DesertWatch Extension

Assessment and monitoring of land condition in Portugal, 2000-2010

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Dissemination level of this document:
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Almeria, March 2011

Contents

1. Scope

This document reports on the application of the *LDI-2dRUE* methodology as a contribution to desertification surveillance in Portugal. The *2dRUE* is an upgraded method for the assessment and monitoring of land condition, and it forms the current implementation of the Land Degradation Index (LDI) of the DesertWatch system.

The current delivery conveys the following UNCCD Impact Indicators[1] for Portugal in the analysis period: Aridity Index, Level of Land Degradation and Land Cover Status.

2dRUE is applied in two stages. The first one is called Version 0 and corresponds to the results of the numerical application using default settings. Such results consist of a map set with associated databases that are already in the format of the final product. Its purpose is to start an interactive process of interpretation and validation involving the concerned users. That process is the second stage and involves several things: known facts from the real world are interpreted in light of the model results, map legends may need to be tuned accordingly, model thresholds and settings may require revision to generate a new model run, independent data are selected to test the model, etc. All those tasks mean a permanent feedback with Version 0, which will be then upgraded to a proper technical product. This is called Version 1 and corresponds to the delivered application.

This report concerns to the Version 0 of the 2dRUE-Portugal application. Its objective is to provide the Portuguese users with a formal basis to start the interactive process described above. This is therefore a working document, which justifies setting its dissemination level to confidential. In addition to that, this report has yet to be enhanced with further analyses, especially concerning the application results.

2. Objective

This application aims at developing a diagnostic of land condition in Portugal during the period 2000-2010. Land condition is considered to convey human and climatic effects on the landscape. The diagnostic of land condition reported here is based both on state of land and on its trends during the period.

3. Methods

3.1. Background on 2dRUE

2dRUE is a methodology for the assessment and monitoring of land condition. It was developed in the frame of the EC DeSurvey Integrated Project (www.desurvey.net). The method is based on the application of statistical techniques to archived time-series of a remotely sensed vegetation density index, and corresponding climate fields. See del Barrio et al. (2010)[2] for a full description and for the application to the Iberian

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[1] L. Berry, E. Abraham & W. Essahli (2009). *UNCCD Recommended Minimum set of Impact Indicators*. Consultancy report.

[2] del Barrio, G., Puigdefabregas, J., Sanjuan, M.E., Stellmes, M., & Ruiz, A. (2010). Assessment and monitoring of land condition in the Iberian Peninsula, 1989-2000. *Remote Sensing of Environment, 114*, 1817-1832

Peninsule during the preceding period 1989-2000. Nevertheless, it is important to stress that the methodology has been upgraded since that pioneering study, especially concerning how the assessment legend is derived. For that reason, the results of these applications to the same area in two successive periods cannot be directly compared without harmonizing their respective legends. This issue will be addressed in a later enhancement of this report of Version 0.

This document is oriented to users and reports only specific aspects of the Portugal application. The generic implementation of the *LDI-2dRUE* methodology is described in existing DWE documents (Table 1).

Table 1. Source documents in DWE for the LDI-2dRUE methodology.

Id	**Title**	**Delivery event**	**Description**
TS V2	Technical Specification V2	CDR	Description of the LDI component approach (mathematical formulation)
./SDD V2	System Design Document V2	QAR	System design for the LDI (SW description) - final
./SUM EN	Software User Manual English	CDR	Contribution to the Software User Manual for the part of EEZA
SW-1 V1	SW mock-up	CDR	Mock-up of the LDI SW
./	System Trade-off analysis V3	QAR	Trade off on design solutions for the LDI component
PVP V3	Product Validation Plan V3	QAR	Validation plan for the LDI component

All the computations were done using the *r2dRue* software library, which can be downloaded from http://cran.r-project.org/web/packages/r2dRue/index.html. This package runs as stand alone in the frame of R, and will also be integrated into the DesertWatch software system.

3.2. Output description

This section aims at providing with an elementary key to understand the nature of the output results and their legend captions.

Assessment and monitoring are performed separately in 2dRUE, each procedure yielding its own maps. Such maps are then merged to the final land condition map. The legend system of it is hierarchical: legend captions correspond to assessment results and reflect land states, and sub-legend captions correspond to monitoring results and reflect land trends.

3.2.1. Assessment

Assessment addresses land states under the paradigm that natural vegetation maximizes Aboveground Net Primary Production (ANPP) per unit rainfall. It is evaluated using Rain Use Efficiency (RUE), which is implemented on two temporal scales to detect long and short term vegetation responses, and corrected for aridity across the whole study area to enable direct comparisons between locations. States are graded accordingly in the corresponding map legend (Table 2).

Table 2. Assessment classes conveying land states used in the land condition map.

Abbreviation	**Legend caption**	**Interpretation**
OA	*Overperforming anomaly*	Vegetation well above the maximum RUE found in rainfed conditions. Typically, irrigated crops.
RP	*Reference performance*	Vegetation within the confidence interval of maximum RUE. Typically, undisturbed natural vegetation.
M	*Range performance: mature*	Vegetation with a relatively high biomass but a relatively low productivity. For example, areas under low intensity grazing.
P	*Range performance: productive*	Vegetation with both relatively high biomass and productivity. This refers typically to initial phases of overgrazing or incipient degradation.
D	*Range performance: degraded*	Vegetation with a relatively low biomass but a relatively high productivity. For example, well established degradation associated with overgrazing or decaying rainfed crops.
VD	*Range performance: very degraded*	Vegetation with both relatively low biomass and productivity. For example, advanced degradation due to overgrazing in the recent past or soil exhaustion after intensive crop management.
BP	*Baseline performance*	Vegetation within the confidence interval of minimum RUE. For example, vegetation limited by other factors than rain, such as saline areas.
UA	*Underperforming anomaly*	Vegetation well below the minimum RUE. For example, heavily disturbed areas.
NA	*Non assigned*	Vegetation excluded from the assessment for methodological reasons. Typically, a small set of locations in the wet extreme of the aridity gradient. Also includes masked territory (snow, etc.)

This system essentially means a two-step discrimination. First, locations are objectively classified according to their observed long term vegetation performance using statistically significant thresholds. In that classification, marginal classes (*Reference performance* and *Baseline performance* respectively) are rather small and need no further discussion. However, the central class (*Range performance*) contains the majority of locations because of the built-in use of boundary functions. Then, the second step is performed on this class.

The central class is likely to target to locations under active land use (because they show neither very good nor very bad performance), where different responses can be expected from the vegetation cover. For that reason, a one-dimensional gradient might not be very clarifying to assess the ‘range’ class. Instead, we have adapted the original hypothesis of Pickup et al. (1994)[3], by which annual average biomass and NPP may be expected to decrease as land degradation proceeds, whilst peak NPP would be maximum at intermediate degradation states. The two implementations of RUE used in*2dRUE* target respectively to such functions, but their observed values cannot be used in comparisons across the study area because of the influence of climate. Therefore, their relative transformations are used for this purpose.

