



**HAL**  
open science

# Much More than Simply “Desertification”: Understanding Agricultural Sustainability and Change in the Mediterranean

Mark Mulligan, Sophia Burke, Andrew Ogilvie

► **To cite this version:**

Mark Mulligan, Sophia Burke, Andrew Ogilvie. Much More than Simply “Desertification”: Understanding Agricultural Sustainability and Change in the Mediterranean. *The End of Desertification?*, Springer Berlin Heidelberg, pp.407 - 425, 2016, Springer Earth System Sciences, 978-3-642-16014-1. 10.1007/978-3-642-16014-1\_15 . hal-04521319

**HAL Id: hal-04521319**

**<https://hal.science/hal-04521319>**

Submitted on 26 Mar 2024

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

# Metadata of the chapter that will be visualized in SpringerLink

Book Title	The End of Desertification? Disputing Environmental Change	
Series Title		
Chapter Title	Much More Than Simply “Desertification”: Understanding Agricultural Sustainability and Change in the Mediterranean	
Copyright Year	2016	
Copyright HolderName	Springer-Verlag Berlin Heidelberg	
Corresponding Author	Family Name	<b>Mulligan</b>
	Particle	
	Given Name	<b>Mark</b>
	Prefix	
	Suffix	
	Division	Department of Geography
	Organization	King’s College London
	Address	Strand, London, WC2R 2LS, UK
	Email	mark.mulligan@kcl.ac.uk
Author	Family Name	<b>Burke</b>
	Particle	
	Given Name	<b>Sophia</b>
	Prefix	
	Suffix	
	Division	
	Organization	AmbioTEK Community Interest Company
	Address	London, UK
	Email	
Author	Family Name	<b>Ogilvie</b>
	Particle	
	Given Name	<b>Andrew</b>
	Prefix	
	Suffix	
	Division	Department of Geography
	Organization	King’s College London
	Address	Strand, London, WC2R 2LS, UK
	Division	
	Organization	Institut de Recherche Pour Le Développement (IRD), UMR G-eau
	Address	Montpellier, France
	Email	
Abstract	In the socio-economic and climatic complexity of a Mediterranean environment, desertification involves many processes and is much more spatio-temporally sophisticated than is often suggested by both the policy and academic communities. Here we examine the spatial variability of the Mediterranean environment and its agriculture—a supposed key driver of desertification in the region. We examine trends in agricultural production and climate in the region and the differences between north and south. We	

review the recent history of Mediterranean desertification research and its changing policy context. In particular, we examine the evidence for Mediterranean desertification, and what we now understand of it, with the hindsight of three decades of research and having 'come out of the other side' of decadal drought events that prompted large-scale concern over the desertification of Mediterranean Europe in the 1990 s. We focus particularly on the spatial heterogeneity of the Mediterranean and the implications of this heterogeneity for understanding perceived desertification in the region, and explore implications for land use and management policy-making, indicating the need for a much more locally nuanced approach.

---

Keywords (separated by '-') Desertification - Land degradation - Europe - Mediterranean - Heterogeneity - Policy

---



# Chapter 15

## Much More Than Simply “Desertification”: Understanding Agricultural Sustainability and Change in the Mediterranean

Mark Mulligan, Sophia Burke and Andrew Ogilvie

**Abstract** In the socio-economic and climatic complexity of a Mediterranean environment, desertification involves many processes and is much more spatio-temporally sophisticated than is often suggested by both the policy and academic communities. Here we examine the spatial variability of the Mediterranean environment and its agriculture—a supposed key driver of desertification in the region. We examine trends in agricultural production and climate in the region and the differences between north and south. We review the recent history of Mediterranean desertification research and its changing policy context. In particular, we examine the evidence for Mediterranean desertification, and what we now understand of it, with the hindsight of three decades of research and having ‘come out of the other side’ of decadal drought events that prompted large-scale concern over the desertification of Mediterranean Europe in the 1990 s. We focus particularly on the spatial heterogeneity of the Mediterranean and the implications of this heterogeneity for understanding perceived desertification in the region, and explore implications for land use and management policy-making, indicating the need for a much more locally nuanced approach.

**Keywords** Desertification · Land degradation · Europe · Mediterranean · Heterogeneity · Policy

---

M. Mulligan (✉) · A. Ogilvie  
Department of Geography, King’s College London, Strand, London WC2R 2LS, UK  
e-mail: mark.mulligan@kcl.ac.uk

S. Burke  
AmbioTEK Community Interest Company, London, UK

A. Ogilvie  
Institut de Recherche Pour Le Développement (IRD), UMR G-eau, Montpellier, France



## 15.1 Introduction

Desertification is an umbrella term that is used to represent a range of biophysical and socio-economic processes that may combine to reduce the biological potential of the land in arid and semi-arid agricultural areas. In contrast, at the edges of true deserts, desertization can be a simple process of desert encroachment by migrating dunes. In the socio-economic and climatic complexity of a Mediterranean environment, desertification involves many more processes than desertization and is much more spatio-temporally sophisticated than is often suggested by both the policy and academic communities. Here we examine the Mediterranean environment and its agriculture—a supposed key driver desertification in the region—and look into the recent history of Mediterranean desertification research. In particular, we examine the evidence for Mediterranean desertification, and what we now understand of it, with the hindsight of three decades of research and, moreover having ‘come out of the other side’ of decadal drought events that prompted large-scale concern over the desertification of Mediterranean Europe in the 1990s. We focus particularly on the spatial heterogeneity of the Mediterranean and the implications of this heterogeneity for understanding perceived desertification in the region in the 1990s and now, having access to much more detailed spatial data.

## 15.2 The European Mediterranean: Environments and Agriculture

The Mediterranean is characterised by a semi-arid to sub-humid climate that is highly seasonal for both solar radiation (and thus temperature) and for cloud generation (and thus rainfall). The long, hot and dry summer ‘drought’ followed by heavy October rainfall provides both a constraint to vegetation production and conditions of low cover and intense rainfall which favour soil erosion and degradation. Degradation is variously attributed to overgrazing, poor soil management, poor drainage on irrigated land, and the over-abstraction of woodland for fuel wood.

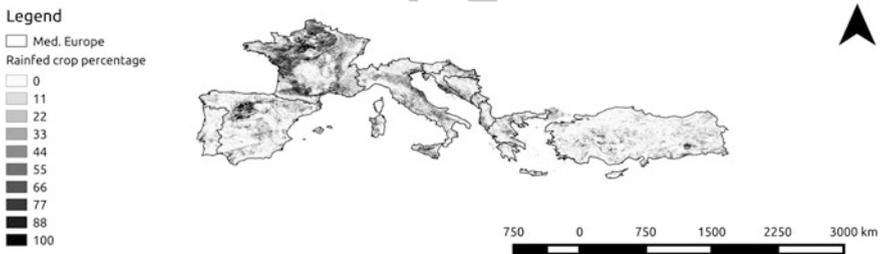
Over the long-term the Mediterranean climate has combined with the region’s geology to create rugged, highly dissected landscapes with sparse vegetation and poor, stony soils. Traditional agriculture is well adapted to this environment through sparse cropping of hardy species (Almond, *Prunus dulcis*; Olive, *Olea europea*; Fig, *Ficus carica*) combined with careful management of water through: runoff capture; mulching of soils; terracing and occasional irrigation. However, recent trends include larger fields, mechanized ploughing, significant soil movements (Ramos and Mulligan 2005; van Wesemael et al. 2005), and intensively irrigated crops including greenhouse vegetables, rice, wheat and citrus. These may not be so well adjusted to both the seasonal water shortages and inter-annual and longer-term climate variability that characterise the region. Agricultural change in the Mediterranean is driven by: complex changes in population distribution

(especially urbanization); demography and socio-economic change (including the development of the service sector and of tourism); changes to transportation costs; subsidies and markets in Europe and beyond; and technological change.

