Deliverable 1.3.3.1.: Desertification syndromes for the target & validation DeSurvey areas

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PREAMBLE

Partnership

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Contracted Scope

The essential objective of this work package is to provide a generic desertification model that can be readily applied to desertification scenarios (identified from the Potsdam Institut für Klimatologie, PIK, syndromes as applied to the European biophysical-socio-economic environments). These are a set of syndromes of degradation describing different kinds of land-use system vulnerability as described by Downing and Ludeke (2002). Our point of departure will be the sustainable renewable resource model developed by Gutierrez and others and adapted by Puigdefabrigas for desertification (Regev et al. 1998; Puigdefabrigas 1995). These models are based on the predator-prey analogues for economic systems. The core characteristic is the stability conditions induced by the interaction between supply (biological productivity) and demand (grazing, crops). The model paradigm permits consideration of climatic fluctuations, technological evolution and factors reducing production, such as disease, soil loss and droughts. Following the ecological strategy, the procedure is to examine and solve a system of differential equations for different trophic levels/economic conditions to evaluate the impact of external forcing. A simple example of this is the competition of erosion and plant growth developed for semi-arid environments adopting the Lotka-Volterra differential equations (Thornes 1987 and 1990; Brandt and Thornes 1993). The recent work of Regev et al. extends this basic paradigm to a more comprehensive set of socio-economic variables shifting the earlier over-emphasis on bio-physical relationships

Additional comments

- DeSurvey is committed to an operational surveillance system
- This will have to cover a range of syndromes that prevail in different parts of the world
- This modelling strategy emphasises the tension between biophysical and socio-economic systems in creating the vulnerability of the interacting combined systems (as reflected by the stability)
- The main deliverables will be (i) models that can estimate the vulnerability of different syndromes to external biophysical and socio-economic perturbations and hence the tendency to desertification; (ii) dynamical systems models of behaviour that could be applied to sub-national level target area examples.
- The major milestones will be (i) the identification of the appropriate syndromes; (ii) the development of the conceptual models for these syndromes; (iii) establishment of operational equations for the models/syndromes according to the prevailing process laws; (v) coding computer models ready for validation exercises in other modules; (v) analysis of stability conditions for the multi-level systems. This is most likely to be analytical for some simple cases and by digital simulation for more complicated cases.
- Much progress has already been made by Gutierrez and his colleagues for this modelling paradigm, but the stability analysis of the syndromes subject to external forcing will be breaking new ground.

Forward

This report comprises three sections:

(i) An introduction to the Desertification Problem (Ulf Hellden)
(ii) An outline of the each of the main frameworks (Hellden/ Thornes)
(ii) A discussion of the PIK Syndromes paradigm in the context of Mediterranean environments and the pilot case of Alentejo and ~La Mancha (John Thornes)

PART I: AN OUTLINE OF THE DESERTIFICATION PROBLEM

1. Historic background.

1.1. Early 1900

The word “desertification” was introduced by the French scientist Aubreville (1949) in his report “Climats, forêts et désertification de l´Afrique tropicale”. The concept was discussed earlier by European and American scientists in terms of increased sand movements, desiccation, desert and Sahara encroachment and man made deserts (Hubert 1920, Boville 1921, Coching 1926, Renner 1926, Stebbing 1935, 1938, Lowdermilk 1935, Jones 1938).

At this time, desertification meant the spreading of deserts or desert-like conditions. The symptoms of the phenomena were often related to sand movement and encroachment into oasis and desert margins. Aubreville (1949) also stated that there are real deserts being born in Africa today, under our very eyes, in the 700-1500 mm annual rainfall areas.

One school favoured the idea of a postglacial climate change (desiccation, gradually increasing aridity following and balancing the Pleistocene cold and assumed pluvial period) as a major driving force causing desertification. Others stressed the importance of human impact. The human impact was expressed in terms of bad land management including over cutting, overgrazing, over cultivation and misuse of water leading to salinization.

The American “Desert Bowl” forced millions of people to leave their farms in the American Great Plains in the 1930´s. The drought and land degradation catastrophe had an important impact on the western scientific thinking for a long time initiating research and development efforts in soil erosion and soil conservation techniques (Thomas and Middleton 1994).

Since then, different concepts of desertification have developed and been discussed over and over again by scientists, politicians and the international aid and development society. Renewed international concern can usually be related to the outbreak of major periods of drought and famine in the Sahelian part of Africa.

1.2. Late 1900

Very important international events were the UN Conference on Desertification (UNCOD) in Nairobi 1977, the UN Conference on Environment and Development (UNCED) in Rio de Janeiro 1992 followed up by the UN Convention to Combat Desertification (UNCCD) adopted in 1994 and entering into force in 1996. In 2003

UNCCD designated the Global Environment Facility (GEF) as a financial mechanism to assist developing countries in implementing the Convention (GEF 2003). GEF expects to commit more than US$500 million to help reduce land degradation in developing countries during the 2003-2006 period.

UNCOD in 1977 was called upon as a result of the severe drought and repeated crop failures that struck the Sahelian zone in Africa during the 1965-1973 period (the Sahelian Drought). It was concluded that desertification was not only an African problem but also a problem of global significance as stressed by Thomas and Middleton (1994). Several definitions were presented in the UNCOD documentation summarized by Mainguet (1991), Helldén (1991) and Thomas and Middleton (1994). It was implicitly understood that desertification leads to "long lasting" and possibly "irreversible" desert-like conditions. "Decreasing productivity" is a key process included implicitly or explicitly in most definitions. Desertification was commonly considered to affect arid, semi-arid and sub-humid ecosystems by the combined impact of droughts and human activities. The relative role of climate, droughts and human impact was discussed. The key problem was identified as a chronic process of land degradation in which man's occupation and use of the dry-lands was playing the major role. Drought was rather seen as a catalyst which exposed the effects of the long-term degradation caused by people (Thomas and Middleton 1994). The most important causes of desertification were considered to be those reported during the first decades of the century i.e. over cutting, overgrazing, over cultivation and misuse of water.

UNCOD formulated and adopted the Plan of Action to Combat Desertification (PACD), endorsed by the UN General Assembly in 1977. The responsibility for following up and coordinating the plan was given to the UN Environment Programme (UNEP). The desertification prone countries were urged to develop National Plans of Action to Combat Desertification. This was seen as a fundamental instrument for the implementation of the PACD recommendations. Many national plans have been written but few, if any, have ever been financed and implemented. The rhetoric, and sometimes unrealistic, content of many of the national plans was pointed out by Thomas and Middleton (1994).

UNEP´s concept of desertification was seriously challenged by groups of scientists during the 1980´s and at the beginning of the 1990´s (Helldén 1984, 1988, 1991, Mainguet 1991, Thomas and Middleton 1994). The mere existence of desertification, as the UN described it, was questioned. The word "myth" circulated in scientific publications and mass media. The criticism probably contributed to a UNEP initiative to modify the prevailing concept of desertification in 1990.

The new definition introduces the idea that desertification does not need to lead to the development of deserts or desert-like conditions. It simply refers to all types of land degradation in the drylands of the world. Human adverse impact on the environment is considered to be the only cause of desertification (Rozanov 1990, UNEP 1991):

-Desertification/land degradation, in the context of assessment, is land degradation in arid, semi-arid and dry sub-humid areas resulting from adverse human impact.

”Land” in this concept includes soil and local water resources, land surface and vegetation or crops. “Degradation” implies reduction of the resource potential by one or a combination of processes acting on the land, including water and wind erosion, sedimentation and siltation, long-term reduction in the level of diversity in natural vegetation, crop yields, soil salinization and sodication.

In mid-1991 UNEP changed the concept again (Helldén 1991):

-Desertification is land degradation in arid, semi-arid and dry sub-humid areas resulting *mainly* (author’s italics) from adverse human impact.

The UN at UNCED redefined the definition once more in 1992. The new definition is confirming that desertification is the same thing as land degradation. New is the recognition that not only human impact but also various factors including climatic variations are important causes of land degradation in the dry-lands. The definition and concept reminds of the old discussions that took place during the first decades of the 20th century.

- Desertification is land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities (UNCED 1992).

The Earth Summit in Rio de Janeiro resulted in the action plan and recommendations documented in Agenda 21 (UNCED 1992). Beside general and global recommendations of conventional soil conservation and land rehabilitation measures many of the most important recommendations cover the sphere of socio-economy and are as valid for poverty fighting and general development measures as they are for desertification control. Socio-economic issues, mainly as indicators of desertification, were discussed already at UNCOD in 1977. However, socio-economic and political factors are now recognized as important driving forces behind bad land use contributing to land degradation and desertification.

UNCED was followed up by the UNCCD in 1994. National Action Programmes (NAP) is one of the key instruments in the implementation of the Convention similar to UNCOD´s previous approach in the Plan of Action to Combat Desertification. More than 40 countries have provided copies of their NAP to the UNCCD Secretariat, most of them during the present millennium. China did so already in 1996.

According to a recent GEF news release, land degradation, which includes desertification, can be described in terms of loss of biodiversity, reduced subterranean carbon sequestration, and pollution of international waters (GEF 2003).

Desertification mitigation approaches and control success or failure varies with concepts of causes and consequences. Nowadays, there is a rich flora of handbooks on all kinds of biophysical theories and practical techniques on how to fight land degradation and desertification assuming it is caused by human impact on the environment (e.g. Wenner1977, Hurni 1985, Hudson 1985, Mainguet 1991, Lal 1994, Morgan 1995). The handbooks cover most aspects of soil conservation (wind & water erosion control e.g. shelterbelts, fencing, bunding, sand fixation, terracing, water harvesting, gully control, species recommendations, plowing techniques, nursery establishment), irrigation, rangeland management and grazing strategies, forestry, agro-forestry and agriculture.

The degradation control difficulties increase when it comes to considering the importance of climate variability in the desertification process. The difficulties grow when the social and economic causes and consequences of human and climate-induced desertification have to be addressed and controlled. The control issue becomes a growing social and political problem when alternative survival strategies, i.e. abandoning the land or stop using it for agriculture, is considered the only available option to save the affected people and land.

DeSurvey is aiming at modeling and simulating desertification and its control variables at different scales to help formulating sustainable mitigation strategies and field implementations. The identification of common desertification syndromes, with its driving forces, effects and control variables, is an important step in this modelling effort, and the essential role of this Work Package

2. Scenarios-Syndromes

2.1. Introduction.

Land degradation leading to a "long lasting" decreased biological productivity may be driven by a variable climate (droughts-rain storms-wind), human impact leading to changes in land use, in turn leading to land degradation or through a combination of both. Both climate and human land use influences vegetation ground cover quantity and quality (cops, natural vegetation species and palatability).

Decreasing of the vegetation canopy cover (<20~30%) accelerates surface water run-off and soil erosion by water and wind. Lack of fertilizer input (natural or human) may lead to decreased soil fertility and "soil mining", the introduction of pests and diseases and a corresponding vegetation loss. In many cases the soil mining status of the land was already reached a long time ago (>100 years).

Soil erosion leads to a loss of soil and nutrients (if available) with serious impact on soil water availability, fertility and therefore productivity in thin soils mainly. It also leads to a redistribution of soil resources with accumulation/sedimentation of soils sometimes killing existing vegetation/crops. Water erosion caused by intense rain storms may lead to intensive sheet, rill and gully erosion creating "badlands" in a very short time on cohesive soils. Wind erosion operates not only by the deflation (exposing roots) - accumulation (dunes covering vegetation) interactive process but also by the mere fact that no vegetation can settle and establish as long as the sand particles are moving. In many desertification cases, sand movement does not lead to a net annul erosion or accumulation of sand but prevents vegetation from establishment by its mere movement forward and backward.

Whilst accepting that evidence supports the role of grazing in producing local loss of vegetation cover, it's unquestioned adoption as a widespread mechanism for land degradation and desertification has to be treated with some caution. Certainly there is little support for adopting a 'carrying capacity' approach to mitigation as has been demonstrated in work based in Africa by Benkhe, Scoones and Kerven (1993).

Climate and human impact on the landscape may also lead to land degradation in the form of "green desertification". This may take place through an increased biological productivity and an increased vegetation cover, e.g. through bush encroachment too dense to let cattle and people to penetrate, and/or through the introduction of unpalatable species.

Desertification, can be described, modelled and analyzed in terms of syndromes. In medicine a syndrome is a complex of symptoms. Downing and Lüdeke (2001 p. 237) referring to Petschel -Held, Block et al 1999, suggested the following definition: *"The basic idea behind syndromes is not to describe Global Change by regions or sectors, but by archetypical, dynamic, co-evolutionary patterns of civilization-nature interactions, which we call syndromes"*. However, we have chosen to include a regional/sector perspective as well.