3.2.2. Monitoring

Monitoring addresses land trends (irrespectively of states) observed along the study period. The effects of inter-annual variations of aridity and those of time are explicitly separated. The former explain resilience to changing rainfall, for example, the wetter the year, the greener the vegetation. Once such effects are removed, the accumulation of depletion of biomass over time is interpreted in terms of ecological self-organisation or ongoing degradation. Three maps make the primary result of monitoring:

- Effect of interannual variations of aridity on vegetation. This map reflects sensitivity to yearly oscillations of aridity (defined as PET/P). Negative values mean that vegetation is less green in dry years. No trend is assessed on the long term.
- Effect of time on vegetation. This map conveys the long term vegetation trends after the interannual climate oscillations have been removed. Positive values mean a linear biomass accumulation over time (e.g. a secondary ecological succession after abandonment), whilst negative values mean some ongoing degradation process.
- Detailed monitoring map. This map is simply a combination of positive, negative and non effects from the two previous maps.

Those results must be distinguished respectively from good conditions or degraded states, which is a subject for the assessment map. Whilst such maps are useful for detailed studies, their respective legends are too complex for showing in the final land condition map. Therefore a simplification is made to provide the trends sub-legend in the final map of land condition (Table 3).

[3] Pickup, G., Bastin, G.N., & Chewings, V.H. (1994). Remote-sensing-based condition assessment for nonequilibrium rangelands under large-scale commercial grazing. *Ecological Applications, 4*, 497-517

Table 3. Monitoring sub-classes conveying land trends used in the land condition map.

Abbreviation	Sub-legend caption	Interpretation
I	*Improving*	Biomass accumulation over time, whatever the response to interannual variations of aridity. Typically, ongoing ecological succession after a disturbance or land abandonment.
F	*Fluctuating*	Biomass fluctuates according to the year rainfall, but with no significant variation on the long term. For example, rainfed crops or grasslands dominated by annual plants.
S	*Static*	No response detected over time neither to changing rainfall within the study period.
D	*Degrading*	Biomass depletion over time, whatever the response to interannual variations of aridity. Typically, ongoing degradation processes. Recently burnt areas may also be included.

4. Data

4.1. Study area

The study area is mainland Portugal.

4.2. Input data sets

2dRUE requires the following input data over a time period approximately spanning 10 years:

- Archived time-series at a monthly temporal resolution:
  - NDVI or other RS-derived vegetation density index
  - Corresponding climate fields (mean maximum, mean and mean minimum temperature, and precipitation)
- Land use or land cover map, to mask irrigated areas, wetlands and other non rainfed surfaces during the climate detrending routine.
- Natural reserves and other pristine natural vegetation areas for validating the maximum potential vegetation performance.
- Also convenient, but not strictly required, are layers of administrative divisions, natural vegetation zones, and other complementary data sets that can be used for the interpretation of the results

The data sets used for Version 0 of the 2dRUE-Portugal application are shown in Table 4.

Table 4. Input data sets for Version 0 of 2dRUE-Portugal.

Variable	***Product* and source**	**URL**
Vegetation density archive	*SPOT VEGETATION NDVI*. Available from 1998 onwards. Coordinated by VITO. Worldwide data are recorded every ten days (dekade) at a spatial resolution of 0.00892857º (approximately 1 km). A quality channel is available to mask clouds and snow. Monthly data were assembled by selecting the maximum value in the three concerned sequential dekades.	http://free.vgt.vito.be/
Temperature and Precipitation archives	*Ad hoc* interpolations following the scheme described in the preceding application. 10 years were added to the existing archive at the same spatial and temporal resolutions of 1 km and 1 month respectively. Georeferenced monthly summaries were downloaded from the Portuguese Sistema Nacional de Informaçao de Recursos Hídricos (SNIRH) and from the Global Summary of the Day (GSOD) database maintained by the US NOAA-NCDC.	http://snirh.pt/ http://lwf.ncdc.noaa.gov/cgi-bin/res40.pl?page=gsod.html
Land use / land cover	*Corine Land Cover 2006 raster data version 13*, and *Corine Land Cover 2000-2006 changes version 13*. Managed by the European Environment Agency. Both datasets in raster format at 100 m resolution in ETRS-LAEA system.	http://www.eea.europa.eu/data-and-maps/data#c5=all&c11=&c17=&c0=5&b_start=0
Administrative divisions	*Administrative units / statistical units (NUTS 1, 2 and 3)*. Managed by Eurostat. Vector layer at 1:3000000, updated 2006.	http://epp.eurostat.ec.europa.eu/portal/page/portal/gisco/popups/references/administrative_units_statistical_units_1

The formulation of 2dRUE requires observed RUE to be detrended with respect to aridity to enable direct comparisons between locations under different climates. Such detrending should be made using only rainfed vegetation responding naturally to climate. For this purpose, only cells allocated to ‘Forest and semi-natural areas’ of CLC level 1 were used. This includes the following classes in CLC level 3: Broad-leaved forest, Coniferous forest, Mixed forest, Natural grasslands, Moors and heathland, Schlerophyllous vegetation, Transitional woodland-shrub, Beaches, dunes, sands, Bare rocks, Sparsely vegetated areas, Burnt areas and Glaciers and perpetual snow (the latter not in Portugal).

4.3. Study period and resolutions

The study period was from 1 September 2000 through 31 August 2010. Hydrological years were used, hence the period is made of ten years starting in 2000/2001. This is a continuation of the previous application that extended from 1989/1990 to 1999/2000. The temporal resolution over that period was of 1 month.

The map sets have been managed using the same Coordinate Reference System (CRS) and grid specification of the *SPOT VEGETATION NDVI* product, to keep the integrity of vegetation values. That CRS consists of unprojected geodetic coordinates in the WGS84 datum. The resolution is of 0.00892857 degrees, which approximately equals to 1 km on a maximum circle. One advantage of this procedure is that relevant maps or window regions can be projected to the CRS of a target user agency with minimum distortion or loss of information.

5. Results and discussion

The maps of assessment, detailed monitoring and land condition are shown in Annex 1, and have been also delivered in digital format. It makes low sense to seek here unifying geographic arguments in a large and heterogeneous study area such as Portugal. In most cases, the maps interpretation and discussion should be made for smaller and homogeneous areas, using local knowledge. However, it is still possible to comment basic outcomes at several levels of spatial detail.

5.1. Observed rain Use Efficiency over Aridity Index

Figure 1 shows the scatterplots of mean and extreme observed RUE over corresponding aridity estimates that were used to define the assessment legend classes (land states). First, mean and extreme relative RUE were computed using the respective boundary functions. Second, the main assessment classes (*UA*, *BP*, *range*, *RP* and *OA* in Table 2) were defined using the boundary functions confidence intervals of mean RUE (Figure 1, left). Third, the range class was further subdivided according to biomass (mean relative RUE) and productivity (extreme relative RUE) thresholds. These correspond to the respective medians of relative RUE across the range class.

In this application, only forests and semi-natural areas were used throughout the procedure (in contrast with earlier applications, where the scatterplot had been built using only natural rainfed areas, but the medians of both relative RUEs within the range class were determined using all kinds of land cover). This upgraded procedure improves the interpretation of biomass and productivity by referring to natural vegetation, and also avoids symmetry in the frequencies of range subclasses.