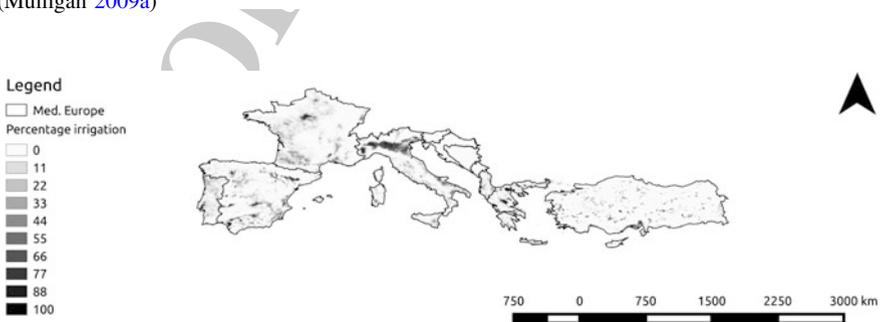
We examine the countries of the northern (largely European) Mediterranean with a coastline on the Mediterranean sea. The Mediterranean countries have strong latitudinal precipitation (P) and temperature (T) gradients. Precipitation decreases from north to south and from west to east and temperature increases along the same gradients. There are, however, significant montane and coastal effects with mountain and coastal areas generally being cooler and wetter.

Rainfed agriculture dominates the northern and western Mediterranean countries (Fig. 15.1) and is intensive in northern France and Spain. If >50 % cover signifies ‘intensive’ then some 16.6 % of the study area can be considered intensive rainfed cropping. Irrigated cropland (Fig. 15.2), on the other hand, is concentrated in a few areas (NE Italy, and parts of Spain, France and Greece) at high intensity but is common over small areas throughout the region. Irrigation is a significant drain on groundwater resources in some of the drier regions and is estimated to use some 16 % of groundwater production in the Mediterranean (Siebert et al. 2010). If >50 % cover signifies intensive then some 2.1 % of the study area can be considered intensive irrigated cropping.

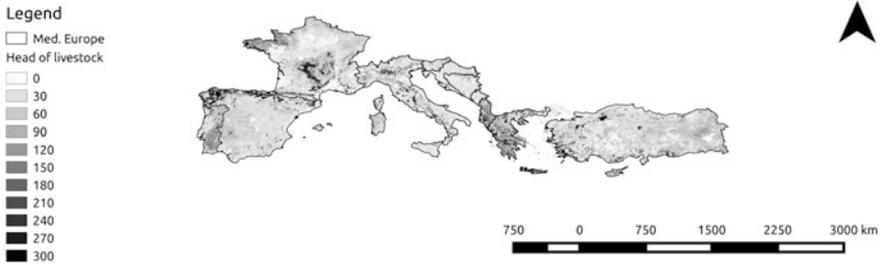
Figure 15.3 shows grazing is much more extensive than intensive in the Mediterranean and occurs throughout the Northern and Eastern Mediterranean,



**Fig. 15.1** Rainfed crops in Mediterranean countries according to GlobCover continuous fields (Mulligan 2009a)



**Fig. 15.2** Percentage of land irrigated. *Source* Siebert et al. (2007)



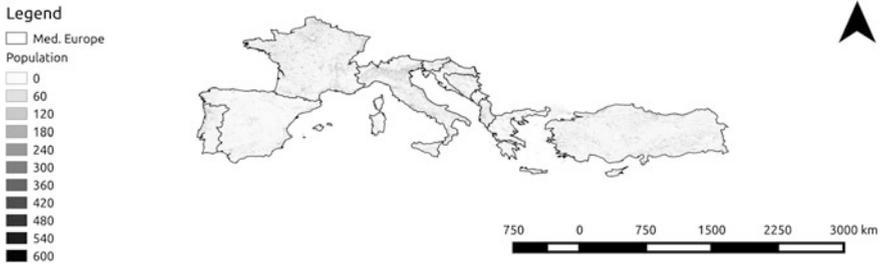
**Fig. 15.3** Total grazers (headcount/km<sup>2</sup>). *Source* Wint and Robinson (2007)

especially in mountains, coastal areas and river margins. If >200 head per square km signifies intensive then some 4.9 % of the study area can be considered intensive grazing land.

The greatest cereals producers in the EU and southern Mediterranean countries in 2007 (an average year for the decade) according to EUROSTAT were France (59.4 million tonnes), Germany (40.6 million tonnes) and Poland (27.1 million tonnes). These are followed by Spain (23.8 million tonnes), UK (19.4 million tonnes) and Italy (18.8 million tonnes). Non-EU southern Mediterranean countries, on the other hand, have lower cereal production, most countries producing 5 million tonnes of cereal annually or less, with the exception of Egypt which produced as much as 15.3 million tonnes of cereal in 2007 (Petit 2007). Though statistics for the southern Mediterranean countries are not as comprehensive, productivity remains lower than for the EU. Fruit and vegetable production is also very variable across the Mediterranean, with Spain, Italy and Egypt having the highest production in the last decade according to EUROSTAT. The European Union is by far the largest producer of olives, producing about 75–80 % of the world's supply (Muller 2004). Greece, Spain and Italy are the top olive producers; followed by Portugal, Algeria, Egypt, Argentina, Lebanon, Libya, Morocco, Palestine, Tunisia and the USA. Production of olives has greatly benefited from EU subsidies. Italy, Spain, and France are the top grape and wine producers in the world, followed by the USA and China. Of the top twelve global producers, the EU producers (Italy, Spain, France and Germany) account for about 67 % of wine production (Patterson and Josling 2005, using FAOSTAT data).

Population is distributed throughout the north and east Mediterranean land-masses with some significant urbanisations also present in those areas (Fig. 15.4). In the southern Mediterranean there are large areas with very low or no populations, people being highly concentrated in the coastal fringe and the major river valleys. This reflects the distribution of climatic and agricultural suitability and also determines the demand for water and the human pressure (directly and through agriculture) on the environment.

The northern Mediterranean is highly urbanised (Fig. 15.5) with these urbanisations being dense (in population terms), extensive and highly concentrated around coasts (e.g. Spain, Italy) and major rivers (e.g. Egypt).



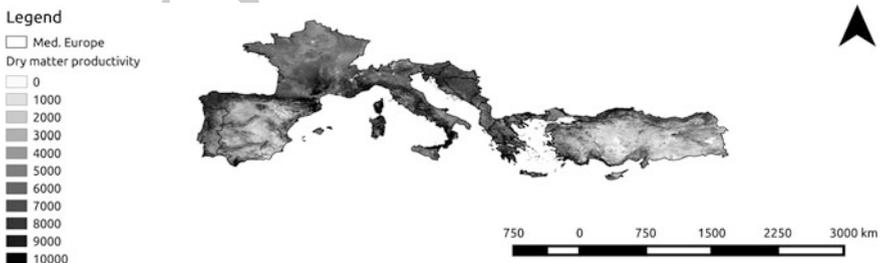
**Fig. 15.4** Population (persons/km<sup>2</sup>). *Source* Landsan (2007)



**Fig. 15.5** Urban areas. *Source* CIESIN (2004)

120 Figures 15.1, 15.2 and 15.3 indicate that the Mediterranean landscape is both  
 121 extensively and intensively agriculturalised, whilst Fig. 15.6 shows dry matter  
 122 productivity for the Mediterranean. This measure is for all plant systems, not only for  
 123 crops and shows strong gradients with the highest observed values in the northern  
 124 areas (of Italy, Sardinia, northern Spain, Greece) and a strong decline towards the  
 125 southern areas (especially of Spain, Turkey). Towards the South and East, water  
 126 becomes limiting because of the gradient of decreasing precipitation in this direction.