Some common desertification syndromes, as viewed by this author, are described below, first from a cause-effect perspective and then from a geographic (region, sector) perspective. The description is focusing on the non-European regions and validation areas covered by the DeSurvey project. For further exploration of the Potsdam Institut für Klimatologie (PIK) syndrome paradigm see Part III of this report.

2.2. Over consumption related syndromes.

The over consumption related syndromes have a least common denominator; i.e. they all refer to a situation where the consumption or exploitation of local landscape generated biomass related resources (food, fodder, wood), soils or water is larger than the production over a long period of time. This is often described as "over use" of the resources. It may lead to a thinner vegetation ground cover in turn resulting in increased surface water runoff, accelerated soil erosion & sand mobility, reduced water infiltration and in general landscape degradation. The situation can also be described, and possibly modelled, in terms of supply-demand and "over use" of the landscape biomass or of the water resources driving the biomass production. A reduction of the resources beyond a certain threshold might generate a feed back (e.g. by erosion and decreased soil water availability) decreasing the re-growth/ regeneration capacity of the system. The process is illustrated as a conceptual system dynamic model of land degradation/desertification in Fig 1. The model will be further developed and explained in the next deliverable from WP 1.3.3. (Deliverable 1.3.3.2)

2.2.1. The Climate Syndrome. Climate variability (and probably climate change) in terms of irregular but recurrent rain and drought episodes create time lagged oscillatory effects on productivity and desertification indicators as well as on land use & pressure (Cf. Fig. 3)

a) Rainfall: Rainfall-rainstorms variable intensity and frequency may accelerate average surface run-off and erosion and even create rill & gully dominated badlands in most types of drylands where the vegetation cover is >20~30% and the soils are cohesive. The rainfall distribution is randomly oscillatory likely to generate oscillatory desertification effects including corresponding impact on biomass productivity and land use response.

b) Drought: As described above with oscillatory and time lagged patterns of impact. Droughts decrease vegetation growth and cover, opening up for wind erosion (deflation), transport and accumulation of sand and silt and creating devastating sand movement stopping any establishment of vegetation even when there is no net transport of sand over time.

2.2.2. The Land Use Syndrome. The human use of the land systems (biomes) forests, woodlands, bushlands, savannas and steppes (savanna woodlands, savanna grasslands, savanna bushlands), semi deserts and deserts is divided into woody biomass exploitation, grazing activities (nomadic and settled livestock raising) and agriculture (rainfed often with crop rotation, fallow/tree-crop rotation, slash & burn rotation and irrigated crop production). The urban land use is not dealt with in this paper. The transformation of cultivated land into urban land use is not considered to be land degradation in the meaning of the UN-defined desertification concept.

The introduction of land use into a natural system often includes clearing of new land leading to a lower over all ground vegetation cover. This process opens for higher surface water run-off leading to decreased water infiltration and soil water content as well as to increased surface water run-off , water and wind erosion. Decreased soil water availability is likely to lead to a decreasing over all biomass productivity. The soil erosion may lead to a decreased soil storage, a degradation of the soil seed bank and an increased sand mobility; a combination of which is likely to have a long term impact on biomass productivity.

a) The over use syndrome. *Over cultivation* is caused by an intensification of cropping activities that leads to shorter fallow periods and longer periods of exposed soil surface or it is introduction of cultivation in an non-suitable environment. *Over cultivation* as well as *over grazing* (possibly passing the carrying capacity of the land) and *over cutting* (cutting>re-growth) leads to a decreased vegetation cover, increased surface run-off & soil erosion, decreased soil and ground water resources, a leaching of soil nutrients that may lead to the introduction of diseases, altogether possibly leading to a decreasing over all biomass productivity feed back.

b) The agricultural expansion syndrome. This is a sub-variant of the over use syndrome. The still growing demand in the developing world (as a contrast to Europe and N. America) for land to cultivate leads to new clearing of forests, woodlands, savannas and steppes. Migration of people and cultivations into new areas also include the introduction, followed by an intensification, not only of crop cultivation, but also of fuel wood collection (over-cutting) and husbandry grazing (sometimes with local overgrazing) often at the sacrifice of nomadic livestock breeding and grazing. The over-use leads to a decreased vegetation cover, exposed soil surface and so forth... as indicated before. Lowered crop yields may force people to cultivate even larger areas possibly resulting in a positive degradation feedback. More degraded land areas lead to increased compensations needs and further growth of the land clearing activities to generate more land to cultivate.

c) The irrigation syndrome. A growing market demand (e.g. urban and tourist request of vegetables) may become an incentive for farmer investments in simple pumps and the establishment of irrigation schemes, starting with open water channels made by soil. Bad management, high evapo-transpiration, water losses to non cultivated land, insufficient drainage and so forth may lead to salinization, lowered water table, depleted fossil ground water and decreased productivity in the long term.

Driving forces: population growth, hunger for cultivated land, droughts e.g. creating a need to compensate decreasing yields with larger cultivations, climate induced migration, (many good years in a row make people move and settle in previous semi-desert), poverty and lack of alternative incomes, ignorance & lack of education, social conflicts on land access, market demands, subsidies, nomad migration/ settlement policies, price and market policies including urban population demands.

2.3. Geographic Syndromes

2.3.1. The North African Syndrome. The rural land use of the North Africa-Mediterranean countries Morocco, Tunisia, Algeria, Libya, Egypt are characterized by grazing in the almost vegetation free mountainous steppes/semi-deserts, rainfed and increasing irrigated crop and vegetable cultivations on the plains and irrigated oasis-agriculture in the deserts. The mountains, often with a very thin mineral soil cover, are suffering from the rainfall, over grazing and over cutting syndromes mainly. The plains are suffering from the rainfall, over cultivation (e.g. indicated by the distribution and density of Nebkhas on the fields) and irrigation syndromes where the last one is a fast growing problem in large areas e.g. in Tunisia.

The North African Syndrome also includes the special Oasis desertification problem described under section 2.3.5. In short, most oases are suffering from sand and dune encroachment from the surrounding or neighboring Sahara desert and from salinization problems (the Irrigation Syndrome). Nomadic livestock herding is no longer common in the region. Almost all rural people are settled as farmers.

2.3.2. The Sahel Region Syndrome. The Sahel region includes all the countries bordering the south of the Sahara from Senegal at the Atlantic coast to Sudan, Eritrea, Ethiopia, Kenya and Somalia at the Red Sea and Indian Ocean coast respectively.

In this study Kenya, Eritrea and Ethiopia are excluded. They do not fit into the traditional Sahelian concept but belongs rather to the North African from the desertification and land degradation point of view. Deforestation for cultivation followed by increased surface water run-off, water erosion and soil loss along the cultivated mountain slopes forms the overwhelming land degradation problem in these very mountain and population dense countries. These countries as well as the Sahel region are also characterized by a low level of education among the rural population.

The degree of literacy is low and the degree of poverty is high all over the Sahelian region. Rainfed agriculture on a subsistence level is common. The introduction of new mechanized farming schemes (rain-fed & irrigated commercial schemes) on previous rangelands grow in importance.

Sahel, like other drylands, has experienced a number of long lasting, recurrent and severe droughts and famines, interrupted by fairly long rainy periods, since the end of the 19th century (as long back as we have observed precipitation data) (Fig. 2). The Sahel region differs a lot from other regions because some of the droughts were very long and the accompanied famines extremely severe. Most notorious is the last one

(1964-2004 ?) that lasted for about 40 years with its driest years around 1983/84. The rainfall situation has improved every decade since then and is now almost back to normal/ average rainfall. A corresponding Sahel "greening" effect, and Sahara desert shrinkage, has been observed with satellite data.

The region is characterized by flat-undulating sandy and silty and clay lands subject to wind erosion and sand movement rather than water erosion. It is likely that people have moved north during the wet periods cultivating new land and that they had to expand their cultivated lands during the long lasting droughts to compensate for decreasing biomass productivity and sand encroachment. This compensation need eventually contributes to the expansion of the degraded lands. The alternative response to desertification is abandoning the land and migrate, possibly contributing to the urbanization process. The nomads and settled farmers are competing for the land resources which are still abundant. Water for the animals and people seem to be the major limiting factors for both nomads and for the establishment of new villages and new farmland (cultivated land). Land and crop- tree (Acacia Senegal) fallow rotation are common land use practices although there is a growing intensification of agriculture through the development of permanent cropping land and commercial agriculture (irrigated as well as rain-fed). There is an observed tendency that farmers compensate years of continuous low rainfall-low yields with increased field size, shrinking the size again as soon as the rains and improved yields return.

The Sahel is suffering very much from the climate (drought) syndrome as well as from the land use syndrome. The drought-precipitation cycles create a time lagged oscillating pattern of livestock population and agricultural production that can probably be related to land degradation oscillations (Fig. 3).

Senegal is the only Sahelian country participating in DeSurvey.

<u>Driving forces</u>: Population pressure and demand for new land to cultivate, Climate and land use syndrome forces. Water erosion is of insignificant importance compared to wind erosion and sand movement (rather than net wind erosion and transport). Water is the limiting factor for vegetation growth...

2.3.3. The China syndrome. Desertification in China is very often defined by the Chinese as "sandy desertification" i.e. sand sheet and dune encroachment threatening cultivated lands and important infrastructure, often inside (oasis) or in the vicinity of the large deserts. The causes are related to "over use" in general and population pressure driven expansion of agriculture and husbandry into the sandy/silty steppe grasslands in specific. This is combined with "freely" and fast growing livestock managed by settled nomads (now farmers), operating inside fenced farms since the mid-end of the 1980íes when market economy ideas were introduced in the agricultural sector.

The tropical karst areas in sub-humid south China, formed by chemical erosion and characterized by its specific geomorphology and water access problems, are also referred to as areas seriously affected by desertification (Zhenda and Shuhong 1995, Ma et al. 2004). The process includes vegetation clearing for cropping (maize) on the steep slopes of the tropical karst towers, followed by water erosion of the thin soil cover and the ultimate exposure of the karst rock surface. Land degradation leading to the exposure of the bedrock surface is also known as “rocky desertification” in China.

However, in reality all the syndromes of desertification can be found in China. Severe surface water loss and soil erosion on the cultivated steep mountain slopes, rill, gully and vast badland formations on silty slopes and in the loess plateaus (N. Africa syndrome, climate & land use syndromes), oasis syndrome in the Taklamakan and Gobi deserts, sand creep and dune encroachment as well as irrigation/salinization problems in the sandy/silty steppes (Sahel syndrome, climate and land use syndromes), deforestation, increased surface water run-off and erosion in the sub-humid mountain ranges.

China differs a lot from the rest of the world because of its present communist governance and its political and economic history. The central government and communist party play an important role in the development of land use, land management and in the land degradation and desertification expansion & control over time.

The Chinese drylands, like all drylands, are affected by oscillating rain and drought periods of varying length and random spatial distribution over time (Fig. 4). This is likely to have a severe impact on the appearance and importance of desertification over time.

<u>Driving forces</u>: Population pressure and demand for new land to cultivate. Please refer to the Sahel, Climate and land use syndrome forces.

2.3.4. The Oasis Syndrome. The Oasis syndrome includes all the over use problems inside the oasis and desert sand/dune encroachment at its margins. Some of the sand creep may also originate from over-grazing and over-cutting in the close periphery of the oasis. The ground water resources, water management and irrigation/salinization related problems are of major importance for the oasis economy and desertification status.

<u>Driving forces</u>: Growing population pressure and demands for a higher standard of living (please see the land use syndrome forces)...

2.3.5. The Chile Syndromes. Most of the text below is condensed from Santibañez (2006).

Land degradation in Chile had diverse historical driving forces and adopted several forms over time and space:

-1) Historically, mining was the main economic activity in the Central and Northern part. Mining exploitations demanded a huge amount of energy, the most part coming from charcoal which was the main cause of deforestation of an important portion of the territory having less than 500 mm of annual rainfall. (Cf. the Katanga syndrome described in Part III).

-2) When this process ended in the first decades of the 20^{th} century, slope cultivation of cereals continued until recent years. This factor was responsible of about 32 millions hectares of eroded soils existing at present. (Cf. the Sahel and agricultural expansion syndromes)

-3) During the sixties, and active expansion of the modern agriculture, mainly fruit species and vineyards oriented to foreign markets, occurred. As part of this deep change, intensive use of pesticides and fertilizers was adopted, causing contamination of soils, rivers, groundwater and natural lakes. (Cf. the Green revolution syndrome described in Part III)

-4) At the beginning of the 60's, as a result of a government initiative to promote forest exports, an extensive plan of forestation with exotic species (Pine, Eucalyptus and forage shrubs) was implemented from the arid environments (100 mm annual rainfall) to humid areas (2000 mm annual rainfall). Primary intention of this initiative was environmentally friendly, but side effects like native forest replacement, appear. This also caused the destruction of habitats and ecosystem fragmentation over a significant part of the territory.