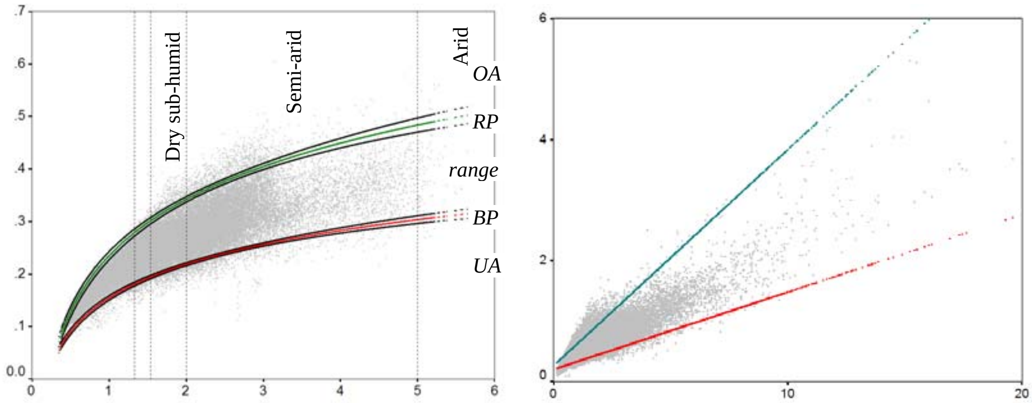

Figure 1. Variation of Rain Use Efficiency (RUE) over Aridity Index (AI) in forests and semi-natural areas of the Iberian Peninsule (2000-2010). Mean (left) and Extreme (right) observed RUE, computed respectively as inter-annual means and for the six-month period preceding the time when maximum vegetation density was detected at each location, are plotted against AI, which is defined as the ratio of Potential Evapo-transpiration to Precipitation over the according period. Boundary functions are fitted to reflect the 5% and 95% percentiles of each scatterplot, and reflect the minimum and maximum vegetation performance from which relative RUE is computed. Confidence intervals are also plotted for mean observed RUE because they are used to define the main assessment classes (horizontal labels, see Table 2). Vertical bars reflect limits between aridity zones according to the FAO-UNEP formulation (vertical labels).

The experimental results show a logarithmic increase of mean RUE over aridity. The increase is very fast in wet and wet sub-humid areas, and tapers beyond the dry sub-humid to become almost linear in the semi-arid and the arid. This is consistent with the findings of Huxman et al. (2004)[4] about convergence to a common maximum RUE across different biomes during dry periods. Using time-series of sites located throughout America, they demonstrated that plots of ANPP over P trended to a common maximum slope when only dry years were used, irrespectively of the vegetation zone. Such a slope, also called sensitivity, is RUE by definition. Our results have been produced on a spatial rather than a temporal dimension, and confirm the increase of RUE over aridity. The fact that such increase does not become constant in this case, as it could be expected from a direct extrapolation of the cited study, reflects that the process of convergence (i.e. the rate of change of ANPP over P under increasingly arid conditions) is non linear and becomes more intense the more intense is the aridity. In terms of the cited study, only 'normal' and 'dry' years were differentiated on a temporal dimension, whilst in this work a comprehensive spatial transition between wet and dry conditions is used.

5.2. Overall results of land states and trends

The final extension of the study area was of 113629 cells (approximately 111850 km^2), after all the masks (mainly clouds) had been applied. Table 5 shows the distribution of land between condition classes.

[4] Huxman, T.E., Smith, M.D., Fay, P.A., Knapp, A.K., Shaw, M.R., Loik, M.E., Smith, S.D., Tissue, D.T., Zak, J.C., Weltzin, J.F., Pockman, W.T., Sala, O.E., Haddad, B.M., Harte, J., Koch, G.W., Schwinning, S., Small, E.E., & Williams, D.G. (2004). Convergence across biomes to a common rain-use efficiency. *Nature, 429*, 651-654

Table 5. Land condition states (rows) and trends (columns) in Portugal peninsular. Entries are extension of land for each assessment and monitoring combination [cells, %].

			MONITORING				
			DEGRADING	FLUCTUATING	IMPROVING	STATIC	Total
ASSESS	UNDERPERFORMING ANOMALY	Count	48	194	261	347	850
		% of Total	.0%	.2%	.2%	.3%	.7%
	BASELINE PERFORMANCE	Count	6	104	176	198	484
		% of Total	.0%	.1%	.2%	.2%	.4%
	VERY DEGRADED	Count	194	6759	7669	8547	23169
		% of Total	.2%	5.9%	6.7%	7.5%	20.4%
	DEGRADED	Count	153	7141	2564	3545	13403
		% of Total	.1%	6.3%	2.3%	3.1%	11.8%
	PRODUCTIVE	Count	340	16522	13406	10326	40594
		% of Total	.3%	14.5%	11.8%	9.1%	35.7%
	MATURE	Count	466	4912	9462	8481	23321
		% of Total	.4%	4.3%	8.3%	7.5%	20.5%
	REFERENCE PERFORMANCE	Count	118	1929	1454	1137	4638
		% of Total	.1%	1.7%	1.3%	1.0%	4.1%
	OVERPERFORMING ANOMALY	Count	328	2611	1835	2396	7170
		% of Total	.3%	2.3%	1.6%	2.1%	6.3%
Total		Count	1653	40172	36827	34977	113629
		% of Total	1.5%	35.4%	32.4%	30.8%	100.0%

5.2.1. Land states

As a whole, better condition classes prevail over poorer ones after discarding anomalies (*UA* and *OA*). *Baseline performance*, *Very degraded*, and *Degraded* land account together for 32.6% of the territory, whilst *Productive*, *Mature* and *Reference performance* land lump in 60.3%. This enables rejecting any views of generalised degradation at the country level, but still almost one third of land is somewhat degraded and desertification hot spots should be found in that domain.

Productive land is dominant in the better condition classes and is also the overall most abundant state. This is likely to reflect agricultural uses with variable degrees of intensification and, along with mature land, account for more than half of the territory. This does not include *Reference performance* land, which shows a comparatively low share. In a European country such as Portugal, this condition conveys the marginal 'land bank' from which land is retrieved to yield more profitable systems, and to which land is abandoned when those systems are no longer in use. The relatively small size of this bank suggests an imbalance between land under some use and buffer land that is perhaps profitable on the short term, but that is potentially unstable on the long term.

5.2.2. Land trends

In contrast with the assessment, which is relative across the territory, the monitoring results are absolute estimates of vegetation trends over time and aridity *during the study period*. Several findings are remarkable here. *Fluctuating* trends prevail in Portugal, shortly followed by *Improving* ones. This means that 67.8% of the territory contains vegetation that is either resilient to inter-annual climate variations or accumulating biomass over time. *Static* land showing neither of these responses has also a relatively high frequency, the obvious question is whether the study period could not have been long enough for any possible trend to be detected. That said, land may not show such trends for a variety of reasons that will not be discussed here.

The amount of land under active degradation processes (*Degrading*) is very low, of only 1.5% of the total. This is consistent with results worked out in other areas such as the Maghreb, the Sahel, the Iberian Peninsula (1989-2000), the Chile IV Region and NW Brazil. It is reasonable as a result, because it reflects a rate of change rather than the final state after the change has stabilised (which is addressed in the assessment). The immediate implication is that such relatively small amount of land should be easily tackled by desertification policies, and the land condition map may help to aim their focus.

5.2.3. Relationships between states and trends

The assessment and monitoring procedures operate on the same data set, but are completely independent exercises both in approach and in methods. For that reason, it is worth questioning whether there is any relationship between land states and trends in Portugal. To investigate it, a chi-square test was applied on a sample of 24185 cells extracted through stratified-random design and containing 21.3% of the study area (Table 6).