127 Overall, the north and west Mediterranean is productive and extensively used for  
 128 dryland or irrigated agriculture or grazing. Despite this intensive, extensive and  
 129 productive agricultural situation, the Mediterranean has long been considered an



**Fig. 15.6** Dry matter productivity (Dg/ha/day) for the Mediterranean. *Source* Mulligan (2009b)

130 area under threat of desertification and land degradation driven by unsustainable  
131 exploitation of water resources, abandonment and subsequent degradation of  
132 managed farmland and significant changes to farming practices over the last dec-  
133 ades (Brandt and Thornes 1996; Puigdefábregas and Mendizabal 1998; Geeson  
134 et al. 2003; Briassoulis 2004; Rubio and Recatalá 2006; Safriel 2009a, b).

## 135 15.3 Recent Drivers for “Mediterranean Desertification”

136 Here we review some of the reasons that Mediterranean desertification has received  
137 a great deal of scientific, political and media attention over the last three decades.  
138 Some of the reasons are biophysical whilst others are socio-economic in origin.  
139 These drivers include agricultural land use change, change to grazing lands,  
140 changes in agricultural policy, climate variability and change and, finally, changes  
141 to human exposure to land degradation.

### 142 15.3.1 Agricultural Land Use Change in the Mediterranean

143 Agricultural production in the Mediterranean has significantly increased over the  
144 past fifty years. Since 1961, production increased 3-fold for cereals, 2.5-fold for  
145 vegetables and 5-fold for citrus fruits and these crops account for over 85 % of the  
146 total agricultural production in the Mediterranean (Plan Bleu 2009). The growth  
147 rate in agricultural production has started to fall in recent years in all Mediterranean  
148 countries with the exception of Egypt, which showed remarkable increases in the  
149 period 1961–1983 and still grew (but at a much slower growth rate) in the period  
150 1984–2007 (Plan Bleu 2009). This has affected trade balances and Mediterranean  
151 countries are becoming increasingly dependent on foreign food imports.  
152 Nevertheless, southern Europe exports much of its produce.

153 Although rain-fed agriculture predominates in the Mediterranean, it is on irri-  
154 gated land that the greatest productivity and productivity gains have been achieved  
155 in recent decades (Montgomery 2009), as is also the case outside the Mediterranean  
156 (Siebert and Döll 2010). The total irrigated area in the Mediterranean countries  
157 doubled in the previous 40 years to exceed 26 million hectares in 2005, possibly  
158 representing over 20 % of the land under cultivation (Plan Bleu 2009). The area  
159 under arable and permanent cropping has not increased alongside annual agricul-  
160 tural production, indicating a trend for intensification rather than extensification,  
161 again replicating the global trend. In fact, since 1961, arable land per capita in both  
162 the north and south of the Mediterranean has halved (Plan Bleu 2009a) as land that  
163 is suitable for cultivation is lost to urbanisation and abandonment every year,  
164 largely because of migration to coastal urban areas but also in response to EU  
165 set-aside policy.

### 15.3.2 Recent Changes to Grazing Lands

In the European Mediterranean—there has been a major shift in land use from livestock that grazed on extensive rangelands to intensively farmed cereals and intensive grazing systems. This is partly driven by markets and regional agricultural policies, in particular subsidies designed to increase biodiversity but also as a more sustainable method of management (Roeder et al. 2008). Taking animals to graze is a hard and time-demanding job (Ruiz et al. 2001) with low economic rewards compared with many others. Intensification necessitates the utilization of supplementary feedstuffs, either on-farm (cultivated pastures and crops) or most frequently off-farm through concentrates and forages (Riedel 2007).

In the Southern Mediterranean, cultivation has encroached onto rangelands, driven by population growth and national policies, often resulting in land degradation (Safriel 2009a, b). In the south and the east (from Morocco to Turkey), despite rural to urban migration, the agricultural population increased by 10 million (16 %) within 40 years, reaching 71 million in 2000 (Thivet 2007). This can be contrasted with the Northern Mediterranean where, from Spain to Greece, the agricultural population decreased from 46 million to 12 million over the same period (Thivet 2007).

### 15.3.3 Recent Changes in Agricultural Policy

Much of the rise in productivity in the EU has been encouraged by the Common Agricultural Policy (CAP), which was set up initially with the treaty of Rome (1957) to control food production across Europe and latterly focuses on environmental concerns. Through the provision of incentives and a number of accompanying policies, the CAP is a key driver of agricultural change in the EU. The impact of the CAP on Mediterranean land use has been well-documented (Shucksmith et al. 2005; van Meijl et al. 2006; Verburg et al. 2008; Serra et al. 2008). The effect of the CAP also needs to be seen alongside other drivers, such as the substantial level of national funding for agriculture, the fluctuations on world markets for food products and the negotiations taking place within the World Trade Organisation (Gay et al. 2005). In particular the CAP has provided support (via intervention buying and storage) for a few Mediterranean products such as olive oil, tobacco and cotton, although this no longer takes place. Increased interest in energy efficiency and climate change is increasingly raising questions about the relevance of current CAP objectives (Cooper and Arblaster 2007). The likely continued future enlargement of the Union will also necessitate significant change to future CAP policy. The Mediterranean will also be affected by the establishment of a Mediterranean Free Trade Zone (MFTZ), which will encompass 12 non-EU nations of the Mediterranean region as well as the entire European Union. This was expected to be completed by now but has been delayed by: foreseen negative social

and environmental consequences; the Sarkozy initiative to set up a Union for the countries that border the Mediterranean sea; and questions as to the relationship between this and the EU-GCC (Gulf Cooperation Council) free trade initiative.

### 15.3.4 *Recent Climate Variability, the Prolonged 1990s Drought and Climate Change Scenarios*

The climate of the Mediterranean region is characterised by hot, dry summers and cool, wet winters (Conacher and Conacher 1998) with December, January and February precipitation (DJF) a major contributor to the annual total. It is a region of significant climate variability, both spatially and temporally. This climate variability is due to the Mediterranean's location in a transitional zone between the competing "marine west coast climate" and the "subtropical desert climate" (Lionello et al. 2006). The Mediterranean climate is exposed to the South Asian Monsoon in summer and the Siberian high pressure system in winter. Variability is expressed as changes in annual total rainfall (both inter-annually and on decadal time scales) and changes in rainfall seasonality and the frequency and magnitude of extreme rainfall events and seasonal drought episodes. Rainfall records since 1900 indicate strong multi-decadal variations in regional precipitation (meteorological drought) coupled with a long term trend in the Palmer Drought Severity Index (PDSI) suggestive of increased land surface aridity associated with observed long term temperature increase since the 1960s (Mariotti 2010). DJF precipitation in the Mediterranean showed a striking decrease during the 1960–1990s which may result from circulation changes in the North Atlantic climate Oscillation (NAO). This meteorological drought has been realised as hydrological drought with river discharge for major Mediterranean rivers such as the Ebro, Jucar and Arno showing a considerable decline over the 20th Century. Current rainfall trends in the region continue the clear downward trend during the second half of the 20th Century (de Luis et al. 2009; García-Ruiz et al. 2011) but much less dramatically than during the 1990s. This drying is experienced in the form of more frequent and intense drought, especially in the winter with 10 of the 12 driest winters since 1902 occurring from 1992–2012 (Hoerling et al. 2012).

Future climate change scenarios for the Mediterranean are also complex. Generally, a change in circulation patterns is expected for the Mediterranean region as a result of increases in sea level pressure, a northward shift of the Atlantic storm track and a deflection of storms north of the Mediterranean into higher latitude areas (Giorgi and Lionello 2008). These changes in circulation are expected to lead to a general reduction in precipitation for the Mediterranean regions and an increase for the northern European regions. Changes in variability of precipitation and temperature are also expected. Schar et al. (2004) concluded that as a result of an increase in inter-annual variability of temperature along with mean long-term warming, the Mediterranean region might experience a much more frequent

245 occurrence of extremely high temperature events and heat waves. As a region with  
 246 already marginal climate for some types of agriculture, the Mediterranean is  
 247 expected to be affected significantly by climate change.