The different ecosystems of Chile are characterized by a variety of syndromes. The suggested Desurvey study site in Chile is located close to La Serena in the arid and semi-arid shrublands of Norte Chico.

Land degradation in this region was caused by deforestation, slope cultivation and overgrazing. The main process affecting soils are erosion. Ecosystems are extremely fragmented and biodiversity reduced to a minimum. The mean plant cover is nearly 8%, exposing soils to high surface water runoff and erosion. Global changes have affected this area reducing precipitation to 2/3 in the last century.

<u>Driving forces</u>: Deplition of non-renewable resources (minerals), lack of appropriate territorial planning to protect important resources, population pressure and demand for new land to cultivate. Please refer to the Sahel, Climate and land use syndrome forces.

2.3.6. The European/Mediterranean Syndrome. These are discussed in the Third Part of this report.

3. A study of global and regional dynamic causal patterns of desertification.

3.1. Background

The desertification syndromes suggested so far in this paper, mainly based on our own experience and expert opinion, are in good agreement with conclusions presented by Geist and Lambin (2004). They recently published a report on what they considered to be immediate (proximate) causes of desertification and what they considered to be the underlying driving forces behind these proximate causes. The study was based on an analysis of 132 case studies of the causes of desertification. The 132 cases of desertification were taken from 54 articles published in 28 journals covered by the Institute of Scientific Information citation index. The cases covered areas from 1-ha sites to multi-province areas. The studies covered time periods from1700 to 2000, with a mean period focusing on 1915-1994. The 132 cases were distributed over a wide range of ecological conditions. Annual rainfall ranged from less than 50 mm in hyper-arid plains to more than 500 mm in sub humid mountain sites. (See further discussion of the Geist and Lambin approach in Part II of this report.

Four broad categories of proximate causes of desertification with a direct impact on dry-land land cover and desertification and six clusters of underlying driving social or biophysical processes, driving the proximate causes of desertification, were identified in the 132 case studies

The four broad categories of proximate causes of desertification identified, including a number of sub-classes, are presented in Fig. 5**.** The six broad clusters of underlying driving forces are indicated in the same figure.

The causal factors were quantified by assessing the most frequent proximate and underlying driving factors reported in the case studies. The results were broken down into six broad geographical regions. Dry-land cases from Asia (n=51) originated from the Central Asian desert & steppe region, the East Mediterranean steppe zone, the Arabian Peninsula and the Thar Desert in India. African cases (n=42) included the Sahelian and Sudano-Sahelian zones of West Africa, the western Mediterranean basin (North Africa), the East African grassland zone and the Kalahari savanna in SW Africa. European dry-lands (n=13) were represented by case studies from the Mediterranean basin only. Australian cases (n=6) were from the central part of the continent. The cases from Unites States (n=6) originated from the US South West. The cases from Latin America (n=14) represented studies in Mexico and Patagonia.

The resulting frequencies presented by Geist and Lambin (2004) are reproduced in Table 1-5**.**

3.2. Case study conclusions

At the proximate level, desertification is best explained by the combination of agricultural activities and increased aridity although many of the other combined factors listed are also important e.g. agricultural activities combined with extension of infrastructure and wood extraction.

At the level of underlying driving forces desertification is best explained by combinations of multiple, coupled social and biophysical factors and drivers acting synergistically. A very frequent combination of driving forces included climatic factors leading to reduced rainfall, agricultural growth policies, newly introduced land use technologies and land tenure arrangements that are no longer well suited to the existing ecosystem and land use management.

Geist and Lambin (2004) pointed at several of the positive desertification feedback loops evident from the case studies. One robust mechanism is an assumed self-perpetuating process that involves the expansion of cropland and grazing land, leading to soil degradation and overstocking in dryland areas affected by erratic rainfall fluctuations. This is in agreement with our own view that land degradation leads to further expansion of cultivated land or to an intensification (overuse) of the land area already under cultivation (e.g. through shorter fallow periods) to compensate for lower productivity and land losses caused by desertification as discussed previously.

Most of the desertification case studies report a variant of the general syndrome discussed previously under section 2.2. It derives from an existing resource scarcity and leads to a growing pressure of production on the resources. The studies report an increased intensity of rural labor and other investments e.g. watering infrastructure, to increase the production of the land. The listed proximate factors related to this syndrome include the addition of new and more livestock species, permanent grazing, increased soil treatment through ploughing and continuous cropping, increased diversion of artificially gained water onto marginal land. Geist and Lambin (2004) suggest that it might be that the final link in the causal chain connecting social to environmental change is land use intensification in dry-land ecosystems that had been immune from such land use before, thus increasing these ecosystems' vulnerability to droughts.

Another recurrent theme mentioned in the desertification case studies is that sociocultural changes have modified the adaptive strategies of dryland societies to cope with natural variability and have therefore decreased the human-environment stability.

Geist and Lambin conclude that the observed causal-factor synergies and pathways of dryland change challenge single factor explanations that put most of the blame for desertification on the overuse of land by growing numbers of rural poor and by nomadic populations. The analysis reveal that at the underlying level, public and individual decisions largely respond to national scale policies promoting advanced land use technologies and creating new economic opportunities.

Finally, the analysis also indicate that, at the proximate level, regionally distinct modes of increased aridity, expansion of cropping and grazing activities, infrastructure extensions and, to a somewhat lesser degree, wood extraction prevail in causing desertification.

4. Dynamic causes and feedback mechanisms of desertification

The findings and tables presented by Geist and Lambin (2004) are complemented with our own findings and summarized below:

Vulnerability. Vulnerability is not a driver but a land-socio-economic system function that describes the vulnerability of the landscape and its people for external pressure; i.e. the system's sensitivity to become degraded/desertified. Important factors contributing to desertification vulnerability are:

- Topography: Steep for water erosion and undulating-flat for wind erosion
- Soils: sandy and silty, thin soil cover
- Climate: arid, high drought frequency and/or rain storm frequency and intensity
- Vegetation: low ground vegetation cover (<20%) and lack of woody biomass (fuel-wood)
- People: high poverty, high population pressure and consequent need for new crop land, low level of education
- Economy: low stage of economic development, local and isolated economy with a high degree of subsistence.

- Policies: Urban-rural relations neglecting rural development needs, system of governance.
- Agriculture: low and very variable productivity.

The hierarchy of important desertification causes are listed below and condensed in the attached table (Table 9).

-1. Top level causes influencing biomass yield and vegetation cover (driven by level 2 below):

- Crops, fodder and natural vegetation & soil seed banks degradation (quality, quantity and ground cover decrease i.e. increased soil exposure)
- Erosion: water& wind (including soil particle movement backward and forward)
- Sedimentation
- Soil compaction, crust development & salt precipitation.
- Soil mining (soil exhaustion through nutrient leaching and consumption)
- Water surplus/deficits (rain, surface-, soil- and ground water content)
- Albedo increase

-2. Level 2. Proximate causes/processes (driving the top level causes):

- Agricultural activities
  -Livestock production/grazing (nomadic, husbandry/household)
  -Crop production (commercial/mechanical, subsistence, irrigated/rainfed)
- Infrastructure extension
  -Watering/irrigation (dams, boreholes, channels etc…)
  -Transport
  -Human settlements
  -Public/private companies (oil, gas, mining, quarrying)
- Wood extraction and related activities
  -Fuelwood & charcoal,
  -Construction, timber
  -Forest, woodland & bushland clearing for cultivation expansion
- Increased aridity (impact on land cover & erosion)

-3. Level 3. Underlying causes/processes (driving the Level 2 proximate causes):

- Demographic factors
  -Migration-urbanisation
  -Growth and densities
  -Age distribution and dynamics
- Economic factors (global & national, taxes and subsidies)
  -Market growth (local, regional, national) and commercialization)
  -Urbanization (see Demographic factors) and industrialization
  -Market economy and prices (land, crops, etc.), (see also taxes-subsides under Policy factors below)
  -International trade agreements

- Technological factors
  -New technologies, innovations diffusion
  -Management (e.g. bad water/irrigation management)
- Climatic factors (variability and change)
  -Concomitantly with other drivers
  -In causal synergies with other drivers
  -Main driver without human impact (natural hazard, climate change…)
- Policy and institutional factors
  -Formal growth policies (market liberalization, taxes-subsidies, education policies).
  -Property rights issues (land distribution & access: tenure, cost, tax, water rights)
  -Poverty programs
  -Soil conservation programs, environment policies (e.g. NAP)
  -International aid
- Cultural and education factors
  -Public attitudes, values and beliefs
  -Individual, household, tribe, community behaviour and education level
- Political factors
  -Governance-democracy,
  -Distributed power - central power
  -International aid and trade

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Part II Main Paradigms Summarized

(References for this section are included in the final reference list)

1. Scenarios

The broad scenario and syndrome descriptions given in the first part are based on the author's (UH) field studies and experience of land degradation/desertification in the Sahel, North Africa and China over the past 30 years. They form a "best expert personal opinion" combined with concepts that the author considers being "common public/scientific community opinion" in the regions discussed. The given descriptions are in close agreement with the results of Geist and Lambin (2004) and in broad agreement with the PIK syndromes discussed in the third part.

The major difference is that they underline the importance of "sandy" desertification as the dominating problem discussed and considered in the Sahel as well as in China. Water erosion is of limited importance in these sandy and slightly undulating regions while droughts and wind generated movement of sand particles are considered to be of major importance. Severe water erosion, on the other hand, is a common problem in the North African mountain regions.

It should be noted that there are numerous examples of “desertification recovery” cases in the Sahel, North Africa and China. Such cases are seldom discussed in the

Syndromes paradigms. Many areas that were once considered to be seriously affected by desertification through overgrazing or over cultivation resumed their pre-desertification natural status soon after the external pressure disappeared. It has been demonstrated in many cases that leaving the land to "rest" for 1-5 years (e.g. through fencing) is enough to recover natural biomass productivity and vegetation cover. It is some times even enough to stabilize sand creep and moving dune systems. In other words; it is not obvious that desertification is always irreversible or even long lasting when the pressure on the renewable resources is released.

Biomass production (mainly water driven) - consumption oscillations disturbed by drought, soil surface wind and/or water exposure and demographic perturbations may result in threshold controlled productivity collapse leading to demands to use/clear more land to compensate for losses in biomass yields. It is assumed that a positive land degradation feedback process often starts this way in the Sahel and Chinese sandy lands.

2. Syndromes

We discuss syndromes at length in the next part of the paper.
It is a paradigm that was designed as a short-hand typology for the description of *global* climate change. It is summarized in the paper by Schellenhuber and others at the Potsdam Insitute of climate Change Impacts (Schellenhuber et. al. 1997). Not only does the paradigm provide a set of descriptions of syndromes, but it also seeks to provide a framework for the interactions in variable man-nature interactions, by fuzzy analysis of kernel variables and their interactions (For a popular account of this technique, see McNeil and Freiburger 1994). There have been detailed descriptions of some key syndromes that are relevant to WP1.3.3 objectives such as the SAHEL and the GREEN REVOLUTION (Scellenhuber et al. 1997) and the OVEREXPLOITATION syndrome syndromes (Cassel-Gintz and Petschel- Held, 2000). In addition, Petscel-Held and Ludeke (2001) assess the use of qualitative differential equations in applications of the paradigm.

3. Ecology-Economic Models

The work of Regev, Gutierrez, Schreiber and Zilberman (1998) Presents a major breakthrough in the formulation ,study and analysis of the interactions between human and natural systems because they manage to bridge the gap that is often present between bio-physical and human forces on resource allocation. Its relevance to desertification was identified by Puigdefabregas (1998) and it's application to stability questions in land Degradation was examined by Thornes (2005b). It therefore appears as a potential candidate for WP 1.3.3 objectives.