Table 6. Results of a chi square test between assessment classes and monitoring subclasses (χ^2=1390.495, df = 21, p < 1E-03). The contingency tables show residual (observed minus expected) frequencies (a), and adjusted residuals in standard deviation units with respect to the mean (observed minus expected divided by the square root of: expected frequencies by row total proportion by column total proportion), which takes into account the overall size of the sample (b).

a)

Residual

		MONITORING			
		DEGRADING	FLUCTUATING	IMPROVING	STATIC
ASSESS	UNDERPERFORMING ANOMALY	6.4	-25.1	.3	18.4
	BASELINE PERFORMANCE	-1.4	-10.0	.9	10.5
	VERY DEGRADED	-26.9	-307.6	15.0	319.4
	DEGRADED	-6.1	516.6	-373.3	-137.3
	PRODUCTIVE	-48.2	465.3	79.8	-496.9
	MATURE	23.4	-716.7	398.5	294.8
	REFERENCE PERFORMANCE	8.9	67.0	-28.4	-47.5
	OVERPERFORMING ANOMALY	43.8	10.6	-92.9	38.5

b) Adjusted residual

ASSESSMENT	MONITORING			
	DEGRADING	FLUCTUATING	IMPROVING	STATIC
UNDERPERFORMING ANOMALY	4	-3.9	0	3
BASELINE PERFORMANCE	-1.2	-2.1	0.2	2.3
VERY DEGRADED	-3.7	-10.3	0.5	11.1
DEGRADED	-1	21.6	-15.9	-5.9
PRODUCTIVE	-5.5	13	2.3	-14.4
MATURE	3.2	-23.9	13.6	10.2
REFERENCE PERFORMANCE	2.4	4.5	-2	-3.3
OVERPERFORMING ANOMALY	9.9	0.6	-5.3	2.2

The test was highly significant, therefore such association can be accepted and interpreted. The residual frequencies indicate departures from the frequencies that should be expected in case of no relationship between assessment and monitoring classes. A simple and uniform pattern does not emerge from Table 6, but several facts are apparent:

- Very poor states (*Baseline performance* and *Very degraded*) show association with *Static* and *Improving* trends. This can be interpreted in terms of recently abandoned or burnt land that is undergoing a spontaneous recovery.
- *Degraded* land is clearly associated with *Fluctuating* trends, suggesting some stability or resilience within the study period.
- *Productive* land trends to be *Fluctuating* or *Improving*, suggesting active land management and intensification.
- Most of *Mature* land shows also a clear preference for *Improving* trends, but a relevant part of it is undergoing *Degrading* trends.
- *Reference performance* is mostly under *Fluctuating* and *Degrading* trends, showing negative associations with *Improving* or *Static* trends. This is contrary to what might be expected from natural and semi-natural vegetation, a part of which is under conservation policies.
- Almost one quarter of *Overperforming anomalies* appear to be under *Degrading* trends. For land under use, this could correspond to irrigated areas that are beyond their prime time.

The general picture is that better trends are found in land under recent or present economic activity, and deteriorating trends begin to be relevant in better states. *Mature* land would be the turn point, as most of it is associated with *Improving* trends, but *Degrading* ones appear here for the first time in the gradation of states. The surprising finding that *Reference performance* is only associated with *Fluctuating* or *Degrading* trends simply confirms this pattern.

A complacent view of these associations would be that land under exploitation is relatively healthy in Portugal, therefore policies to combat desertification and land degradation should focus only in concrete hot spots, the location of which is facilitated by the land condition map. However, a deeper insight demonstrates that reference vegetation has a low extension in the country, and in addition to that a significant part of it is undergoing degradation. This suggests a low key impact of conservation policies, a weak safety network for the 'land bank' and, overall, an emphasis on land management over ecological self-organisation to maintain healthy landscapes, which is inherently unstable.

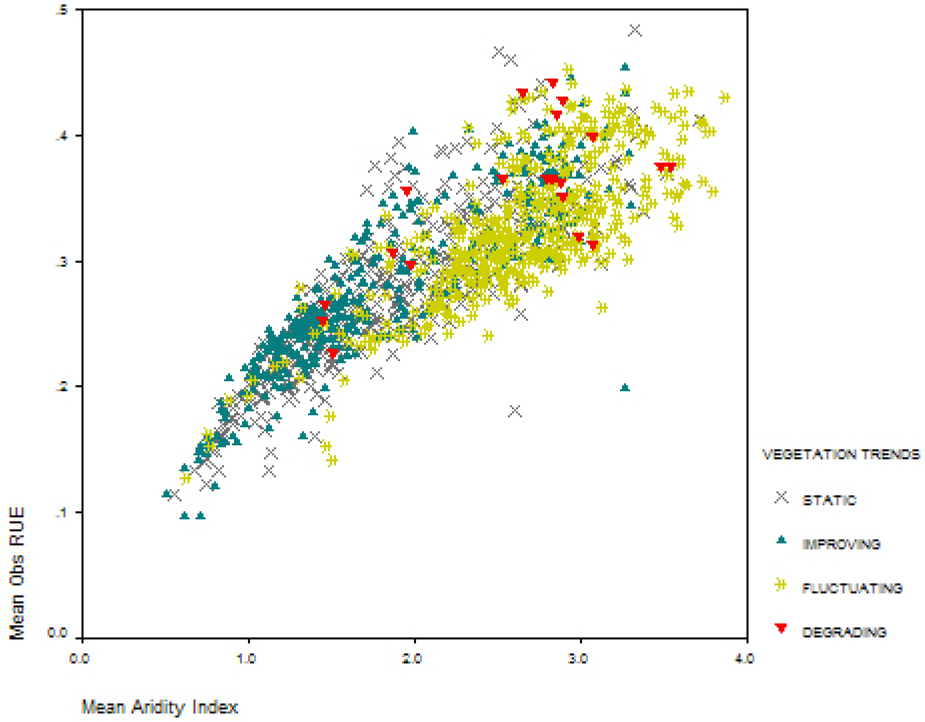

Figure 2. Distribution of the monitoring results (*Vegetation trends*) with respect to the assessment results (*Mean Observed RUE* and *Mean Aridity Index*) in Portugal (2000-2010). A stratified-random sample of 1242 cells was used to avoid graph clutter.

5.3. Relationship between land condition and land cover

Land condition is linked to land use through feedback loops: condition controls which uses can be developed on a piece of land, and uses can make condition change. To test this hypothesis, associations were explored using chi-square tests between the resulting assessment and monitoring classes on the one hand, and CLC classes on the other. The sample dataset consisted of 35159 cells (30.9% of the study area) selected through a stratified-random design. Artificial surfaces and Wetlands were not considered, and to respect the test requirements concerning expected frequencies, Pastures and Rice fields were also eliminated, and Bare rock, Sparsely vegetated areas and Burnt areas were lumped in the Open spaces class of CLC level 2.

Table 7. Results of a chi square test between land states and CLC2006 classes in Portugal (2000-2010). (χ^2=20113.11, df = 112, p < 1E-03). The contingency table shows residual (observed minus expected) frequencies.