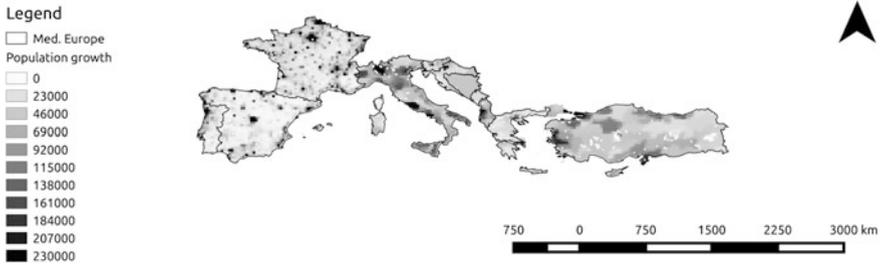
248 Giorgi (2006) analyzed IPCC SRES AR4 simulations to calculate a climate  
 249 change index based on precipitation and temperature means and variation. The  
 250 Mediterranean was amongst a small number of climate change “hot-spots” glob-  
 251 ally. Weib et al. (2007) considered socio-economic and climate changes as indi-  
 252 cated by the IPCC SRES A2 and B2 scenario forcing the ECHAM4 GCM. Under  
 253 this scenario a current 100-year drought would likely occur 10 times more fre-  
 254 quently in the Northern Mediterranean while in North Africa, a current 100-year  
 255 drought will occur less frequently. There is thus the expectation of significant  
 256 negative effects of climate change in the Mediterranean. According to Giorgi and  
 257 Lionello (2008), climate change scenarios from general circulation models (GCMs)  
 258 indicate a “*pronounced decrease in precipitation, especially in the warm season,*  
 259 *except for the northern Mediterranean areas (e.g. the Alps) in winter*”. These  
 260 effects are projected to lead to a progressive decline in streamflow (García-Ruiz  
 261 et al. 2011).

262 Using the more recent Coupled Model Intercomparison Project Phase 5 (CMIP5)  
 263 data, Peleg et al. (2014) compared current climate with projected mid-21st century  
 264 climate based on Representative Concentration Pathway (RCP) RCP4.5 and  
 265 RCP8.5 scenarios using four of the available CMIP5 models. The models projected  
 266 a decreasing frequency of rainfall in the region with a 10–22 % reduction in wet  
 267 events. Also using CMIP data, Diffenbaugh and Giorgi (2012) indicate the  
 268 Mediterranean as one of a few hotspot areas for prominent climate change using a  
 269 multi-variable metric including rainfall and temperature.

270 However, a large source of uncertainty in projections for the Mediterranean  
 271 region derives from unrealistic modelling of the climate influence of the  
 272 Mediterranean Sea (Somot et al. 2008; Lionello et al. 2008). Furthermore, partic-  
 273 ularly for regional models, uncertainties in future land use and land cover change  
 274 adds considerably to uncertainty in climate projections. Uncertainties in climate  
 275 simulations with RCMs for Europe were addressed in the PRUDENCE project  
 276 (<http://prudence.dmi.dk/>) which found that, particularly for temperature, uncertainty  
 277 in boundary forcing plays a greater role than the RCM used (Déqué et al. 2007). In  
 278 addition to these climate changes, the future of the Mediterranean environment will  
 279 also be determined by changes in population, technology, agriculture and thus land  
 280 use and cover.

### 281 ***15.3.5 Changing Exposure: Population Growth*** 282 ***and Economic Development***

283 Spatial projections for population and GDP are publicly available in map form only  
 284 for the Special Report on Emissions Scenarios (SRES) B2 scenario (Fig. 15.7).

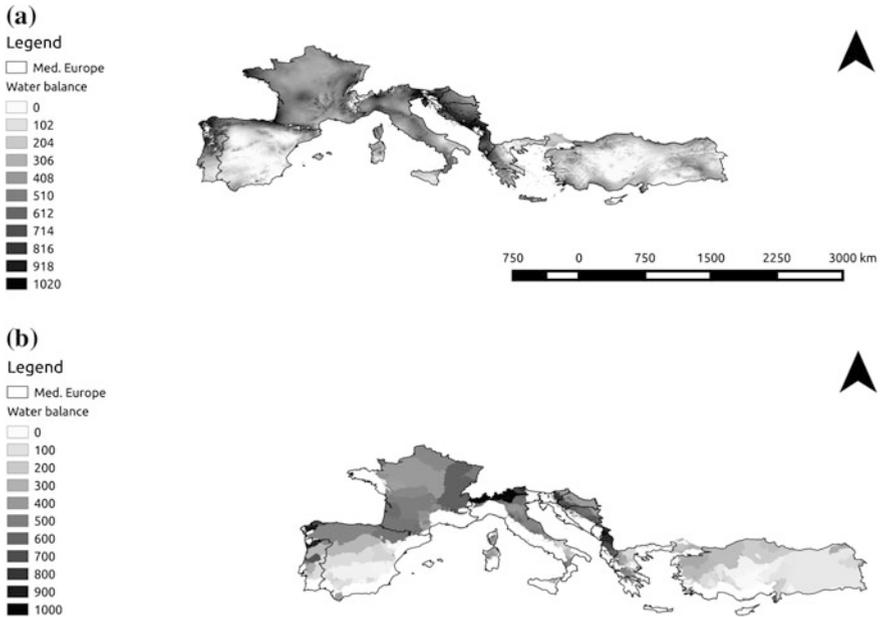


**Fig. 15.7** Population projection for 2025 (persons/km<sup>2</sup>, SRES B2). *Source* CIESIN (2002)

285 Under SRES B2, population increases by 2025 are expected to be greatest in the  
 286 south and east of basin, concentrated in coastal areas. De-population is expected to  
 287 occur in parts of the north Mediterranean (especially Spain, Italy and Greece).

### 288 **15.3.6 The Water Resources Situation**

289 In addition to the observed low productivity in some areas of the Mediterranean  
 290 (and expectation that this will reduce further with land degradation and climate  
 291 change), water resources are also a key constraint on productivity and sustainable  
 292 land management in this environment. We have calculated water balance as rainfall  
 293 (Hijmans et al. 2005) minus actual evapotranspiration (Mu et al. 2011) on a 1 km  
 294 resolution basis with negative local water balances (representing areas where  
 295 evapotranspiration is supported by lateral surface or subsurface inflows) set to zero.  
 296 The results of this analysis are shown in Fig. 15.8a. Dark areas have plenty of  
 297 water, whereas those in lighter shades show progressively lower water balance. The  
 298 most water stressed areas are in the southern Mediterranean, in the eastern  
 299 Mediterranean and in coastal northern Mediterranean. Water stress can lead to  
 300 over-cultivation and to the negative effects of irrigation in drylands. Note that this  
 301 water balance does not include inflows of water from rivers nor unsustainable use of  
 302 fossil water but focuses on the locally produced renewable water resources (the  
 303 water balance) since this will be critical for sustainable agricultural production.  
 304 Some 8 % of the area has a local water balance of zero, indicating all local rainfall  
 305 consumed by local evapotranspiration. Figure 15.8b shows the same data averaged  
 306 over watersheds, indicating clearly the more water stressed catchments. Only 0.3 %  
 307 of basin area experiences basin closure (all rainfall evaporated within the basin) on  
 308 an annual basis under current conditions. Though a positive water balance will lead  
 309 to the generation of runoff and thus river flow, this analysis does not explicitly  
 310 account for available water in rivers and groundwater that is used to supplement the  
 311 local water balance at the pixel scale in some regions, though these are determined  
 312 entirely by water balance at the basin scale.