Regev et al (1997) set up a differential equation to describe the transfer of resources through a multi-level trophic web. It assumes resources at the lowest level and human-harvesting at the top level (Fig 6), and an objective function based on either individual gain or community gain optimization. They then conduct a sensitivity analysis and a stability analysis of the model. The parameters include a discount rate, technological Progress, wastage rates and maintenance costs. One experiment examines the effects of a declining resource base. The central issue becomes, under what exploitation and consumption rules is the system stable in gain and therefore sustainable in time? Thornes (2005) examined the system (Fig. 7) common in Land degradation studies in which vegetation is driven by rainfall, and drives the soil erosion rate. The vegetation is harvested by grazers and the grazers by human beings. As climate fluctuations or change occurs the whole trophic web is adjusted. For soil and vegetation the attack is coming from above and below. The desertification problem is to sustain output in the form of food for humans in the face of resource fluctuations. It is thus an extension of the vegetation-erosion competition of Thornes (1987) that was extended to the spatial case (Thornes 2002)

Of course the closed-form solution to optimization is mathematically demanding, restricting the solutions that might be considerable not only to 'reasonable' but also to 'possible '. At the time the optimal solution was pursued through the Pontragyin maximum principle. Nowadays, commercial digital simulation programmes (such as OPL) are available. Also, the development of spatial optimization is especially attractive(Hof and Bevers1998) as a device for deciding which areas could be cropped or grazed to allow optimum management of an ecosystem In this case 'optimum' might be that which minimizes land degradation (as measured by run-off and sediment yield from a basin)

4. Geist-Lambin Approach

Geist (2004) and Geist and Lambin(2004) evaluate the literature in an inductive and empirical study of the causes of desertification in different regions and at different times. In what they call a "configurational comparative research design", they examine the causes of desertification across geographical regions and clustered at various levels from 'single causations to as many as five causal factors. This is achieved by assessing the frequency with which particular causes are identified in each of 132 separate studies. The tables of cause vs. frequency are interpreted to identify (i) the most frequent single or multiple causal factors, (ii) the major regional variants and (iii) the most important pathways that lead to desertification. The authors outline four caveats to the work, (a) that they filtered the literature search by the term 'desertification' (Would 'land degradation' have produced different results? Did this filter induce a bias towards a particular view of the problem?) (b) They had to assume that the authors of the papers correctly identified the causes in their particular case studies. (Were they all carefully and rigorously undertaken investigations? Were the authors conditioned by the prevailing desertification paradigm at the time of their investigations?). (c) There were differences in what constituted 'cause (Is just a mention of drought enough or should there be a forma presentation and analysis of the climatic data? Are there strict criteria for the inclusion, or exclusion of a 'cause'?). Despite these limitations, the exercise produces a valuable discussion of the causes of desertification and their implications across a very broad canvas.

A major result is a list of six clusters of the most frequent underlying clusters of driving forces (Fig. 5). The six main six clusters of forces are Demographic factors, Economic Factors, Technological factors, Climatic factors, Policy and institutional factors and Cultural factors. These are immediate human or biophysical actions with a direct impact on dryland cover.) Table 1 shows groupings by regions of causes grouped as single factors- agriculture, increased aridity, infrastructure extension, wood-related extraction- or as combinations of 2-4 factors. We can see in the discussions of these factors parallels with the syndromes identified by the PIK work. The overall conclusions are that "most of the case studies of desertification report variants of a general syndrome that derives from resource scarcity and leads to a gradual pressure of production on resources". These studies report an increased intensity (per unit area) of rural labor investment, such as watering infrastructure, to increase the production of land. There are strong resonances here with the economic-ecology approach of Regev and others described in the previous section, and with the brief descriptions of Alentejo and La Mancha described in Part IV of this report.

Another recurrent theme reported by Geist and Lambin is that Socio-cultural changes have modified the adaptive strategy of dry-land societies in the face of natural variability (which is inherent in dry-land systems and have therefore reduced the resilience of soicio-ecological systems. Again, the parallel with the stability analysis of Regev et al. (1998) is quite telling for this is a primary motivation for their analysis. Perhaps the two conclusions that carry the most important weight as far as DeSurvey is concerned, and this W.P. in particular, are that (i) "our results do not reflect irreducible complexity and (ii) neither do they identify a single cause responsible for an irreversible extension of desert landforms and landscapes. The second comes as no surprise but the first encourages and motivates our search for a suitable methodology for understanding and identifying cases of desertification at the regional scale.

Part III Syndromes

1 Back-ground

As is evident from the Part I of this report, the continuing debate about the cause of desertification and the identifiers for its existence fall into two camps: (i) local, detailed systematic studies largely based on process studies in small areas and strongly polarised between physical and socio-economic driving forces with not much interaction between them. In a few cases this has led to important regional generalisation, especially of soil erosion across the European Community (as in the PESERA Project). The very idea of emergent mosaics of desertified patches each with its own set of processes and interactions played out against a background of local geology, climate, society, race and culture was developed in Geeson, Brandt and Thornes (2002) (ii) Broad sweeping generalisations based on global generalities and now-redundant scientific arguments largely motivated by political needs at the regional and international level.

DESURVEY seeks to avoid this dichotomy, as revealed by the modular groupings of work packages, though these are rather polarised into physical forcing and socio-economic forcing. Module 1.3, on land use vulnerability, reaches above this division by partitioning the work packages into major economic sectors – agricultural systems, rangeland, marginal land and forest vulnerability.

WP 1.3.3 has the responsibility of integrating the identification and modelling of activities across these sectors and across regions and of avoiding, as far as possible, the dichotomous approach (reductionist v. sweeping generalisations) mentioned above. We also seek to avoid the large-volume data-gathering empirical exercises redolent of the 1960s approach to these problems.

To achieve this, the problem is approached through the recently (over the last 20 years) developed paradigm of *Global Change Syndromes* actively pursued by the Potsdam Institut fur Klimatologie (PIK). This provides a conceptual methodology, a set of tools and a framework at the global scale for the identification, classification and mitigation of the impacts of climate change. The basics are contained in three papers from PIK that explain the broader vision (Schellenhuber et al., 1997) that explain it tersely in a highly condensed form (Petschel-Held and Ludeke, 2001), and provide a detailed worked example of its application to global forest threat (Cassel-Gintz and Petschel-Held, 2000). A fourth contribution (Downing and Ludeke, 2001) deploys the concept in discussing *International Desertification: the Social Geographies of Vulnerability and Adaptation.*

It is the task of WP1.3.3 to examine the suitability of the concept for identifying and addressing the regional level of desertification and to integrate it with newly-emerging models of economic ecology (Regev,Gutierrez, Schreiber and Zilberman, 1998) that provide a multi-trophic level approaches to renewable resources modelling under conditions of human harvesting. We expect to use two of the pilot areas of DESURVEY to explore and develop these two paradigms as core tools for investigating the desertification problems beyond the pilot areas.

A syndrome in the medical sense is 'a complex clinical picture' from the Greek origin, meaning 'a flowing together of many factors'. As developed by the PIK group, it is a better-defined and deeper idea than the much-abused term 'scenario', though clearly there are close parallels. First, both seek to avoid a spurious level of precision as a basis for understanding global change impacts. In this sense they are 'fuzzy' in the modern usage of the term (McNeil and Freiberger, 1993), i.e. they avoid the positivist scientific philosophy implied by terms such as 'forecast' and deploy qualitative as well as quantitative tools. Second, both seem to reach above the local level of explanation and prescription. While 'scenarios' paint broad pictures of the processes, interaction syndromes seek to qualify and group them into a typology of major 'bundles of interactive processes which appear repeatedly and widely-spread in typical combinations.' They are not merely complexes of causes and effects, but patterns of interactions, frequently possessing clear feedback character.

In Table 6 are the main Global Change Syndromes, grouped into four classes, as presented in Schellenhuber et al. (1997). For any one, there is a large complex network of inter-relation, most of which have not been teased out yet and undoubtedly there are more syndromes still to be described. In the paradigm, the description of syndromes rests on symptoms of global change and the interactions between them. By 1997, more than 80 symptoms had been identified as commonly occurring in several syndromes.

In the Sahel Syndrome, underpinned by the over-use of marginal land, the core symptoms are soil erosion, impoverishment, expansion of agriculturally-used lands, and intensification of agriculture. This syndrome will figure strongly in WP 1.3.3. Once the network of interactions is mapped out in the 'box-and-arrow' format of the earlier systems analysis (Bennett and Chorley, 1986), the stage is set for the mapping of their intensities and using these to obtain a feeling for the tendency (or disposition) towards a syndrome in a given region. Qualitative differential equations have been adopted to describe the interactions and fuzzy logic, to avoid the simple dichotomising of variables in the interactions. This again emphasises the attempt to free the approach from the earlier limitations of the structures imposed by positive science on the interdisciplinary methods needed to solve environmental problems.

Table 6. Overview of global change syndromes.

(from Cassel –Gintz and Petschel- Held,2000 after WBGU,1997)
Utilization syndromes-resulting from inappropriate use of natural resources as production factors
1. Overcultivation of marginal land. SAHEL SYNDROME
2. Overexploitation of natural ecosystems: OVEREXPLOITATION SYNDROME
3. Environmental degradation through abandonment of traditional agricultural practices: RURAL EXODUS SYNDROME
4. Non-sustainable agro-industrial use of soils and bodies of water:DUST BOWL SYNDROME
5. Environmental degradation through depletion of non-renewable resources : KATANGA SYNDROME
6. Development and destruction nature for recreational needs: MASS TOURISM SYNDROME
7. Environmental destruction through war and military action: SCORCHED EARTH SYNDROME
Development Syndromes-people-environment problems arising from non-sustaiable development
8. Environmental damage of natural landscapes as a result of large-scale projects: ARAL SEA SYNDROME
9.Environmental Degradation through the introduction of inappropriate farming methods: GREEN REVOLUTION SYNDROME
10. Disregard for environmental in the corse of rapid economic growth. ASIAN TIGER SYNDROME
11. Environmental degradation through uncontrolled urban growth: FAVELA SYNDROME
12. Destruction of landscapes through planned expansion of urban infrastructures: URBAN SPRAWL SYNDROME
'Sink' syndromes- environmental degradation through society's use of non-adapted disposal systems
14. Environmental degradation through large scale diffusion of long-lived substances:SMOKESTACK SYNDROME
15. Environmental degradation through controlled and uncontrolled disposal of waste: WASTE DUMPING SYNDROME
16. Local contamination of environmental assests at industrial locations: CONTAMINATED LAND SYNDROME

2. Mediterranean Syndromes

The large land area drained by rivers that are tributary to the Mediterranean Sea (the Mediterranean Basin) has a highly variable topography, climate and culture and there has emerged a complex mosaic of man-environment interactions that almost defies description and interpretation (Wainwright and Thornes, 2004). Nevertheless, and perhaps surprisingly, some of the great shibboleths of our time about man-environment relations have taken root there. 'Overgrazing' and 'deforestation' are but two. These arose partly from misinterpretation of the earlier writings of Greek and Roman authors and also from the north-west European concepts of the 'Lost

Eden' and the 'Ruined Landscape'. Both of these concepts have been seriously questioned as they apply to the Mediterranean basin in Grove and Rackham's ecological history of Mediterranean Europe (2001). In particular, they challenge the application of the desertification paradigm. They say (page 16) that:

"Some scholars and propagandists use 'degradation' and 'desertification' in situations with no evidence of environmental change at all. The mere existence of a desert or of something that can be described as one is taken as evidence of desertification, whereas (for all the writer knows) desert may have been present throughout history and may even have shrunk."

We must approach the question in the same spirit of scepticism. There can be no doubt that there has been constant and complicated land use change in the Mediterranean throughout history and much of pre-history. Some of these have been very recent indeed, such as the harnessing of water across the Mediterranean as the hydraulic civilisations advanced. We are concerned to explore in WP 1.3.3 the extent to which the syndrome framework can enable us to cut through the Gordian knot of disciplinary reductionism at a scale sufficient to bring order to the complex mosaic of land uses and livelihoods.

Almost universally in the basin, soil erosion is the major component of land degradation (Sala and Conacher, 2000) even if the absolute rates are sometimes exaggerated for political effect. The more-or-less independent CORINE survey supports the view that soil erosion is almost universal across the basin even if the rates vary enormously both spatially and seasonally.

Thus the Sahel syndrome, with its KERNAL symptoms and interactions based on soil erosion (Schellenhuber, 1977, gives a full description of the syndrome) and the OVER-EXPLOITATION syndrome (Cassel-Guntz and Petschel-Held, 2000) appear almost universal either contemporaneously or in tandem across the basin. Nor is there a debate about causation any longer, both bio-physical and socio-economic factors are responsible in different amounts in different places. Sometimes one has triggered another in time (as in the Alentejo, see below) or there has been spatial contagion of one or other syndrome. The Mediterranean basin region has also seemed highly prone to the DUSTBOWL syndrome – the non-sustainable agro-industrial use of soils and bodies of water. This is often through the poor quality of soils as well as the seasonality of the climate coupled with heavy pressures of rural population growth. The environmental impact of the mechanisation of agriculture is also well-documented. In the middle of the last century, the introduction of heavy machinery, improved cultigens and fertiliser revolutionised agricultural yields, reduced reliance on alternative forms of employment and left Mediterranean rural areas disposed (sensitive) to the vagaries of the international markets. This GREEN REVOLUTION syndrome has plagued the Iberian Peninsula from east to west.

Throughout the Mediterranean drylands irrigation systems and practices left behind by the Moors and the Grande Hydraulique of the 18th century are examples of the OVER-EXPLOITATION syndrome.

Although the typology gives a short-hand method of identifying the class of environmental change, it is easy to forget that the typology alone is not enough for the development of policy or mitigation strategies. It is the need to model the interaction at an intermediate scale of resolution Below we attempt an outline of the main features of human environment interactions in two plot areas: the Alentejo of Southern Portugal and the La Mancha region of Central Spain, as a first step towards our more detailed analysis of the phenomena in the remainder of the DESURVEY Project.