Residual

		ASSESSMENT							
		UNDERPERFORMING ANOMALY	BASELINE PERFORMANCE	VERY DEGRADED	DEGRADED	PRODUCTIVE	MATURE	REFERENCE PERFORMANCE	OVERPERFORMING ANOMALY
LC	Non-irrigated arable land	-15.3	-17.1	-291.8	498.7	990.5	-805.5	-42.4	-317.1
	Permanently irrigated land	-2.1	-2.5	-116.4	-31.9	168.2	-91.3	32.3	43.7
	Vineyards	-4.6	3.1	277.6	-31.1	-167.9	22.7	-31.5	-68.2
	Fruit trees and berry plantations	-2.0	-1.7	-.9	-22.1	-31.2	6.6	23.0	28.2
	Olive groves	-3.4	-2.8	2.8	157.2	-35.8	-11.4	-34.9	-71.6
	Annual crops assc with permanent crops	-4.4	-3.8	77.6	-45.8	-50.1	118.2	-26.3	-65.2
	Complex cultivation patterns	-6.1	-2.1	94.4	-70.0	-90.9	126.3	-5.6	-45.9
	Agriculture land with natural veg	-4.2	-3.5	170.3	196.4	-276.2	-6.3	-21.8	-54.6
	Agro-forestry areas	-12.9	-12.8	-397.8	256.3	677.0	-430.7	55.4	-134.4
	Broad-leaved forest	-25.8	-22.2	-610.5	-517.1	-186.9	255.9	215.2	891.3
	Coniferous forest	-3.4	-6.0	-248.8	-263.4	-9.2	331.8	67.9	131.1
	Mixed forest	-6.6	-5.7	-151.7	-156.4	-5.9	216.7	40.1	69.4
	Natural grasslands	-1.1	-2.7	276.9	32.4	-212.2	-12.5	-29.4	-51.5
	Moors and heathland	-5.2	-1.5	331.0	29.1	-279.1	43.3	-44.9	-72.8
	Sclerophyllous vegetation	-3.5	-3.0	-50.6	-6.8	24.3	14.2	-3.5	28.9
	Transitional woodland-shrub	-27.4	-18.2	383.6	-6.2	-230.5	332.8	-156.0	-278.1
	Open spaces with little or no veg	127.9	102.5	254.2	-19.4	-284.1	-110.6	-37.5	-33.0

Table 8. Results of a chi square test between land trends and CLC2006 classes in Portugal (2000-2010). (χ^2= 10730.50, df = 48, p < 1E-03). The contingency table shows residual (observed minus expected) frequencies.

Residual

		MONITORING			
		DEGRADING	FLUCTUATING	IMPROVING	STATIC
LC	Non-irrigated arable land	-77.2	1396.6	-774.0	-545.5
	Permanently irrigated land	-12.4	-111.7	116.3	7.9
	Vineyards	-16.4	-82.1	225.9	-127.4
	Fruit trees and berry plantations	-8.4	-68.5	6.4	70.5
	Olive groves	-13.8	247.4	-56.5	-177.2
	Annual crops assc with permanent crops	-17.9	-90.8	6.3	102.4
	Complex cultivation patterns	-28.3	78.9	64.0	-114.6
	Agriculture land with natural veg	-20.1	132.1	-123.1	11.1
	Agro-forestry areas	-53.4	1266.2	-390.6	-822.3
	Broad-leaved forest	83.2	545.0	-105.4	-522.8
	Coniferous forest	196.7	-730.5	427.3	106.5
	Mixed forest	-8.0	-345.2	420.7	-67.6
	Natural grasslands	-12.1	-168.1	139.3	40.9
	Moors and heathland	-21.1	-258.7	185.4	94.5
	Sclerophyllous vegetation	-9.8	-33.1	-124.6	167.5
	Transitional woodland-shrub	3.4	-1525.4	-136.0	1657.9
	Open spaces with little or no veg	15.7	-252.2	118.4	118.1

The results were significant in both analyses, and the residual frequencies can be interpreted (Tables 7 and 8). The following facts are apparent concerning the assessment results:

- There is a positive association between very poor states (*Undeperforming anomaly* and *Baseline performance*) and Open spaces.
- *Very degraded* land is associated with Transitional woodland-shrub, Moors and heathlands, Natural grasslands and Vineyards.
- *Degraded* state is mostly associated with Non-irrigated arable land and Agro-forestry areas.
- *Productive* state is dominant in Non-irrigated arable land and Agro-forestry areas.
- *Mature* state is associated with natural or semi-natural vegetal ligneous vegetation (e.g. Transitional woodland-shrub, Coniferous forest), but also with

land under traditional uses (e.g. Complex cultivation patterns, Annual crops associated with with permanent crops).

- *Reference performance* is found with a high frequency in Broad-leaved forest and other woody formations.
- *Overperforming anomaly* is associated with forest formations (mainly Broad-leaved forest) and with agricultural pattern that are often under intensification (e.g. Permanently irrigated arable land, Fruit and berry plantations).

The above interpretations have been made assessment-wise rather than CLC-wise because they aim at enhancing the contents to the *2dRUE* results. The first impression is that such results are consistent by comparing the vegetation performance of any location with what could be expected taking natural vegetation as a reference. This is particularly well conveyed by the interpretation of *Reference performance,* but also in the opposite extreme by lower condition states. For example, the association of Open spaces with little or no vegetation with deteriorated land suggests that such a kind of cover is non natural in Portugal, and wherever it is found is following a land degradation process. Possibly, the greater outlier in this interpretation is the association of *Overperforming anomaly* with Broad-leaved forest, which treats this coverage as 'excessive' for its corresponding climate in many cases. We believe it could be due to the fact that the scatterplot of RUE over aridity was fitted using data from the whole Iberian Peninsule, where dense coverages of this type are found under comparatively drier climate. However, this aspect only exaggerates but does not contradict the interpretation of the assessment results and can be left as it is, only to be treated with some caution.

The association between assessment results and CLC classes indicates somewhere that certain types of land cover are inherently degraded forms when compared to natural vegetation. This seems to happen with Vineyards, that in general appear only and always as *Very degraded* states. Nevertheless, this is far from being a general fact, and a CLC-wise interpretation of Table 7 leads to mixed and often opposite states for a given CLC class. This suggests that each land cover type has a typical range of RUE, and that any assessment of its condition should be conducted internally within its domain, so that departures can be interpreted with respect to its particular reference. This is shown in Figure 3.