**Fig. 15.8** **a** Water balance (rainfall-ET) (mm/yr). **b** Water balance (rainfall-ET) (mm/yr) by catchment

**Table 15.1** Evapotranspiration by different land covers and as a percentage of rainfall as calculated by WaterWorld

All vegetation	Irrigated croplands	Croplands	Pastures	Natural vegetation
Actual evapotranspiration (percent of total)	0.41	26.8	16.1	56.1
Actual evapotranspiration (percentage of rainfall)	0.2	15.3	9.2	31.9

313 We carry out an analysis of evapotranspiration through the different types of  
 314 vegetation cover in the region (Table 15.1), calculated using WaterWorld<sup>1</sup> and  
 315 based on the actual evapotranspiration (AET) dataset of Mu et al. (2011), the  
 316 irrigated cropland dataset of Siebert et al. (2007) and the cropland and pasture  
 317 dataset of Ramankutty (2008). Results indicate that, some 0.41 % of actual evap-  
 318 otranspiration in the region occurs through irrigated croplands, 26.8 % through all

<sup>1</sup>WaterWorld is a modelling platform containing a range of global databases and the capacity to run detailed algorithms at scales from local through to continental. It is available free for non-commercial use from [www.policysupport.org](http://www.policysupport.org).



**Fig. 15.9** Watersheds of dams

319 croplands, 16.1 % through pastures and 56.1 % through natural vegetation, with the  
 320 remainder over bare soil and water bodies. The majority of AET thus occurs  
 321 through natural vegetation, though croplands also evaporate a significant volume. In  
 322 total AET consumes 56 % of rainfall in the region, some 32 % of which is evap-  
 323 orated through natural vegetation though only 15 % is evaporated through  
 324 croplands and 0.2 % through irrigated croplands. The remaining 44 % is available  
 325 to fill surface stores and generate runoff. On this basis irrigation consumes relatively  
 326 little of the available rainfall, most of which evaporates through natural  
 327 vegetation. The pressure points on water are thus highly localised to low rainfall  
 328 and high AET areas, including those under intensive irrigation and pressure is not  
 329 extensive throughout the region. The French and Italian Alps in particular will  
 330 experience very different conditions that lower elevation areas with warmer, drier  
 331 climates.

332 The demand for water storage (in reservoirs) during the dry season in the  
 333 Mediterranean is evidenced by the distribution of dammed watersheds in the  
 334 Mediterranean (Fig. 15.9), with the exception of certain dams in central France  
 335 whose primary output is hydropower. The black areas indicate those watersheds  
 336 that outflow at a dam according to the global census of Mulligan et al. (2011). Some  
 337 45 % of the European Mediterranean area, 41 % of its rainfall according to  
 338 WorldClim (Hijmans et al. 2005) and 33 % of its water balance (according to  
 339 WorldClim rainfall minus  $\mu$  et al. (2011) AET) drains into a dam. This represents  
 340 a very significant human appropriation of the hydrological fluxes of this region,  
 341 supporting irrigation, industrial and domestic use.

342 As well as the annual total, the seasonality of rainfall and evaporation is a key  
 343 component of water stress in the Mediterranean. Figure 15.10 shows the Walsh and  
 344 Lawler (1981) seasonality index calculated using WorldClim monthly rainfall  
 345 (mean 1950–2000) and indicates that seasonality is greatest in the SW of the Iberian  
 346 peninsula, in southern Italy, Greece and Turkey. Some 8.2 % of the area is con-  
 347 sidered seasonal and some 0.7 % is markedly seasonal using this metric. In these  
 348 areas a high winter rainfall elevates the annual total but the summer rainfall is a key  
 349 limit to crop growth.

**Legend**

Med. Europe

Rainfall seasonality



Precipitation spread throughout the year



Precipitation spread throughout the year, but with a definite wetter season



Rather seasonal with a short drier season



Seasonal



Markedly seasonal with a long dry season



Most precipitation in &lt; 3 months



Extreme seasonality with almost all precipitation in 1-2 months



**Fig. 15.10** The Walsh and Lawler (1981) seasonality index for the Mediterranean

## 15.4 The Scientific Response to Perceived Mediterranean Desertification

Concern over desertification in the European Mediterranean has led to the funding of a range of field and modelling based assessments in the region. The field programmes aimed to understand the processes operating and assess desertification at various sites whereas the modelling projects aimed to provide a detailed analysis of causes and consequences in a spatially explicit manner, at the landscape scale. We will focus here on the modelling projects since they operate at more policy relevant scales than the field programmes, though they are—of course—informed by data and knowledge from the field. A series of models have been developed at scales from the hillslope to the continent. The MEDALUS I project developed and applied models for soil erosion at the hillslope scale (Thornes et al. 1996), MEDALUS II combined these soil erosion models with models for vegetation growth and development as well as soil hydrology and MEDALUS III culminated in the development of the MEDRUSH model for forecasting hydrology, soil erosion and sediment yield in catchments of up to 2000 km<sup>2</sup> in a spatially explicit fashion using the GRASS GIS (Kirkby et al. 2002). The MODMED project (1995–1999, Mazzoleni and Legg 1998) built predictive models for understanding natural vegetation dynamics and their response to changes in grazing and burning pressure resulting from developments in agricultural policy. The MODULUS project (1998–1999) led by the Research Institute for Knowledge Systems (RIKS) took models

371 and datasets developed in a range of previous EC projects (in particular EFEDA  
372 1988–1991 (Bolle 1995), MEDALUS and MODMED 1995–1999) and combined  
373 them in an integrated model for climate, hydrology, plant growth and vegetation  
374 development, soil erosion and socio-economic processes as an operational decision  
375 support system (DSS) aimed at regional policy-makers and applied in the Marina  
376 Baixa, SE Spain and the Argolid of Greece (Oxley et al. 2004). The hydrology, crop  
377 growth, climate and erosion models were based on the PATTERN model (Mulligan  
378 1996, 1998) which was developed alongside the EFEDA project.

379 MODULUS was a technical experiment in that it took existing models that had  
380 been developed in previous projects, left them in their native code and wrapped  
381 them with a software ‘layer’ to permit their integration as a single model capable of  
382 running simulations for scenarios of land use and climate change and provided  
383 results as graphics and maps. The project showed that models developed for  
384 scientific purposes could be integrated together to tackle policy-relevant questions  
385 and then supported by a sophisticated but user-friendly interface and thus approach  
386 the requirements for policy application. MedAction (2001–2004) further developed  
387 the MODULUS DSS into a Policy Support System (PSS) capable of advising  
388 policy. This required the engagement of end users at the start of the project, the  
389 definition of clear policy goals with them and the re-engineering of models from  
390 the bottom up for careful integration into an integrated model. The PSS was applied  
391 to land use and water management issues in the Guadalentin basin (SE, Spain)  
392 (van Delden et al. 2007). In the DESURVEY project (2005–2010), the  
393 MedAction PSS was further developed for application across Europe and North  
394 Africa as the DESURVEY surveillance system. It was enhanced through the  
395 incorporation of multi-scale modelling with a simpler model, based on PESERA  
396 (Kirkby et al. 2003) being applied for application at the pan-European scale (1 km  
397 resolution) and a more complex and data demanding model based on PATTERN  
398 (Mulligan 1998)—as implemented in MedAction—used for application for local  
399 scale analyses (at 1 hectare resolution). New process descriptions, policy options  
400 and datasets necessary for application to North Africa were also developed  
401 alongside much more extensive training and application throughout Europe.