3. Alentejo & La Mancha Syndromes

3.1. Alentejo

Alentejo is a Portuguese province occupying much of the centre south of the country and stretching from the west coast to the Spanish border in the east (Fig. 8). It was selected as a Target Area for the MEDALUS Project (Roxo et al., 1996) and now for DESURVY
It comprises mainly extensive plain lands with rolling rounded hills covered by thin soils on mica-schist. In the early 1960s it became clear that, in Inner Alentejo, the Portuguese agricultural policy of widespread wheat cultivation was causing land degradation. Productivity was falling rapidly and the most visible consequence was a steady migration of people towards major cities and to the burgeoning tourist industry of the Algarve. They were escaping agriculture that in some areas was no longer viable. The study of land degradation has consequently been a high priority for overt 40 years. As a consequence the New University of Lisbon created experimental centres at Vale Formoso and Herdade de Almocreva that emphasised the role of wheat cultivation and land use in soil conservation.

Climatologically speaking (Roxo et al., 1996), the rainfall has a strong seasonal distribution, with rainfall in autumn and winter. The winter rainfall is critical for wheat production. The history of Alentejo is outlined by these authors and in a further helpful paper by Rodriguez (1998) that outlines the economic vicissitudes of the town of Mertola at the centre of Inner Alentejo. This clearly shows the steep population decline from a peak of 29,000 in 1940/50 to about 10,000 in the early 1990s (Fig. 9). This decline reflects not only the exodus from a failing agricultural campaign, but also the decline of the mining activities notably at Santo Doming and in Mertola itself. We see here too other symptoms of rural stress in the pressure exerted on the common lands (*baldios)* in Mertola municipality (Roxo, 1994). Roxo et al. (1996) have traced the land use history of the area since 1897 when, by then, only 30% of the municipality of Mertola was in natural vegetation, implying that cropping and grazing were already very significant. But they claim that degradation commenced as early as the 12th century as the country was being reconquered from the Arabs and immense feudal properties were donated to religious orders for management and protection. By the beginning of the 20th century, 63% of Mertola municipality had already been cultivated, though productivity was extremely low.

In a recent published study of land abandonment and farming strategies in southern Portugal, Lourenco et al. (2001) showed that there are strong spatial variations in the strategies used by farmers in the shift from the traditional agro-silvo- pastoral economy with its mixture of cork oak and shrub (*montados*) components ranging from the poor farmers in the north-east of Alentejo (around Vaqueiro) to the farmers in the coastal areas Mira and Alto Sado on the west side of the Sierra de Grandola with a different land-holding system with medium and large farms.

This short characterisation of the Alentejo reveals quite clearly three major points about the relevance of the syndromes approach:

(i) There has been a succession of syndromes, each leaving a mark in both the historical records and the landscape. The country is a veritable palimpsest of syndromes and the residues of their various symptoms will have to be carefully demonstrated.

(ii) There are strong within-region variations in human activity from commercial cropping to subsistence farming that will add significant spatial noise to the broader syndrome characterisation of the region.

(iii) There is some evidence to suggest that the earlier syndromes have triggered the later one in an evolutionary kind of way.

Clearly the identification of *disposition* towards change to new conditions of land degradation will require more than a trivial application of the assessment of symptoms in a qualitative fuzzy programming mode as prescribed in the PIK literature. Nevertheless in Table 7 we present a first attempt to identify the syndromes and variables that might be relevant to the Alentejo as a basis for further discussion with local experts in the DESURVEY team.

Table 7. Proposed time sequence of syndromes for Alentejo

Syndrome	**Symptoms**	**Interacting variables**
SAHEL Pre-1890	Rural poverty and population pressure drives farmers to overuse marginal land	Climate, productivity and population
ARAL SEA (1940-1960)	Bad management or failure of centrally planned, large scale projects involving deliberate reshaping of the natural environment	Govt. policy on wheat. Wheat production Land degradation
DUST BOWL1960-1990	Industrialised farming in Wheat campaign	Vegetation cover, soil erosion, population densities
SAHEL(AGAIN)(1980-2000)	Overuse of marginal land	E.U. subsidies, extensification of agriculture, new farming 'intakes' from commons.
RURAL EXODUS(2000-)	Abandonment of traditional agricultural practices	Abandonment of land, population changes,

3.2. La Mancha

La Mancha is a broad flat plain in the centre of Spain, mainly south-east of Madrid, with occasional ranges of low rocky hills. It was the focus of major studies in the early 1990s. EFEDA was a large EU Project related to the ECHIVAL experiments that sought to examine the effect of surface land use patterns on meso-scale climatology as a contribution to the programme of desertification studies of successive Framework Programmes. Like the Alentejo, it has a complex land use history. Its major characteristic today is the huge dependence on irrigation from groundwater. This monotonic dependence on a single resource underlies all the man-nature interactions that will define the appropriate syndromes. Not only has irrigation had a long and distinguished history since pre-Moorish times, with some of Spain's first irrigation works occurring in the area, but a large major irrigation scheme was implemented at the end of the last century and, in the last decade, the National Hydraulic Plan has had a major impact on the availability of water and its functioning as a major resource. In fact the creation of real and proposed inter-basin water transfer has become a major policy issue at the trans-national as well as local and national levels. The groundwater crisis in the Upper Guadiana basin has been described in detail by Bromley (2000) and Fig. 10 demonstrates very clearly the essential features of the crisis. It has been highlighted also by the political and ecological furore of the internationally relevant Ojos de Guadiana wetlands, whose degradation has been described by Llamas (1989). Burke and Thornes have outlined and modelled the principal features of the degradation of the groundwater of the Guadiana (2000). Although the hydrology is neither simple nor simply physically-dictated it is at the core of the problem.

In summary, water levels have been declining for a period of 25 years and the national government, together with the E.U. have introduced measures to prevent the further expansion of irrigated areas, to implement a 5 year programme of subsidies totalling 100M ecu to encourage farmers to reduce abstraction by taking land out of irrigated production and diverted water towards the Tablas de Damiel wetlands from the Tajo-Segura Trasvase via the Ciguela and Guadiana Rivers. Although these measures have halted the spread of irrigated land, ground-water levels continue to decline (in 2000).

However according to Bromley et al. (2000) the results of their modelling are encouraging. Groundwater levels are predicted to remain virtually unchanged. Aquifer storage recovers to pre-1975 levels after 15 years, but river flow shows no increase and the mean discharge of the Guadiana at El Vicario continues to be zero. Re-coupling of the ground and surface water systems is thus not achieved. The Guadiana and Las Tablas de Damiel wetland continue to be dry throughout the entire simulation period (up to 2010). The main reason for the dramatic change in recharge rate in the period 1970-1990 was a period of below average rainfall, combined with a massive increase in borehole abstraction rates from 85-481 $Mm^3\ yr^{-1}$. These results are clear indications of the combined operation of the Overexploitation Syndrome and there is evidence of soil erosion following land-use changes resulting from the irrigation. In other words there appears to be a triggering of the DUST BOWL SYNDROME. There is an interesting parallel here with the situation in the Murcia Autonomous Region, some 500 km to the East. Land was extensively prepared for irrigation with the projected arrival of irrigation from the Tajo-Segura water transfer canal in the mid-eighties. There was insufficient water to meet the needs of the newly-prepared lands that combined with the severe drought of the 'eighties. As a result extensive sheet and bad-land erosion ensued, with heavy loss of cultivable soil. In many areas of dry-land rural Spain, the overexploitation of soil resources has been coupled to the SAHEL Syndrome. It is described by Schellenhuber et al. (1997). The proposed La Mancha syndromes are indicated in Table 8.

Table 8. Proposed syndromes for La Mancha

Syndrome	**Symptoms**	**Interacting variables**
SAHEL	Overuse of marginal land leading to degradation	Population, climate, productivity, area under cultivation
KATANGA	Environmental degradation through depletion of non-renewable natural resources	Falling water levels. Increase in cultivated land, salinisation of soils

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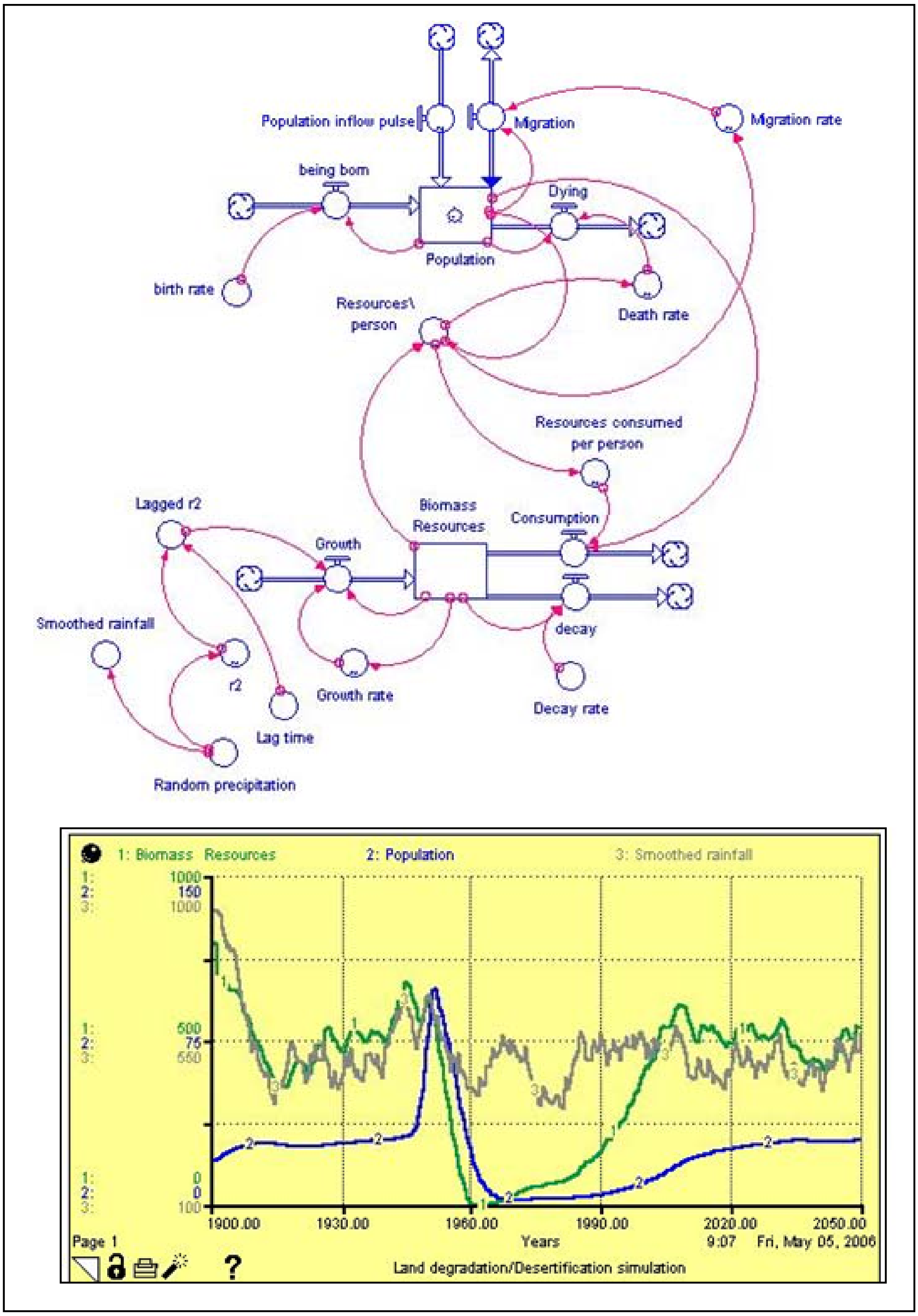

Fig. 1. A system dynamic conceptual model simulating desertification 1900-2050 over a 1 km^2 Sahelian arid environment. The graph illustrates the development of 1: Biomass resources (tons), 2: Population 3: Smoothed random rainfall (100-1000 mm), assuming a population perturbation (new settlements, 80 people 1946-1950). Over consumption leads to a collapse of the resources mainly caused by a decreasing regrowth rate modelled as a function of the remaining biomass stock. The growth rate starts decreasing when the biomass stock goes below the 30% threshold (soil water decrease & erosion) and above the 60% level (competition for space and water).

