, planted at higher densities and supported by drip irrigation, a process driven to a large extent by subsidies and short-term benefits. The encroachment of olive plantations into marginal lands with steep hillslopes increases the risk of soil erosion. In addition, shallow-rooted trees keep the soil under tree canopies almost permanently at field capacity. The consequences of this transformation process are not yet fully understood.

COASTAL IRRIGATED AGRICULTURE

The main drivers of land degradation in south-east Iberia result from consumer demand that threatens the sustainability of intensive horticulture. The over-exploitation of water and the subsequent declines in groundwater, including the intrusion of seawater into coastal aquifers, are driven by low water prices. The declining water supply and quality may constrain further expansion of irrigation systems in the area. Beyond this, secondary effects associated with subsidies have also triggered the expansion of almond trees over vast areas of marginal land formerly used for low-intensity grazing. On sloping terrain this leads to sheet wash, rill and tillage erosion.

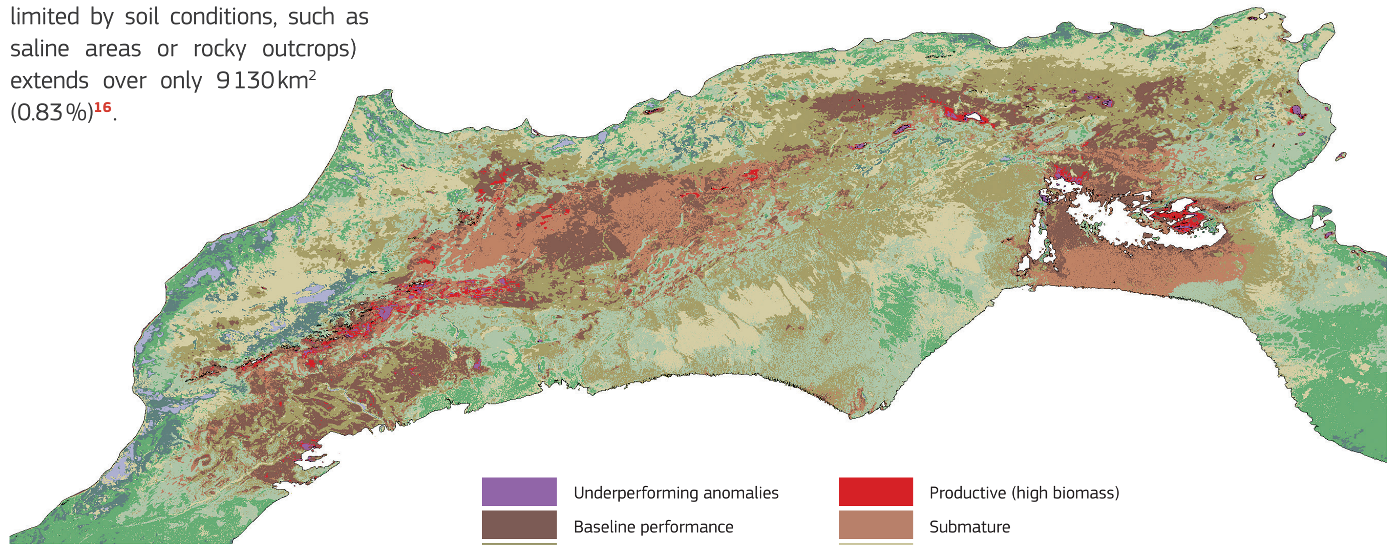
Desertification trends in the Maghreb

The north-western Maghreb covers north-west Africa between the Mediterranean Sea and the Sahara Desert (Morocco, Algeria and Tunisia). The region has experienced major land-use changes since gaining political independence around 1960, and is now undergoing dynamic economic changes. Traditional knowledge, combined with new land-use opportunities, underlies current, specific drivers of land degradation: the movement of population to urban areas of emerging economic activity comes at the expense of the abandonment of rural areas, the extension of arable land into forested areas, soil salinisation and overgrazing. Climate conditions are often harsh, including extreme droughts and rainfall events, and associated floods. New agricultural developments include drilling boreholes, ploughing hillslopes and building roads for moving livestock, all of which aim to increase local production in the short-term at the expense of long-term land sustainability.

Atlas Mountains, Morocco.
Source: Del Barrio, G.