402 Throughout this period of model building, the models have become more and  
403 more sophisticated both in terms of the processes represented, the degree of feed-  
404 back between processes, the degree of integration and inclusion of biophysical and  
405 socio-economic processes, and the degree of spatial detail and spatial heterogeneity  
406 incorporated. This evolution reflects our improved understanding of the complex-  
407 ities of processes that are grouped together under the umbrella of desertification.  
408 Later projects built upon these efforts to interface and adapt models for use in  
409 advising policy—driven by increasing pressure from the EC to connect its science  
410 with its policy agendas, though there is little evidence that such tools are used in  
411 supporting policy at the EC.

## 15.5 Revisiting Mediterranean “Desertification”

With 20 years of hindsight we now revisit the science on Mediterranean desertification with a view to understanding better the current thinking around this issue.

### 15.5.1 *Where Actually Desertified?*

According to the literature, land degradation is said to affect 80 % of the arid and dry areas of the Mediterranean, especially pasturelands and rain-fed croplands, but even irrigated land is considered under threat (Thivet 2007). Degradation is variously attributed to overgrazing, poor soil management, poor drainage on irrigated land, and the over-abstraction of woodland for fuel wood. This has been linked to population migration in the past, for example the Thessaly Plain was grazed for centuries by transhumance flocks and herds but after significant immigration in the early 1920s these areas were converted for wheat cultivation (Kosmas et al. 1999). For sure groundwater resources in the region have declined significantly, largely reflecting increasing agricultural abstraction (Iglesias et al. 2007).

Yet, agricultural production has continued to increase in the European Mediterranean (Leetmaa et al. 2004; Montgomery 2009) at the same time that much land has been returned to nature. Moreover, the rainfall-use-efficiency corrected negative NDVI (normalised difference vegetation index) analysis of Bai et al. (2008) indicate negative trends in vegetation cover (possibly reflecting degradation) over only 1 % of the study region, largely in the intensive agricultural areas of SW Spain, NE Italy and Montenegro—which are likely the result of major land use changes rather than actual land degradation. Coastal parts of North Africa and of the eastern Mediterranean are also considered to be degrading (García-Ruiz et al. 2011). Therefore developments so far in agricultural practices and technology seem to be keeping pace with any degradation so that ‘desertification’ appears not to be having large-scale societal impacts in the region. Increasingly fewer families depend on agricultural livelihoods, especially in the EU; agriculture is generally larger scale and more ‘commercialised’; and much of the population lives and works in an urban setting. The land degradation picture is thus more heterogeneous and complex than the large scale ‘desertification’ of the region that was anticipated in the 1990s.

### 15.5.2 *What Did We Really Mean by Mediterranean “Desertification”?*

Desertification is a term used to cover a ‘multitude of evils’ and can fairly well incorporate any socio-economic or biophysically-driven problem in a dryland

447 context from the multiple impacts of climate change, through land degradation,  
448 through application of over-intensive methods to overgrazing, water resource stress  
449 and other issues associated with poor management of common pool resources. So  
450 what did (do) we really mean by Mediterranean desertification? We can identify  
451 three different lenses that have been used.

#### 452 **15.5.2.1 The Land Degradation Lens (Pressure-Response)**

453 In the land degradation phase, desertification is considered to be the response of the  
454 landscape to the application of pressure (drought, overcropping, overgrazing,  
455 over-extraction of groundwater). As the pressure increases, the environment reacts  
456 to create a problem (agricultural drought, soil exhaustion and erosion, grazing-land  
457 degradation, salinisation of groundwater), see for example Catalinas and Cantón  
458 2012). The system is seen as a pressure response system and the kinds of  
459 pressure-response tools (models) used suggested continued progressive degradation  
460 into the future (see Mulligan 2009a, b, c). Each element of the system is considered  
461 independently as an independent pressure response system and research is usually  
462 focused on one set of processes e.g. soil erosion, ignoring the links between dif-  
463 ferent pressure-response systems. The focus is on land degradation as the outcome  
464 (to be avoided) rather than as we might see it today: as a driver itself that will act to  
465 reduce economic and agricultural pressure in a negative feedback cycle (where  
466 alternatives to agricultural livelihoods exist).

#### 467 **15.5.2.2 The Sustainability Lens (Pressure-Response-Feedback)**

468 With this approach the focus is on understanding the limits of environmental  
469 systems and the likely impacts once these limits are reached. This approach  
470 examines desertification in a more integrated manner looking into a range of pro-  
471 cesses and systems and focusing on the changes to socio-economic systems that  
472 would be required to achieve sustainability. The focus is thus on sustainability as  
473 the outcome (to be achieved), see Laraus (2004), Perry (2006) and Turner et al.  
474 (2007).

#### 475 **15.5.2.3 The Ecosystem Services (ES) Phase (Tipping Points 476 and Complexity)**

477 With this approach the focus is on maintaining the ES that are critical to local  
478 populations. This involves understanding how and where ES are delivered, the role  
479 of natural environments and of agriculture in delivery, and who benefits from them.  
480 The science concentrates on highlighting the pressures on ecosystems that are likely  
481 to result in degradation of the ecosystem functions that provide these ES and seeks  
482 to maintain these pressures at levels below those tipping points that would lead to

483 significant impact on humanity. Maintenance of ecosystem service provision whilst  
484 maintaining and increasing agricultural production is the outcome sought (see for  
485 example Schröter et al. 2005; Benayas et al. 2007; Bugalho et al. 2011; Willaarts  
486 et al. 2012).

## 487 **15.6 The Importance of Policy, Place, Space** 488 **and Variability in Assessing and Managing** 489 **Desertification**

490 As Figs. 15.1, 15.2, 15.3, 15.4, 15.5, 15.6, 15.7, 15.8, 15.9 and 15.10 highlight, the  
491 European Mediterranean shows significant spatial variability in the biophysical and  
492 socio-economic factors that might influence land degradation. This variability  
493 combines with the policy context to determine the impact of policies on desertifi-  
494 cation. Farming policy in Mediterranean Europe is dominated by the CAP. Current  
495 trends in the CAP could lead to further abandonment of production in zones of high  
496 nature conservation value (Caraveli 2000) and this may lead to reduced land  
497 degradation (Ruecker et al. 1998) or increased land degradation especially on steep  
498 slopes (e.g. Koulouri and Giourga 2007) in the areas abandoned. Mediterranean  
499 water policy is largely focused on drought management. According to Iglesias et al.  
500 (2007) water management in the region works best when carried out at the basin  
501 scale and when institutional responsibilities are clear but they argue that all  
502 countries in the region show weak inter-institutional cooperation and gaps the roles  
503 of the state, the region and the river basin authorities. This situation impairs the  
504 implementation of legislation. The European Water Framework Directive  
505 (2000/60/EC) does attempt to develop legislation and institutions for water man-  
506 agement and planning at the basin level. However, key issues in implementation of  
507 the WFD include the difficulties of transboundary cooperation (across regions as  
508 well as countries) and lack of provision for water quality management during  
509 drought conditions (Iglesias et al. 2007). Indeed monitoring, early warning and  
510 management of drought, including the provision of contingency sources needs  
511 much further development throughout the Mediterranean region. Legislation around  
512 the management of groundwater pumping for irrigation also requires a much more  
513 adaptive and locally nuanced approach that takes better account of varying climatic  
514 and hydro-geological conditions over time and space.

515 According to WDPA (2013) some 18 % of the area studied here is at least  
516 nominally protected with 0.06 % of this with RAMSAR designation as wetlands of  
517 international importance. Protected areas cover 13.75 % of the rainfall of the region  
518 calculated with WorldClim data (Hijmans et al. 2005) and 17.25 % of the water  
519 bodies calculated with SRTM SWBD (lakes, rivers, USGS 2006) data. To the  
520 extent that protected area designation is effective at reducing pressure on the  
521 ground, these represent an important mechanism to manage land degradation.