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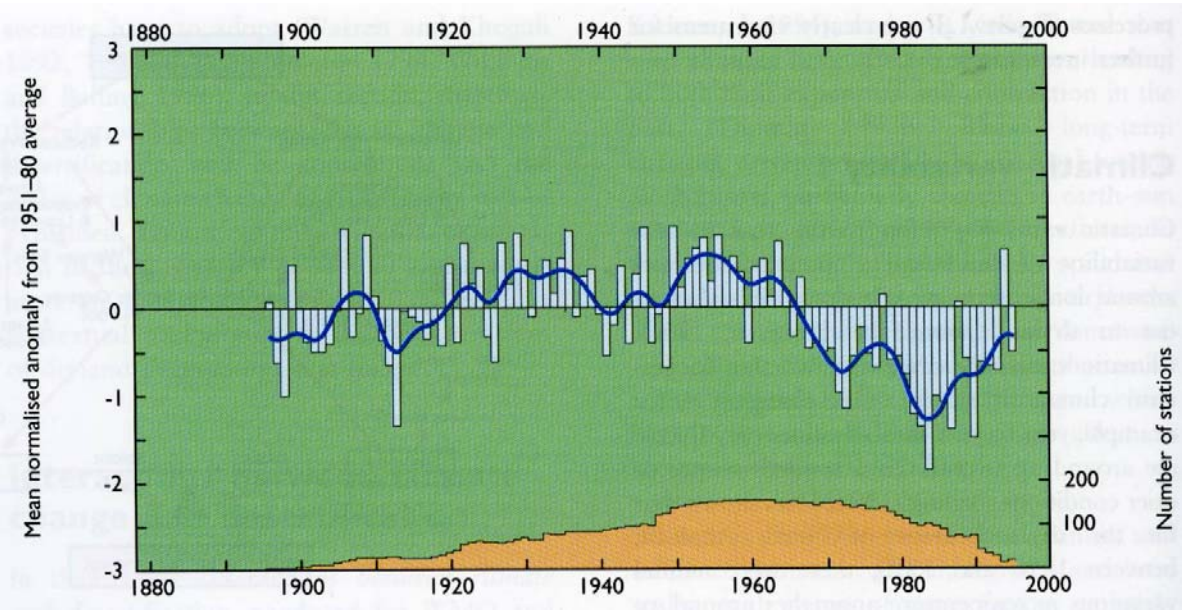

Fig. 2. Sahel annual rainfall anomalies 1896-1995 (1951-1980 mean=524 mm). From UNEP (1997)

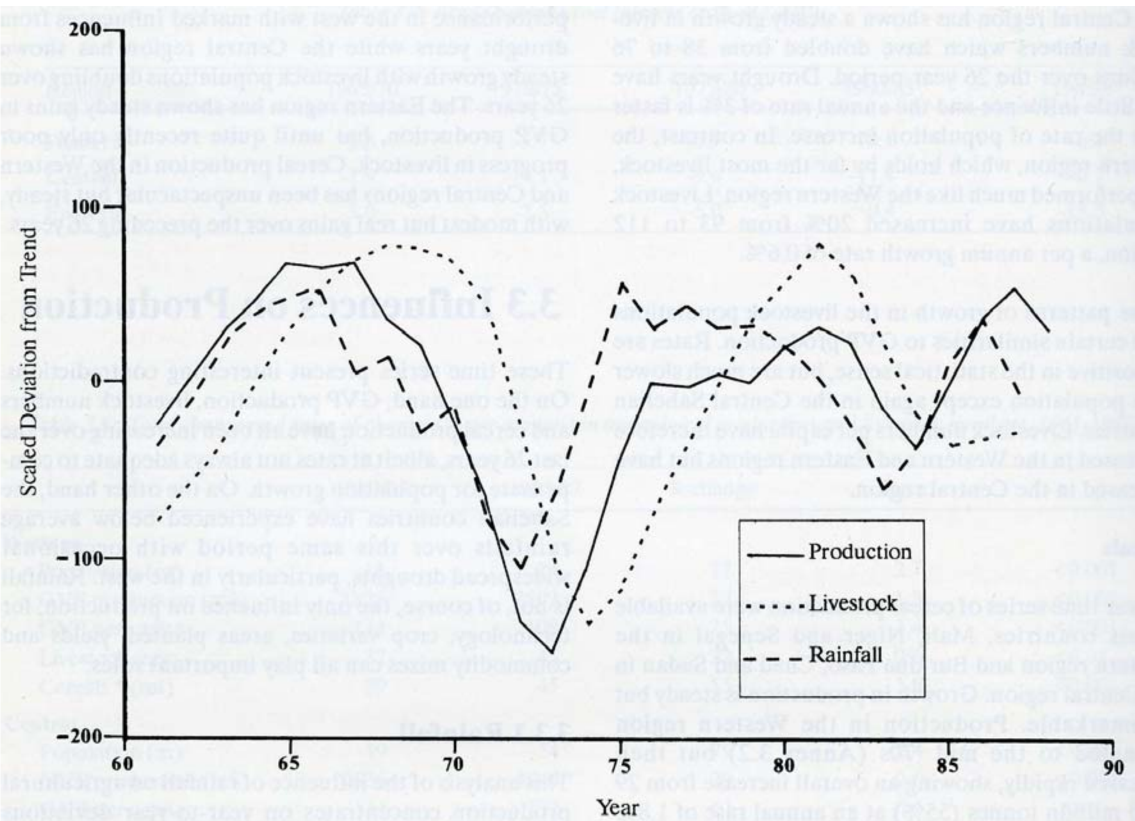

Fig. 3. West Africa Sahelian oscillations. From IUCN (1989)

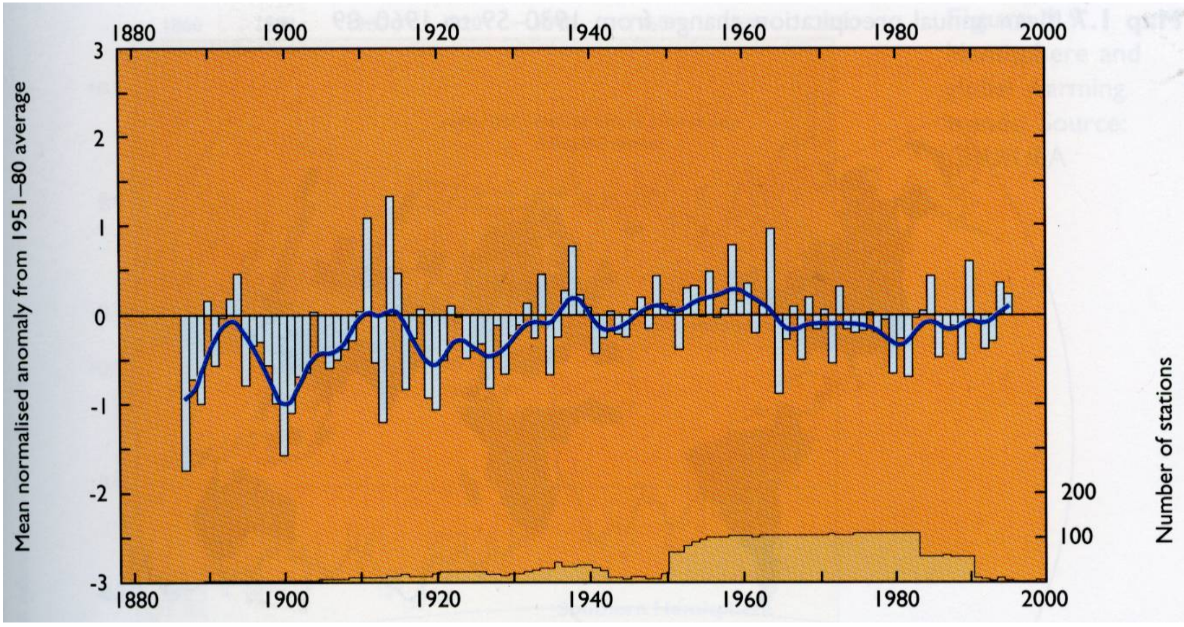

Fig. 4. Northern China annual rainfall anomalies, 1887-1995 (1951-1980 mean=491 mm). From UNEP (1997)

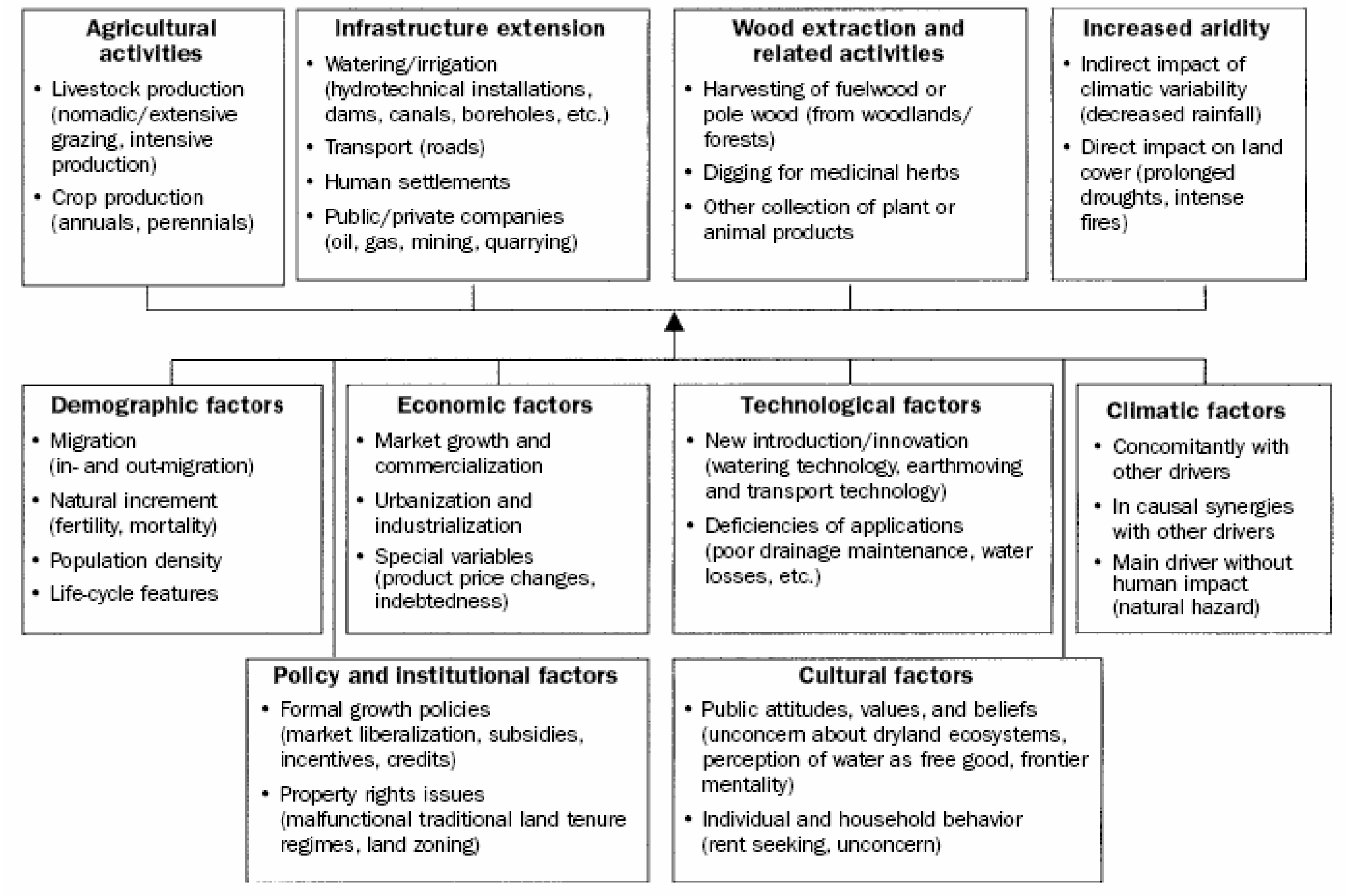

Fig. 5. Causes of desertification. Four cluster of proximate (immediate) causes of desertification and six broad cluster of underlying driving socio-economic and bio-physical processes. From Geist and Lambin (2004).

Table 1. Frequency of broad clusters of proximate causes in desertification, by number and relative percentage.

Cause	All cases (*n* = 132)		Asia (*n* = 51)		Africa (*n* = 42)		Australia (*n* = 6)		Europe (*n* = 13)		United States (*n* = 6)		Latin America (*n* = 14)	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Single factor														
Agriculture	7	5	6	12	1	2	0	–	0	–	0	–	0	–
Increased aridity	7	5	0	–	6	14	0	–	1	8	0	–	0	–
Infrastructure extension	0	–	0	–	0	–	0	–	0	–	0	–	0	–
Wood-related extraction	0	–	0	–	0	–	0	–	0	–	0	–	0	–
Two factors														
Agriculture, increased aridity	34	26	6	12	10	24	0	–	8	62	3	50	7	50
Agriculture, infrastructure extension	4	3	2	4	2	5	0	–	0	–	0	–	0	–
Three factors														
Agriculture, infrastructure extension, increased aridity	27	20	9	18	9	21	6	100	1	8	1	17	1	7
Agriculture, wood-related extraction, increased aridity	15	11	3	6	10	24	0	–	1	8	0	–	1	7
Agriculture, wood-related extraction, infrastructure extension	7	5	1	2	0	–	0	–	1	8	0	–	5	36
Four factors														
Agriculture, increased aridity, infrastructure extension, wood-related extraction	31	23	24	47	4	10	0	–	1	8	2	33	0	–
Total	132	98[a]	51	101[a]	42	100	6	100	13	102[a]	6	100	14	100

No., absolute number; %, relative percentage.
a. Does not total 100 because of rounding.