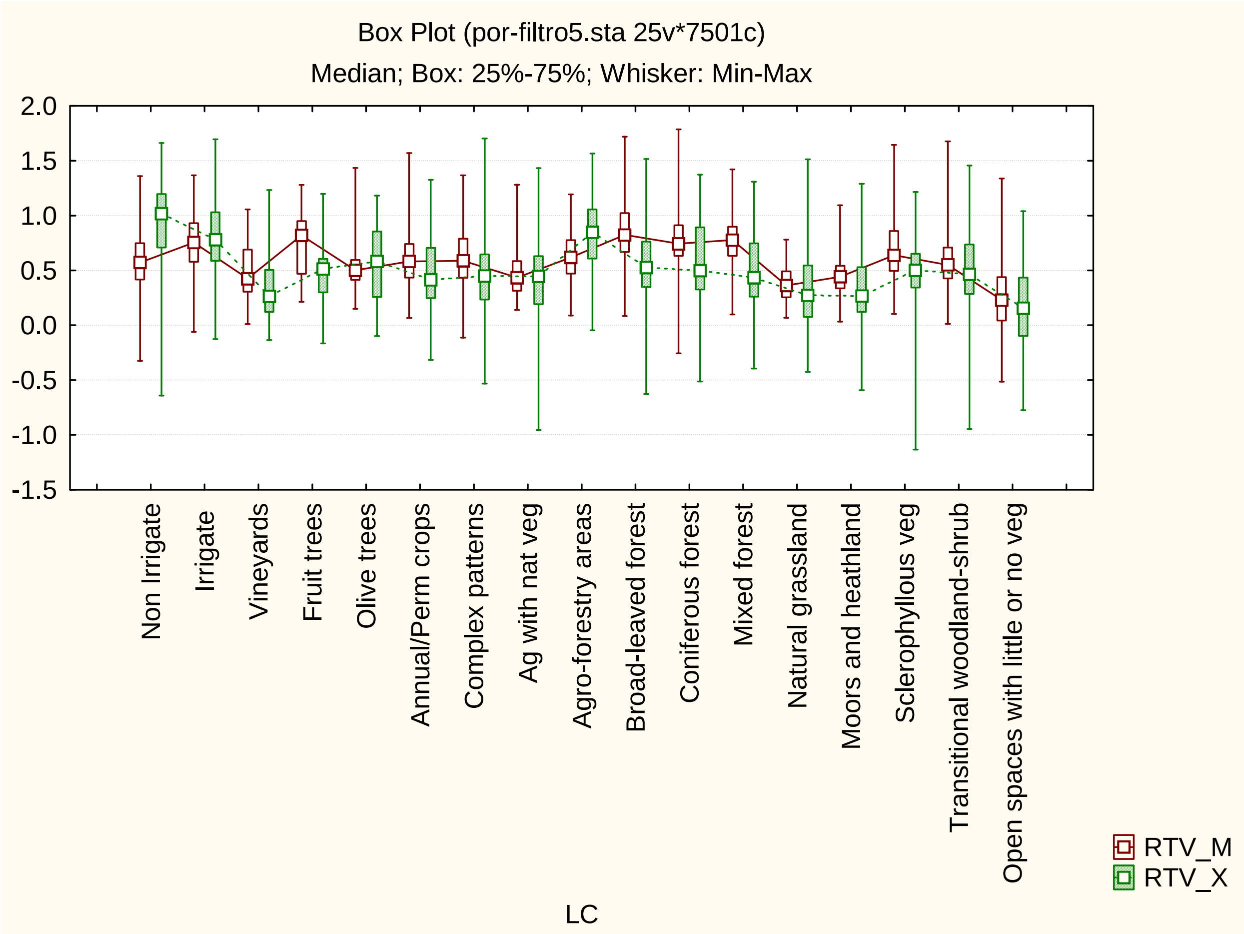

Figure 3. Ranges of relative mean and extreme RUE (*RTV_M* and *RTV_X* respectively) for CLC classes in Portugal (2000-2010).

Possible relationships between assessment results, in terms of relative mean and extreme RUE, and CLC classes, deserve further investigation. For this purpose, a double test was performed to detect differences in the ranks of relative mean and extreme RUE that can be attributed to the CLC classes. First, a Kruskal-Wallis test served to accept or reject the null hypothesis that relative mean and extreme RUE are evenly distributed between CLC classes. In case of rejection, a Tukey test served to test pairwise comparisons between CLC classes, and then to form homogeneous groups of CLC classes. Tables 9 and 10 show the results.

Table 9. Differences between means of relative mean RUE (Kruskal-Wallis $H_{16,\ N=7501}$=1859.450, p<10E-3). CLC classes are ordered by increasing relative mean RUE, and groups of homogeneity resulting from the Tukey test are indicated by columns. Asterisks across any given row or column indicate statistically similar values between the concerned CLC classes or groups respectively.

LC	RTV_M-rango Mean	1	2	3	4	5	6	7	8
Open spaces with little or no veg	1346.000	****							
Natural grassland	1521.241	****	****						
Moors and heathland	2058.784		****	****					
Ag with nat veg	2359.541			****					
Vineyards	2491.550			****					
Olive trees	2572.106			****					
Transitional woodland-shrub	3245.844				****				
Non Irrigate	3360.923				****				
Annual/Perm crops	3424.813				****	****			
Complex patterns	3563.056				****	****	****		
Agro-forestry areas	3741.575					****	****		
Sclerophyllous veg	4158.071						****	****	
Fruit trees	4709.408							****	****
Irrigate	4804.337							****	****
Coniferous forest	4972.329								****
Mixed forest	5010.580								****
Broad-leaved forest	5326.768								****

Table 10. Differences between means of relative extreme RUE (Kruskal-Wallis $H_{16,\ N=7501}$=1790.641, p<10E-3). CLC classes are ordered by increasing relative mean RUE, and groups of homogeneity resulting from the Tukey test are indicated by columns. Asterisks across any given row or column indicate statistically similar values between the concerned CLC classes or groups respectively.

LC	RTV_X-rango Mean	1	2	3	4	5	6	7	8
Open spaces with little or no veg	1626.361	****							
Vineyards	2070.643	****	****						
Natural grassland	2177.141	****	****	****					
Moors and heathland	2299.160		****	****					
Ag with nat veg	2866.616			****	****				
Complex patterns	3009.906				****				
Annual/Perm crops	3026.645				****	****			
Fruit trees	3067.212			****	****	****	****	****	
Mixed forest	3201.111				****	****	****		
Sclerophyllous veg	3231.370				****	****	****	****	
Transitional woodland-shrub	3279.930				****		****		
Broad-leaved forest	3588.387					****		****	
Olive trees	3691.812						****	****	
Coniferous forest	3720.650							****	
Irrigate	4867.692								****
Agro-forestry areas	5164.145								****
Non Irrigate	5495.067								****

These analyses enable two conclusions. First, the distribution of any relative RUE across CLC classes is uneven, which confirms that the assessment of land condition of any given land cover type should be performed within its particular rank of relative RUE (e.g. by comparing the values of a location with the frequency distribution of relative RUE for the land cover class under consideration). Moreover, CLC classes show different responses to both implementations of relative RUE. For example, broad-leaved forest scores the highest in relative mean RUE, which is a surrogate of biomass, but is mid-rank in relative extreme RUE, which means productivity. Second, the ranked sequence of CLC classes enables forming homogeneous groups in terms of relative RUE. These groups are not merely numerical lumps, but are physiognomically consistent and reflect the land use options available.

Using existing knowledge of land management on the skeleton resulting of this analysis, a relevant fact can be drawn. Given any of such groups and inspecting its mean relative RUE (Table 9), it can be agreed that: i) it is very easy to convert any of its CLC classes to any of the classes in a lower group; ii) it is relatively easy to interconvert CLC classes within the same group; and iii) it is very difficult or almost impossible to convert any of its classes to any of the classes in a higher group. If this true, the number of groups is linked to the options available for land management at a given land state (i.e. relative mean RUE level). In other words, land condition could be expressed as a number of degrees of freedom. Degradation would mean loss of degrees of freedom, whilst aggradation (or upgrading) would mean to gain degrees of freedom, often at a big expense. Concrete examples derived from Portugal for the analysis period are: Broad-leaved forest has all the management options with 7 out of 7 degrees of freedom (i.e. total number of homogeneous groups minus 1), and Olive trees has less management options with only 2 out of 7 degrees of freedom. This rationale must be still refined, particularly by including thresholds of relative RUE for the interconversion between land cover classes. However, it provides a useful insight of how a formal relationship between land use and land condition could be used to link socio-economic to ecological applications.