522 South of the Mediterranean Sea, a large divide exists between national deserti-  
523 fication policy objectives and their local implementation, notably as a result of  
524 institutional complexity and inadequacies. Institutions suffer from weak resources  
525 and capacities, as well as the legal pluralism generated by the overlap of traditional,  
526 state and project-led institutions which can undermine the effective regulation of  
527 practices (Briassoulis 2004). Though the success of these policies hinge largely on  
528 changing end user practices, consultation of these stakeholders in the design and  
529 implementation of policies remains low, leading to weak participation and concern  
530 for desertification issues. Degradation of resources (overgrazing, over-abstraction  
531 etc.) often ensues with officials and traditional authorities turning a blind eye to  
532 support smallholder's agricultural practices in the absence of alternative livelihoods  
533 (Le Goulven et al. 2009).

534 Past policies also suffered from ministries addressing complex socio-  
535 environmental problems from an isolated, single perspective, leading to unex-  
536 pected results such as reducing aquifer recharge as a result of local irrigation  
537 efficiency improvements (Molle 2009). Concepts such as green, blue and virtual  
538 water accounting (Allan 1998) or payment for ecosystem services have started to  
539 filter into policies (Besbes et al. 2010) and further holistic methods are required for  
540 researchers and stakeholders to understand the mutual interactions between  
541 hydrological and agricultural processes as well as wider socio-economic influences  
542 (subsidies, land tenure, water pricing, etc.) on land degradation. Data scarcity (both  
543 absolute and as a result of deficient data sharing) on the spatial and temporal gravity  
544 of desertification also currently impedes the targeting of resources towards local,  
545 site specific strategies.

## 546 **15.7 Conclusions: If the Problem Is Complex, the Solution** 547 **Is Complex**

548 Change in agricultural policy is often not tested for long-term sustainability in the  
549 face of soil degradation and long-term climate variability and this has the potential  
550 to lead to severe degradation that may render short term economic gains as long  
551 term losses. To be of real benefit, land use strategies and incentives for the  
552 Mediterranean must be sustainable and profitable in the long term and land man-  
553 agement options must also be effective for the long-term. The impacts of both land  
554 use and land management strategies must also be understood for the range of  
555 socio-economic and biophysical conditions that exist in the region of influence of  
556 the proposed policy, since response will not be uniform across variable landscapes  
557 and those applying policy should not assume it will. The legislative and institutional  
558 framework must recognise this need for spatio-temporal sophistication to build  
559 robust and sustainable agriculture.

Policies that need to be tested in this way include:

- (a) investment or incentivisation of particular crop choices or land management techniques including irrigation, terracing, contour ploughing, ploughing and slope reforming,
- (b) infrastructural investments such as dams, water transfers, desalinisation facilities,
- (c) conservation and protection schemes such as designation of protected areas, deforestation, buffer strips, check dams.

All of these have complex interactions with biophysical processes and thus stores and fluxes of water, sediment, soil and plant productivity and on human behaviour such as crop choice and land management.

It is clear that the desertification narrative of the 1990s was not representative of the spatial complexity and subtlety of land degradation processes in the Mediterranean (see Geeson et al. 2003; Mulligan et al. 2004) and the spatial heterogeneity that is clear in Figs. 15.1, 15.2, 15.3, 15.4, 15.5, 15.6, 15.7, 15.8, 15.9 and 15.10 here. The significant declines in rainfall throughout the region in this decade provoked concerns about large-scale desertification that then never materialised. Even under current intensive agriculture, much of the rainfall in the region still evaporates through natural vegetation rather than agriculture and there is little evidence (for example in agricultural or economic output) of large scale degradation in the region. In fact the abandonment of agricultural land is generally reducing soil and water degradation (Ruecker et al. 1998), except in areas of very steep slopes where terraces are now breaking down (Koulouri and Giourga 2007) but will revegetate and recover in time. Over spatially and temporally explicit landscapes the kinds of large scale desertification mapping efforts of the 1990s (e.g. UNEP 1997) do not capture this spatial heterogeneity at all. An effective way to manage such complexities and test policies in silico before they are applied in vivo is through the application of data and process-based, spatially detailed modelling of the type used here but also to ensure that such modelling is accessible in a policy-support context (cf. Mulligan 2009a, b, c) and is well supported by extensive field and remote sensing datasets.

## References

- Allan, J. A. (1998). Virtual water: A strategic resource. *Ground Water*, 36(4), 545–546.
- Bai, Z. G., Dent, D. L., Olsson, L., & Schaepman, M. E. (2008). *Global assessment of land degradation and improvement 1. Identification by remote sensing*. GLADA Report 5. Version 5.
- Benayas, J. R., Martins, A., Nicolau, J. M., & Schulz, J. J. (2007). Abandonment of agricultural land: An overview of drivers and consequences. *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources*, 2(57), 1–14.
- Besbes, M., Chahed, J., Hamdane, A., & de Marsily, G. (2010). Changing water resources and food supply in arid zones: Tunisia. *Water and Sustainability in Arid Regions* (pp. 103–121). Netherlands: Springer.

- 601 Bolle, H. J. (1995). Identification and observation of desertification processes with the aid of  
602 measurements from space: Results from the European Field Experiment in  
603 Desertification-threatened Areas (EFEDA). *Environmental Monitoring and Assessment*, 37  
604 (1–3), 93–101.
- 605 Brandt, C. J., & Thornes, J. B. (1996). *Mediterranean desertification and land use*. Hoboken:  
606 Wiley.
- 607 Briassoulis, H. (2004). The institutional complexity of environmental policy and planning  
608 problems: The example of Mediterranean desertification. *Journal of Environmental Planning  
609 and Management*, 47(1), 115–135.
- 610 Bugalho, M. N., Caldeira, M. C., Pereira, J. S., Aronson, J., & Pausas, J. G. (2011). Mediterranean  
611 cork oak savannas require human use to sustain biodiversity and ecosystem services. *Frontiers  
612 in Ecology and the Environment*, 9(5), 278–286.
- 613 Caraveli, H. (2000). A comparative analysis on intensification and extensification in  
614 Mediterranean agriculture: Dilemmas for LFAs policy. *Journal of Rural Studies*, 16(2),  
615 231–242.
- 616 Catalinas, M. A. R. T. A., & Cantón, Á. G. (2012). Relationships between anthropogenic pressures  
617 and ecological status in a Mediterranean river basin district in Spain. In *9th International  
618 Symposium on Ecohydraulics 2012 Proceedings*. ISBN: 978-3-200-02862-3.
- 619 Center for International Earth Science Information Network (CIESIN). (2002). *Country-level  
620 Population and Downscaled Projections based on the B2 Scenario 1990–2100 [digital  
621 version]*. Palisades NY: CIESIN Columbia University. Available online at [http://www.ciesin.  
622 columbia.edu/datasets/downscaled](http://www.ciesin.columbia.edu/datasets/downscaled)
- 623 Conacher, A. J., & Conacher, J. (1998). Introduction. In A. J. Conacher & M. Sala (Eds.), *Land  
624 degradation in Mediterranean environments of the World*. Chichester, UK: Wiley.
- 625 Cooper, T., & Arblaster, K (2007). *Climate change and the rural environment in a European  
626 context: Implications for land use and land use policy*. Background Paper for the LUPG/BfN  
627 Conference on ‘Future Policies for Rural Europe. 2013 and Beyond’, held in Brussels, 19–20  
628 September 2007. Available online at [http://www.ieep.eu/publications/publications.php?pub=  
629 68412](http://www.ieep.eu/publications/publications.php?pub=68412)
- 630 de Luis, M., González-Hidalgo, J. C., Longares, L. A., & Štěpánek, P. (2009). Seasonal  
631 precipitation trends in the Mediterranean Iberian Peninsula in second half of 20th century.  
632 *International Journal of Climatology*, 29(9), 1312–1323.
- 633 Déqué, M., Rowell, D. P., Lüthi, D., Giorgi, F., Christensen, J. H., Rockel, B., et al. (2007). An  
634 intercomparison of regional climate simulations for Europe: Assessing uncertainties in model  
635 projections. *Climatic Change*, 81(1), 53–70.
- 636 Diffenbaugh, N. S., & Giorgi, F. (2012). Climate change hotspots in the CMIP5 global climate  
637 model ensemble. *Climatic Change*, 114(3–4), 813–822.
- 638 Florke, Weib M., Menzel, L., & Alcamo, J. (2007). Model-based scenarios of Mediterranean  
639 droughts. *Advances in Geosciences*, 12, 145–151.
- 640 García-Ruiz, J. M., López-Moreno, J. I., Vicente-Serrano, S. M., Lasanta-Martínez, T., &  
641 Beguería, S. (2011). Mediterranean water resources in a global change scenario. *Earth-Science  
642 Reviews*, 105(3–4), 121–139.
- 643 Gay, S. H., Osterburg, B., Baldock, D., & Zdanowicz, A. (2005). *Recent evolution of the EU  
644 Common Agricultural Policy (CAP): State of play and environmental potential*. Report from  
645 MEACAP project n°SSPE-CT-2004-503604, Document number: MEACAP WP6 D4b,  
646 Institute of European Environmental Policy. Available online at: [http://www.ieep.eu/  
647 publications/pdfs/meacap/WP6/WP6D4B\\_CAP.pdf](http://www.ieep.eu/publications/pdfs/meacap/WP6/WP6D4B_CAP.pdf)
- 648 Geeson, N. A., Brandt, C. J., & Thornes, J. B. (Eds.). (2003). *Mediterranean desertification:  
649 A mosaic of processes and responses*. Hoboken: Wiley.
- 650 Giorgi, F. (2006). Climate change hot-spots. *Geophysical Research Letters*, 33(8).
- 651 Giorgi, F., & Lionello, P. (2008). Climate change projections for the Mediterranean region. *Global  
652 and Planetary Change*, 63(2), 90–104.