Land-degradation states

The results of the 2dRUE-based land-condition assessment for the period from 1998 to 2008[9] demonstrate that moderate land conditions (productive with either low or high biomass) prevail and account for 454 880 km^2 (41 % of the drylands domain). Good conditions (submature and mature) follow with 331 232 km^2 (30 %), while poor conditions (degraded and very degraded) were less common, with 228 070 km^2 (21 %). In general, better condition states appear to be more common than poorer ones, which is also true for the references: reference performance, representing optimum vegetation cover (in terms of RUE), occupies 37 896 km^2 (3.45 %), whilst baseline performance (which relates to vegetation limited by soil conditions, such as saline areas or rocky outcrops) extends over only 9 130 km^2 (0.83 %)[16].

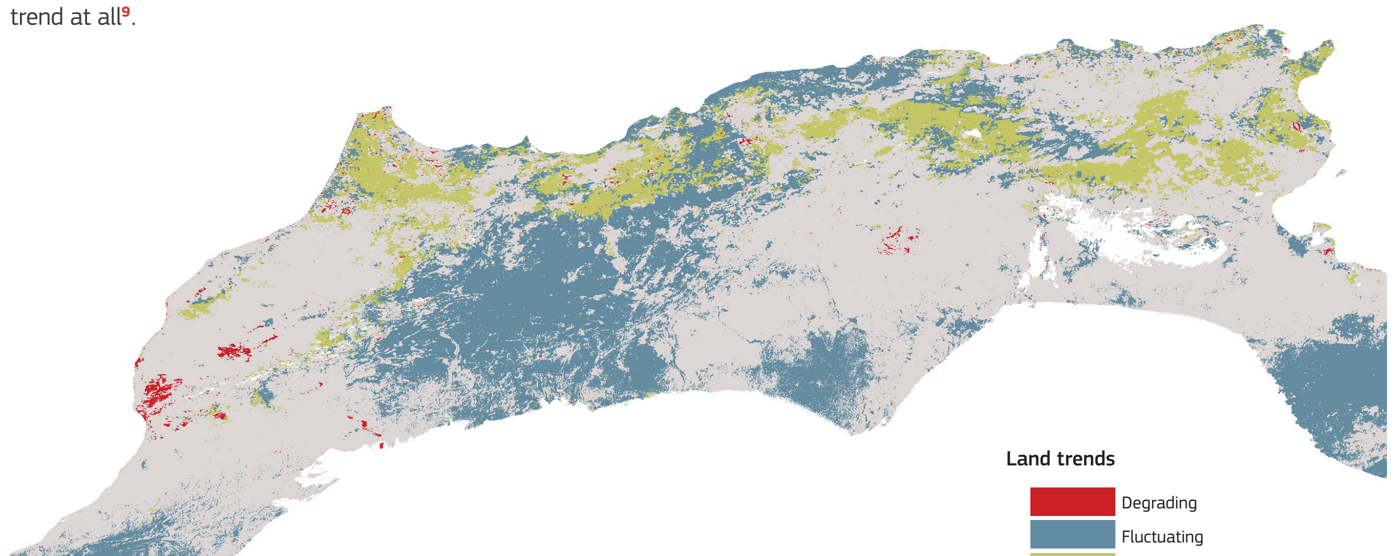


Source: Del Barrio, G. (based on Del Barrio, G. et al., 2010[9]) (AP).

Marabout* burial site
Sepulchre sites have been respected through the history of the Maghreb; nowadays they serve as well as permanent reminders of the original landscape. Here, an isolated juniper (*Juniperus oxycedrus*) with exposed roots shows the extent of recent landscape transformation and soil loss in the Plateau of Rekkham, Northern Morocco.
*"a Muslim holy man or hermit, especially in North Africa" (OED Online. Oxford University Press, March 2018. Web. 23 April 2018)
Source: Del Barrio, G.

Land-degradation trends

The area of land undergoing active degradation (degrading trend) is only 0.7 % of the total. In contrast, much more land (24.1 %) is found to be increasing in productivity. Land where productivity is fluctuating only in correspondence to interannual climate oscillations extends over 10.8 % of the territory. Finally, there is a vast proportion of static land (64.4 %) that shows no trend at all[9].



Panorama from the hills south of Marrakesh, Morocco, dominated by olive trees (*Olea europaea*).
Source: Hill, J.