5.4. Relationship between land condition and administrative units

One of the efforts made in the design of *2dRUE* did target to enabling direct comparisons between locations under different climates. Therefore, the next question was to investigate whether land condition is homogeneously distributed between administrative units of Portugal, or alternatively, some units are especially affected by land degradation.

NUTS II (regions) and III (sub-regions) were used to generate results at relevant management levels. The same sample described in the preceding section was used here, again with chi-square tests. Assessment and monitoring were treated separately to avoid low expected frequencies.

Table 11. Results of a chi square test between assessment classes and NUTS II regions of Portugal. (χ^2=6642.0144, *df* = 28, *p* < 1E-03). The contingency table shows residual (observed minus expected) frequencies. See definitions in Table 2.

ASSESS * NUTS2 Crosstabulation

Residual

		NUTS2				
		NORTE	CENTRO	LISBOA	ALENTEJO	ALGARVE
ASSESS	UNDERPERFORMING ANOMALY	47.8	-3.9	11.1	-60.0	5.0
	BASELINE PERFORMANCE	45.2	-10.7	-1.2	-31.0	-2.4
	VERY DEGRADED	1315.8	228.7	-56.5	-1397.5	-90.3
	DEGRADED	-54.2	-237.2	-67.1	327.0	31.5
	PRODUCTIVE	-1084.9	-171.5	-74.7	1412.5	-81.3
	MATURE	281.8	479.4	1.7	-769.6	6.7
	REFERENCE PERFORMANCE	-193.9	-52.2	26.9	211.8	7.3
	OVERPERFORMING ANOMALY	-357.6	-232.5	159.7	306.8	123.6

Table 12. Results of a chi square test between monitoring classes and NUTS II regions of Portugal. (χ^2=6649.2711, *df* = 12, *p* < 1E-03). The contingency table shows residual (observed minus expected) frequencies. See definitions in Table 2

MON * NUTS2 Crosstabulation

Residual

		NUTS2				
		NORTE	CENTRO	LISBOA	ALENTEJO	ALGARVE
MON	DEGRADING	-58.7	-17.9	1.1	76.9	-1.6
	FLUCTUATING	-1452.7	-972.9	40.4	2432.4	-47.2
	IMPROVING	536.8	849.7	-62.8	-945.5	-378.2
	STATIC	974.5	141.0	21.2	-1563.8	427.0

Tables 11 and 12 show the results, that enabled significant acceptance of the alternative hypothesis that land condition is heterogeneously distributed across NUTS II regions. Concerning land states (Table 11), the patterns of residual frequencies suggest that the Norte region contains most of the deteriorated land, as positive associations are consistently found from *Underperforming anomaly* through *Very degraded* states. The region of Alentejo, conventionally put forward to exemplify land degradation of Portugal, is much less clear in this sense and shows high positive frequencies of *Degraded* and *Productive* states, probably indicating a high impact of agriculture. The other regions show mixed patterns that will not be interpreted here.

The diagnosis is different when considering land trends, which indicate ongoing evolution. Whilst it was established in Section 5.2.3 that *Degrading* trends have a low representation in Portugal, Table 12 shows that they are concentrated in the Alentejo, which also accounts for most of the *Fluctuating* trends. On the contrary, the regions of Norte and Centro account together for most of the *Improving* trends, suggesting that degradation processes did occur there in past times but are no longer very active.

The portrait of Alentejo made by the above results is of a region under active agricultural development that does not yet contain much degraded land with respect to other Portuguese regions, but which is undergoing most of the land degradation processes of the country. This confirms the perception of the users and focuses a domain for the search of land degradation hot spots. An attempt in this sense was made by testing whether land condition is evenly distributed between its NUTS III sub-regions (Table 13). The two lowest land states (*Underperforming anomaly* and *Baseline performance*) are poorly represented in the region and were not used in this analysis.

Table 13. Results of a chi square test between land condition classes and NUTS III sub-regions of the Alentejo. (χ^2=10355.8578, *df* = 92, *p* < 1E-03). The contingency table shows residual (observed minus expected) frequencies. See definitions in Tables 2 and 3.

LC * NUTS Crosstabulation

Residual

		NUTS				
		Baixo Alentejo	Alto Alentejo	Alentejo Central	Leziria do Tejo	Alentejo Litoral
LC	VERY DEG DEGRADING	-3.5	3.8	-5.4	-2.7	7.8
	VERY DEG FLUCTUATING	48.1	104.4	-65.9	-31.5	-55.1
	VERY DEG IMPROVING	-17.7	2.5	-18.2	45.7	-12.3
	VERY DEG STATIC	-3.6	13.7	-9.5	-4.3	3.7
	DEG DEGRADING	3.2	-3.4	.4	-2.9	2.6
	DEG FLUCTUATING	643.6	53.6	-169.7	-241.9	-285.6
	DEG IMPROVING	90.7	-5.7	-40.6	-7.5	-37.0
	DEG STATIC	21.1	48.8	-14.1	-26.6	-29.3
	PRODUCTIVE DEGRADING	-10.1	-12.8	-4.0	-5.2	32.0
	PRODUCTIVE FLUCTUATING	501.5	160.8	262.8	-550.0	-375.1
	PRODUCTIVE IMPROVING	-249.6	41.8	54.4	255.4	-101.9
	PRODUCTIVE STATIC	-42.3	-44.0	167.9	8.3	-89.8
	MATURE DEGRADING	-44.4	-22.0	-35.8	8.2	93.9
	MATURE FLUCTUATING	-177.9	107.8	-101.4	180.3	-8.8
	MATURE IMPROVING	-132.5	4.0	-79.9	242.8	-34.4
	MATURE STATIC	-53.1	29.2	-52.1	67.8	8.2
	REFERENCE P DEGRADING	-8.5	-7.5	5.5	1.2	9.3
	REFERENCE P FLUCTUATING	-62.4	-114.8	130.6	-53.2	99.8
	REFERENCE P IMPROVING	-43.2	-28.8	.9	36.5	34.6
	REFERENCE P STATIC	-28.7	-20.0	12.6	24.5	11.7
	OVERP A DEGRADING	-28.8	-22.1	24.0	-5.3	32.2
	OVERP A FLUCTUATING	-198.5	-154.9	9.0	-78.1	422.4
	OVERP A IMPROVING	-113.5	-75.6	-49.7	75.1	163.6
	OVERP A STATIC	-90.2	-58.6	-22.0	63.6	107.2

The results show that land condition is not homogeneous in the Alentejo. For example, the sub-region of Alentejo Litoral has strong positive association with *Degrading* trends in all the land states, although also positive associations with *Static*, *Fluctuating* and *Improving* trends in better condition states (e.g. *Reference performance*) indicate active degradation hot spots interspersed in a matrix that is in relatively good condition. However, *Degrading* trends are found elsewhere too, and it is worth mentioning that Baixo Alentejo and Alto Alentejo account for most of the *Very degraded* and *Degraded* land, Leziria do Alentejo is very associated with *Productive* land, and Alentejo Central contains most of the *Reference performance* land. A comprehensive interpretation of these results is beyond the scope of this study and should be done along with the map of land condition and in light of local knowledge.