Table 1. From Geist and Lambin (2004)

Table 2. Frequency of specific proximate causes in desertification, by number and relative percentage.

Cause	All cases (n = 132)		Asia (n = 51)		Africa (n = 42)		Australia (n = 6)		Europe (n = 13)		United States (n = 6)		Latin America (n = 14)	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Agricultural activities	125	95	51	100	36	86	6	100	13	100	5	83	14	100
Livestock production	98	74	36	71	32	76	6	100	7	54	5	83	12	86
Extensive grazing	74	56	23	45	26	62	6	100	7	54	5	83	7	50
Nomadic grazing	38	29	28	55	10	24	0	–	0	–	0	–	0	–
Crop production	78	59	40	78	20	48	5[a]	83[a]	10	77	1	17	2	14
Annual cropping	58	44	24	47	17	40	5	83	9	69	1	17	2	14
Increased aridity	114	86	42	82	39	93	6	100	12	92	6	100	9	64
Indirect impact of climatic variability	63	48	25	49	27	64	1	17	7	54	2	33	1	7
Increased precipitation deficit	37	28	3	6	24	57	1	17	7	54	1	17	1	7
Warmer, drier, more storms, and so on[b]	34	26	23	45	5	12	0	–	4	31	2	33	0	–
Direct influence on surface vegetation	62	47	17	33	21	50	5	83	6	46	5	83	8	57
Prolonged droughts	42	32	17	33	20	48	0	–	0	–	3	50	2	14
Infrastructure extension	73	55	36	71	20	48	6	100	3	23	2	33	6	43
Water technology, irrigation infrastructure	53	40	24	47	17	40	6	100	0	–	0	–	5	36
Residential infrastructure, human settlements	43	33	26	51	14	33	0	–	1	8	2	33	0	–
Wood extraction	59	45	31	61	17	40	0	–	4	31	1	17	6	43
Extraction from forests or woodlands	56	42	29	57	17	40	0	–	3	23	1	17	6	43

No., absolute number; %, relative percentage.

Note: Multiple counts are possible; percentages are related to the total of all cases for each category.

a. Cropping on an intermittent basis only at the semiarid fringe.

b. Including more droughts, more dust emissions, shifts of winter rainfall season (in low-latitude drylands), less snow cover, withdrawing glaciers, and alteration of freeze-thaw soil processes (in high-latitude drylands).

Table 2 . From Geist and Lambin (2004)

Table 3. Frequency of broad underlying driving forces in desertification, by number and relative percentage.														
	All cases (*n* = 132)		Asia (*n* = 51)		Africa (*n* = 42)		Australia (*n* = 6)		Europe (*n* = 13)		United States (*n* = 6)		Latin America (*n* = 14)	
Cause	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**
Single factor														
Clim	7	5	0	–	6	14	0	–	1	8	0	–	0	–
Inst	5	4	0	–	0	–	0	–	0	–	0	–	5	36
Econ	0	–	0	–	0	–	0	–	0	–	0	–	0	–
Tech	0	–	0	–	0	–	0	–	0	–	0	–	0	–
Cult	0	–	0	–	0	–	0	–	0	–	0	–	0	–
Pop	0	–	0	–	0	–	0	–	0	–	0	–	0	–
Two factors														
Pop–clim	10	8	0	–	10	24	0	–	0	–	0	–	0	–
Tech–clim	9	7	0	–	0	–	1	17	6	46	2	33	0	–
Econ–tech	2	2	2	4	0	–	0	–	0	–	0	–	0	–
Econ–inst	2	2	0	–	2	5	0	–	0	–	0	–	0	–
Cult–clim	1	1	1	2	0	–	0	–	0	–	0	–	0	–
Three factors														
Tech–inst–clim	4	3	0	–	4	10	0	–	0	–	0	–	0	–
Pop–tech–inst	4	3	3	6	0	–	0	–	1	8	0	–	0	–
Pop–econ–clim	2	2	0	–	2	5	0	–	0	–	0	–	0	–
Econ–tech–clim	2	2	0	–	1	2	0	–	0	–	1	17	0	–
Tech–cult–clim	2	2	0	–	2	5	0	–	0	–	0	–	0	–
Pop–cult–clim	3	2	1	2	0	–	0	–	1	8	1	17	0	–
Four factors														
Econ–tech–inst–clim	6	5	3	6	0	–	0	–	0	–	0	–	3	21
Pop–econ–inst–clim	4	3	3	6	1	2	0	–	0	–	0	–	0	–
Tech–inst–cult–clim	3	2	0	–	2	5	0	–	0	–	1	17	0	–
Pop–tech–inst–clim	5	4	1	2	3	7	0	–	1	8	0	–	0	–
Pop–econ–cult–clim	2	2	0	–	0	–	0	–	0	–	0	–	2	14
Econ–tech–cult–clim	1	1	1	2	0	–	0	–	0	–	0	–	0	–
Pop–econ–tech–clim	1	1	1	2	0	–	0	–	0	–	0	–	0	–
Pop–econ–tech–inst	1	1	1	2	0	–	0	–	0	–	0	–	0	–
Five factors														
Econ–tech–inst–cult–clim	15	11	1	2	5	12	5	83	0	–	0	–	4	29
Pop–econ–tech–inst–clim	12	9	11	22	1	2	0	–	0	–	0	–	0	–
Pop–econ–inst–cult–clim	5	4	4	8	1	2	0	–	0	–	0	–	0	–
Pop–econ–tech–inst–cult	4	3	3	6	1	2	0	–	0	–	0	–	0	–
Pop–econ–tech–cult–clim	3	2	0	–	0	–	0	–	3	23	0	–	0	–
Six factors														
Pop–econ–tech–cult–clim–inst	17	13	15	29	1	2	0	–	0	–	1	17	0	–
Total	132	104[a]	51	101[a]	42	99[a]	6	100	13	101[a]	6	101[a]	14	100

%, relative percentage; clim, climatic; cult, cultural; econ, economic; inst, institutional; No., absolute number; pop, demographic; tech, technological.
a. Does not total 100 because of rounding.

Table 3. From Geist and Lambin (2004)

Table 4. Frequency of specific underlying driving forces in desertification, by number and relative percentage.

Cause	All cases (n = 132)		Asia (n = 51)		Africa (n = 42)		Australia (n = 6)		Europe (n = 13)		United States (n = 6)		Latin America (n = 14)	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Climatic factors	114	86	42	82	39	93	6	100	12	92	6	100	9	64
Synergistically or concomitantly[a]	55	42	21	41	21	50	5	83	4	31	1	17	3	21
Technological factors	91	69	42	82	20	48	6	100	11	85	5	83	7	50
Innovative developments, introductions[b]	73	55	35	69	12	29	5	83	3	23	3	50	7	50
Deficiencies of technical applications	67	51	31	61	17	40	5	83	8	62	3	50	3	21
Institutional or policy factors	86	65	45	88	20	48	5	83	2	15	2	33	12	86
Malfunctioning common property regulation	42	32	21	41	8	19	0	–	0	–	1	17	6	43
New land tenure, land zoning measures	37	28	19	37	11	26	5	83	0	–	1	17	1	7
Agricultural development policies[c]	35	27	27	53	7	17	0	–	2	15	1	17	0	–
Economic factors	79	60	45	88	15	36	5	83	3	23	2	33	9	64
Market growth, commercialization[d]	64	48	37	73	8	19	5	83	0	–	5	83	9	64
Economic depression, impoverishment[e]	48	36	22	43	9	21	5	83	3	23	1	17	8	57
Demographic factors	73	55	43	84	21	50	0	–	6	46	1	17	2	14
Population growth, increases in size	42	32	31	61	4	10	0	–	2	15	1	17	2	14
In-migration, rising population densities	33	25	15	29	14	33	0	–	3	23	1	17	0	–
Cultural and sociopolitical factors	55	42	26	51	12	29	5	83	4	31	3	50	6	43
Public attitudes, values, and beliefs	52	39	30	59	10	24	5	83	1	8	1	17	5	36
Individual and household behavior	53	40	18	35	10	24	5	83	3	23	3	50	9	64

No., absolute number; %, relative percentage.

Note: Multiple counts are possible; percentages are related to the total of all cases for each category.

a. In causal synergy or concomitant occurrence with other socioeconomic drivers.

b. New land and water management technology (new crop varieties, hydrotechnical installations), new transport and earthmoving technology, and improvements in research and veterinary services.

c. Growth and reform-oriented policies (agrarian reforms, land distribution or redistribution, rural development projects), including agricultural market liberalization.

d. Export-oriented market production, responding to high external demand for products such as cotton, beef, rice, and oil; increased land demand for raising livestock and producing grain; and industrialization and urbanization.

e. Land scarcity, low labor availability, low investments, unviable farm sizes, indebtedness, rural unemployment, and lack of nonagrarian income opportunities.

Table 4. From Geist and Lambin (2004)

Table 5. Driving forces of desertification, by scale of influence.

	Demographic factors[a] (*n* = 73)		Economic factors (*n* = 79)		Technological factors (*n* = 91)		Institutional factors (*n* = 86)		Cultural factors (*n* = 55)		Climatic factors (*n* = 114)	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Individual scales												
Local[b]	17	23	14	18	26	29	10	12	1	2	0	–
Regional[c]	0	–	0	–	0	–	0	–	8	15	0	–
National	0	–	10	13	0	–	17	20	2	4	0	–
Global	0	–	3	4	0	–	5	6	0	–	14	12
Total	17	23	27	34	26	29	32	37	11	20	14	12
Cross-scalar interactions (interplays)												
Local–regional	8	11	0	–	10	11	21	24	16	29	40	35
Local–national	13	18	34	43	41	45	15	17	17	31	17	15
Local–global	0	–	9	11	14	15	4	5	0	–	11	10
Regional–national	0	–	0	–	0	–	4	5	11	20	0	–
Regional–global	0	–	0	–	0	–	0	–	0	–	0	–
National–global	0	–	9	11	0	–	10	12	0	–	0	–
Total	21	29	52	66	65	71	54	63	44	80	68	60
No data, unknown (scale not specified)	35	48	0	–	0	–	0	–	0	–	32	28

No., absolute number; %, relative percentage.

Note: Percentages may not total 100 because of rounding.

a. "Rising population densities" were coded as a local phenomenon, but "increase in population" was coded as unspecified in terms of scale of impact.

b. Farm, household, society, community, or small ecosystem.

c. District or province.

Table 5 . From Geist and Lambin (2004)

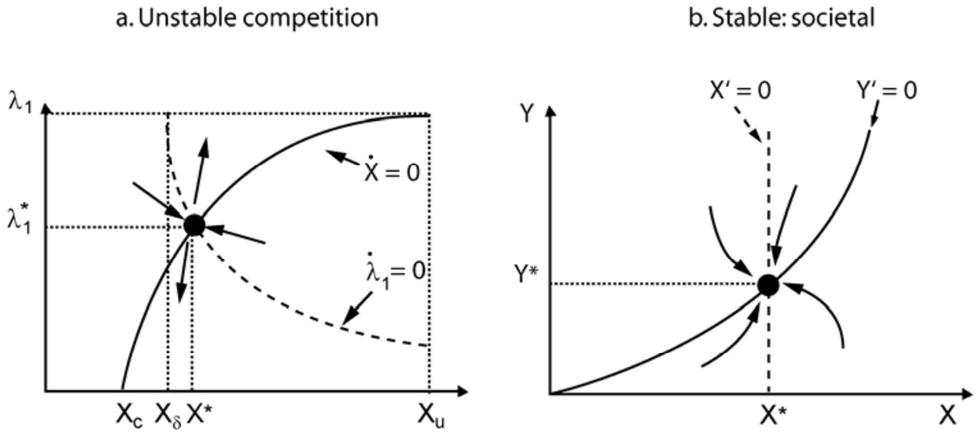

Fig. 6. Stability conditions for free market (left) and community constrained(right)Objective functions(Regev and Gutierrez).
In the left figure (free market) gain ($\lambda_{1)}$ is plotted against resource (x) and the corresponding isoclines for Dx/dt=0 and $d\lambda_1/dt=0$ are given. The joint equilibrium, for the free open competition case, is an unstable saddle. Because the trajectories move away from the equilibrium in the upper and lower quadrants, a slight perturbation into either of these quadrants will drive the system towards an upper limit of $\lambda_{1,}$ or towards $\lambda_{1=0.}$ By contrast, the societal objective function analysis, depicted in the right-hand graph, shows a stable equilibrium at x* and y*.