6. Preliminary conclusions

The real result of this study consists of the final map of land condition and the preceding assessment and monitoring maps it was derived from. Such map set shows geographic variations of land states and trends as well as local configurations that could be associated with hot spots. Now it should be interpreted by the users on the basis of their regional knowledge, and validated by the research team using independent data. (Note that interpretation and validation are different jobs, each of them involving its own methods and data). Only after these tasks have been completed, the final land condition map would be ready for its delivery to a regional planning agency or to the Portuguese National Action Programme to combat desertification.

The *2dRUE* method allows room for further tuning of its results. Typically, this may involve making a formal comparison between the results of the reporting period (2000-2010) and those yielded by a previously published study (1989-2000). Unfortunately, DWE is very limited in its budget and such type of experimentation could easily be beyond the allocated effort the EEZA team can put in the project.

The 2dRUE methodology was designed to be flexible, economical, and repeatable. This means that new applications to Portugal could be conducted on a different period, and also means that such applications could be developed by a Portuguese team with appropriate training.

In spite of being preliminary, the results so far are computationally consistent and reflect regional patterns of vegetation performance that are seemingly associated with land degradation. Now it is the task of the users to investigate elements supporting or rejecting these preliminary conclusions, and to start a feedback with the EEZA technical team for advancing in the knowledge of land degradation in Portugal.

The following preliminary conclusions emerge from this study:

- The 2dRUE paradigm to assess land condition is consistent with previous results published in independent studies. It also shows that a shift in the response of vegetation to increasingly drier conditions occurs beyond the dry sub-humid zone, where (or when) water stands as the dominant limiting factor for vegetation performance. (Section 5.1)
- There is no generalised degradation at the country level, but still almost one third of land is somewhat degraded and desertification hot spots should be found in that domain. Natural and semi-natural vegetation in good conditions is particularly lacking. (Section 5.2.1)
- The amount of land under active degradation processes is very low, of only 1.5% of the total. The immediate implication is that it should be easily tackled by desertification policies, and the land condition map may help to aim their focus. (Section 5.2.2)
- A complacent view of the association between land states and trends would be that land under exploitation is relatively healthy in Portugal, therefore policies to combat desertification and land degradation should focus only in hot spots. However, a deeper insight demonstrates that reference vegetation has a low extension in the country, and in addition to that a significant part of it is undergoing degradation. This suggests a low key impact of conservation

policies, a weak safety network for the ‘land bank’ and, overall, an emphasis on land management over ecological self-organisation to maintain healthy landscapes, which is inherently unstable. (Section 5.2.3)

- The assessment of land condition of any given land cover type should be performed within its particular rank of relative RUE (e.g. by comparing the values of a location with the frequency distribution of relative RUE for the land cover class under consideration). Moreover, land cover classes show different responses to both implementations of relative RUE.. (Section 5.3)
- The ranked sequence of land cover classes enables forming homogeneous groups in terms of relative RUE. These groups are not merely numerical lumps, but are physiognomically consistent and reflect the land use options available. Land degradation can therefore be defined and quantified in terms of loss of degree of freedom for land management. (Section 5.3)
- Land condition is heterogeneously distributed across NUTS II regions of Portugal. Concerning land states, the patterns of residual frequencies suggest that the Norte region contains most of the deteriorated land. Concerning trends of ongoing degradation, Alentejo is the most affected region. (Section 5.4)
- Alentejo is under active agricultural development that does not yet contain much degraded land with respect to other Portuguese regions, but which is undergoing most of the land degradation processes of the country. This confirms the perception of the users and focuses a domain for the search of land degradation hot spots. A statistical analysis of its sub-regions indicates that Alentejo Litoral is particularly affected by ongoing degradation processes, and Baixo Alentejo and Alto Alentejo account for most of already deteriorated land (Section 5.4)

7. Output dataset description

The layers in the table below are delivered along with this document to make Version 0 of the Portugal_2dRUE application. They represent the end products, and as such are closer to a layman, interpreted approach to land condition in the area. All the layers are raster with the following specifications:

```
data type   : byte
file type   : binary
columns     : 400
rows        : 667
ref. system : latlong (WGS84)
ref. units  : deg
unit dist.  : 1.0000000
min. X      : -9.6010000
max. X      : -6.0010002
min. Y      : 36.4990002
max. Y      : 42.5019997
resolution  : 0.0089999995
```

The files are delivered in ERDAS Imagine format because it preserves the associated color palette, and can be easily imported into other software packages as required.

Layer name	Description
v-fao aridity index.img	FAO-UNEP Aridity Index (ERDAS Imagine format)
v-portugal land condition.img	Land condition map (ERDAS Imagine format)
v-portugal-assess.img	Assessment map (ERDAS Imagine format)
v-portugal-mon.img	Monitoring map (detailed) (ERDAS Imagine format)
portugal-assessment 0010.kmz	Assessment map (to be overlaid using Google Earth)
portugal-land condition 0010.kmz	Land condition map (to be overlaid using Google Earth)

See map legend codes in the next page.

Legend codes of the land condition map:

```
code      1 : UNDERP A DEGRADING
code      2 : UNDERP A FLUCTUATING
code      3 : UNDERP A IMPROVING
code      4 : UNDERP A STATIC
code      5 : BASELINE P DEGRADING
code      6 : BASELINE P FLUCTUATING
code      7 : BASELINE P IMPROVING
code      8 : BASELINE P STATIC
code      9 : VERY DEG DEGRADING
code     10 : VERY DEG FLUCTUATING
code     11 : VERY DEG IMPROVING
code     12 : VERY DEG STATIC
code     13 : DEG DEGRADING
code     14 : DEG FLUCTUATING
code     15 : DEG IMPROVING
code     16 : DEG STATIC
code     17 : PRODUCTIVE DEGRADING
code     18 : PRODUCTIVE FLUCTUATING
code     19 : PRODUCTIVE IMPROVING
code     20 : PRODUCTIVE STATIC
code     21 : MATURE DEGRADING
code     22 : MATURE FLUCTUATING
code     23 : MATURE IMPROVING
code     24 : MATURE STATIC
code     25 : REFERENCE P DEGRADING
code     26 : REFERENCE P FLUCTUATING
code     27 : REFERENCE P IMPROVING
code     28 : REFERENCE P STATIC
code     29 : OVERP A DEGRADING
code     30 : OVERP A FLUCTUATING
code     31 : OVERP A IMPROVING
code     32 : OVERP A STATIC
code     33 : NON ASSIGNED
```

Legend codes of the assessment map:

```
code      1 : underperforming ANOMALY
code      2 : baseline performance
code      3 : very degraded
code      4 : degraded
code      5 : productive
code      6 : mature
code      7 : reference performance
code      8 : overperforming ANOMALY
code      9 : non assigned
```

Legend codes of the monitoring map:

```
code      1 : Decrease in Time and with Aridity
code      2 : Decrease with Aridity
code      3 : Increase in Time and decrease with Aridity
code      4 : Decrease in Time
code      5 : Non significant response to Time or Aridity
code      6 : Increase in Time
code      7 : Decrease in Time and increase with Aridity
code      8 : Increase with Aridity
code      9 : Increase in Time and with Aridity
code     10 : Masked areas
```