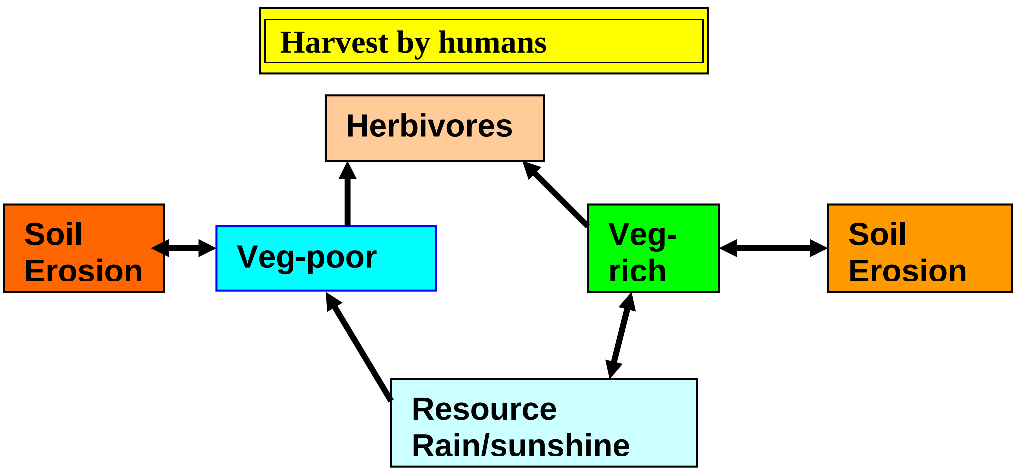

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Fig 7. Schematic representation of muti-trophic web with resource and harvesting.

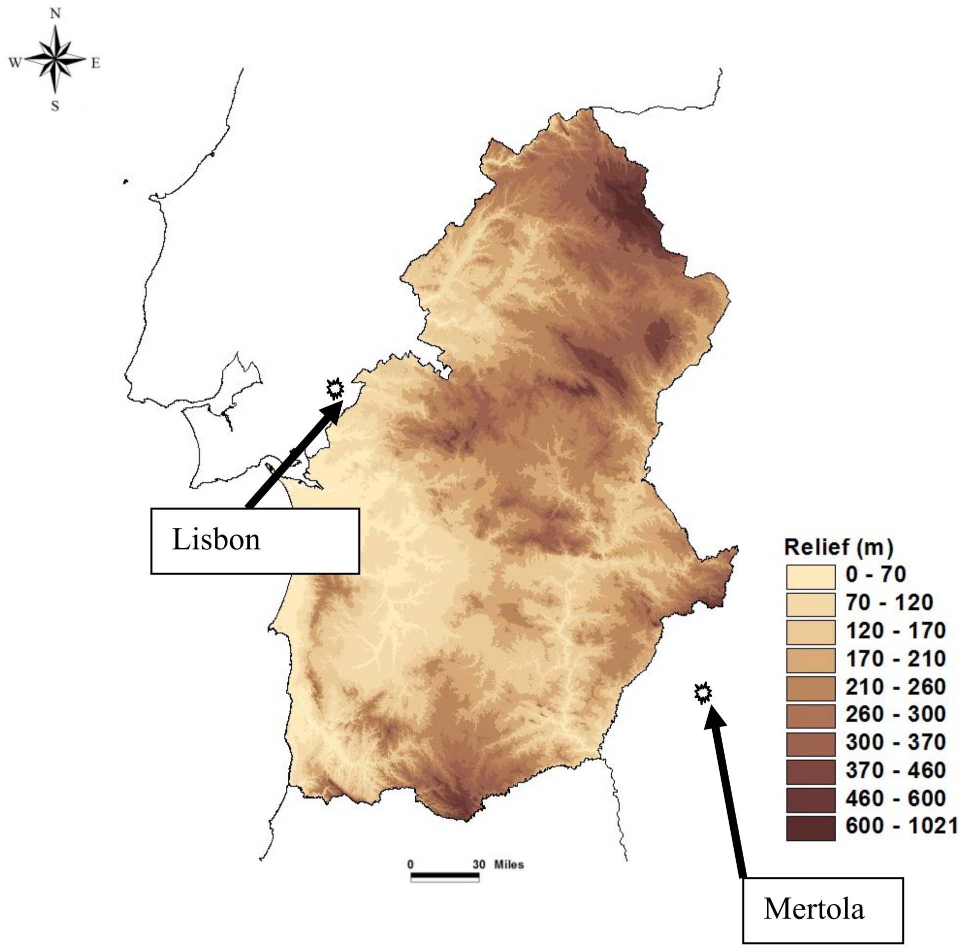

Fig. 8. Physical Map of Alentejo(supplied by M.Roxo)

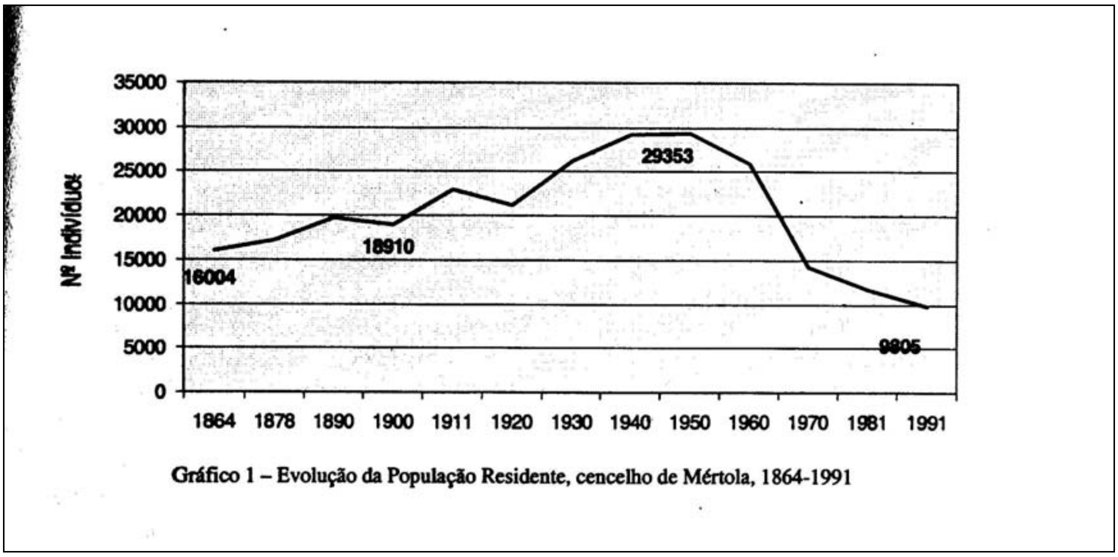

Fig. 9. Population development 1864-1991, Mértola, Portugal.

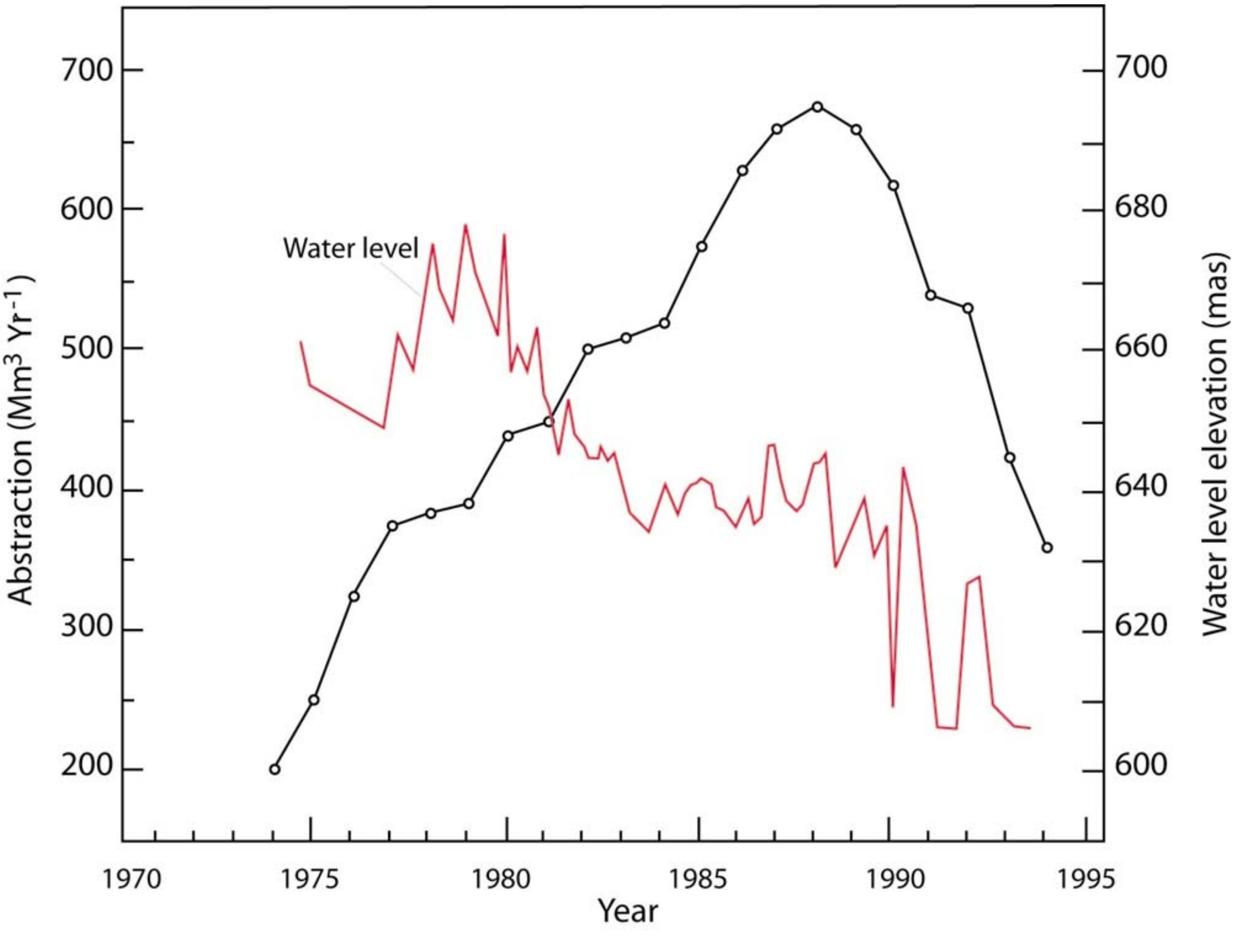

Fig. 10. Abstraction rates and falling groundwater levels in La Mancha (based on Bromley, 1998)

Table 9. The hierarchy of important desertification causes as condensed and somewhat modified from Geist and Lambin (2004).

Top level causes influencing biomass yield and vegetation cover (driven by level 2 below)

- Crops, fodder, natural vegetation & soil seed banks degradation (quality, quantity and ground cover decrease i.e. increased soil exposure)
- Erosion: water& wind (including soil particle movement backward and forward)
- Sedimentation
- Soil compaction, crust development & salt precipitation.
- Soil mining (soil exhaustion through nutrient leaching and consumption)
- Water surplus/deficits (rain, surface-, soil- and ground water content)
- Albedo increase

Level 2. Proximate causes/processes (driven by level 3 below)

Agricultural activities
-Livestock production/grazing (nomadic, husbandry/ household)
-Crop production (commercial/ mechanical, subsistence, irrigated/rainfed)

Infrastructure extension
-Watering/irrigation (dams, boreholes, channels etc…)
-Transport
-Human settlements
-Public/private companies (oil, gas, mining, quarrying)

Increased aridity (impact on land cover & erosion)

Wood extraction and related activities
-Fuelwood & charcoal,
-Construction, timber
-Forest, woodland & bushland clearing for cultivation expansion

Level 3. Underlying causes/processes (driving the Level 2 proximate causes)

Demographic factors
- Migration-urbanisation
- Growth and densities
- Age distribution and dynamics

Economic factors (global & national, taxes and subsidies)
- Market growth (local, regional, national) and commercialization)
- Urbanization (see Demographic factors) and industrialization
- Market economy and prices (land, crops, etc.), (see also taxes-subsides under Policy factors below)
- International trade agreements

Technological factors
- New technologies, innovations diffusion
- Management (e.g. bad water/irrigation management)

Climatic factors (variability and change)
- Concomitantly with other drivers
- In causal synergies with other drivers
- Main driver without human impact (natural hazard, climate change…)

Policy and institutional factors
- Formal growth policies (market liberalization, taxes-subsidies, education policies).
- Property rights issues (land distribution & access: tenure, cost, tax,water rights)
- Poverty programs
- Soil conservation programs, environment policies (e.g. NAP)
- International aid

Cultural and education factors
- Public attitudes, values and beliefs
- Individual, household, tribe, community behaviour and education level

Political factors
- Governance-democracy,
- Distributed power - central power
- International aid and trade