- 653 Hijmans, R. J., Cameron, S. E., Parra, J. L., Jones, P. G., & Jarvis, A. (2005). Very high resolution  
654 interpolated climate surfaces for global land areas. *International Journal of Climatology*, 25,  
655 1965–1978.
- 656 Hoerling, M., Eischeid, J., Perlwitz, J., Quan, X., Zhang, T., & Pegion, P. (2012). On the increased  
657 frequency of Mediterranean drought. *Journal of Climate*, 25(6), 2146–2161.
- 658 Iglesias, A., Garrote, L., Flores, F., & Moneo, M. (2007). Challenges to manage the risk of water  
659 scarcity and climate change in the Mediterranean. *Water Resources Management*, 21(5),  
660 775–788.
- 661 Kirkby, M. J., Abrahart, R. J., Bathurst, J. C., Kilsby, C. G., McMahon, M. L., Osborne, C. P.,  
662 et al. (2002). MEDRUSH: A basin-scale, physically based model for forecasting runoff and  
663 sediment yield. In N. A. Geeson, C. J. Brandt, & J. B. Thornes (Eds.), *Mediterranean  
664 Desertification: A mosaic of processes and responses* (pp. 203–229). Chichester: Wiley.
- 665 Kirkby, M. J., Jones, R. J. A., Irvine, B., Gobin, A., Govers, G., Cerdan, O., .... & Van Lynden, G.  
666 (2003). *Pan-European Soil Erosion Risk Assessment: The PESERA Map*, Version 1 October  
667 (2003). Explanation of Special Publication Ispra 2004 No.73 (S.P.I.04.73). European Soil  
668 Bureau Research Report No. 16, EUR 21176, 18 pp. Office for Official Publications of the  
669 European Communities, Luxembourg.
- 670 Kosmas, C., Kirkby, M. J., & Geeson N. (1999). *Manual on key indicators of desertification and  
671 mapping environmentally sensitive areas to desertification*. European Commission  
672 Publication EUR 18882, 87 pp
- 673 Koulouri, M., & Giourga, C. (2007). Land abandonment and slope gradient as key factors of soil  
674 erosion in Mediterranean terraced lands. *Catena*, 69(3), 274–281.
- 675 LandScan™ Global Population Database. (2007). Oak Ridge, TN: Oak Ridge National  
676 Laboratory. Available online at <http://www.ornl.gov/landscan/>
- 677 Larau, J. (2004). The problems of sustainable water use in the Mediterranean and research  
678 requirements for agriculture. *Annals of Applied Biology*, 144(3), 259–272.
- 679 Le Goulven, P., Leduc, C., Bacht, M. S., & Poussin, J.-C., (2009). Sharing scarce resources in  
680 Mediterranean river basin: Wadi Merguellil in Central Tunisia. In F. Molle & F. Wester (Eds.),  
681 *River Basin Trajectories: Societies, environments and development* (pp. 147–170). CAB  
682 International.
- 683 Leetmaa, S. E., Arnade, C., & Kelch, D. (2004). *A comparison of US and EU agricultural  
684 productivity with implications for EU enlargement*. Leetmaa: US-EU Food and Agriculture  
685 Comparisons. Mary Anne Normile and Susan E. 33.
- 686 Lionello, P., Malanotte-Rizzoli, P., & Boscolo, R. (Eds.). (2006). *Mediterranean climate  
687 variability*. Amsterdam: Elsevier.
- 688 Lionello, P., Platon, S., & Rodo, X. (2008). Trends and climate change in the Mediterranean  
689 region. *Global and Planetary Change*, 63, 87–89.
- 690 Mariotti, A., (2010). Recent changes in Mediterranean water cycle: A pathway toward long-term  
691 regional hydroclimatic change? *Journal of Climate*, 23(6), 1513–1525.
- 692 Mazzoleni, S., & Legg, C. (1998). Modmed: Modelling vegetation dynamics and degradation in  
693 Mediterranean ecosystems. In P. Mairota, J. B. Thornes, & N. Geeson (Eds.), *Atlas of  
694 Mediterranean environments in Europe—the desertification context* (pp. 14–18). Chichester:  
695 Wiley.
- 696 Molle, F. (2009). Water scarcity, prices and quotas: A review of evidence on irrigation volumetric  
697 pricing. *Irrigation and Drainage Systems*, 23(1), 43–58.
- 698 Montgomery, R. (2009). *Crop production in the Mediterranean Partner Countries continues to  
699 increase*. Statistics in Focus, Eurostat, Office for Official Publications of the European  
700 Communities. Available online at [http://www.pcbs.gov.ps/Portals/\\_PCBS/Documents/KS-SF-  
701 09-012-EN.pdf](http://www.pcbs.gov.ps/Portals/_PCBS/Documents/KS-SF-09-012-EN.pdf)
- 702 Mu, Q., Zhao, M., & Running, S. W. (2011). Improvements to a MODIS global terrestrial  
703 evapotranspiration algorithm. *Remote Sensing of Environment*, 115, 1781–1800. doi:10.1016/j.  
704 rse.2011.02.019.
- 705 Mulligan, M. (1996). *Modelling the hydrology of vegetation change in a degraded semi-arid  
706 environment*. Unpublished Ph.D. Thesis, King’s College London, University of London.

- 707 Mulligan, M. (1998). Modelling the geomorphological impact of climatic variability and extreme  
708 events in a semi-arid environment. *Geomorphology*, 24(1), 59–89.
- 709 Mulligan, M. (2009a). *Vegetation continuous fields by land cover class based on GLOBCOVER*.  
710 Available online at <http://www.ambiotech.com/vcfclasses>. Source Data: © ESA/ESA Globcover  
711 Project, led by MEDIAS-France/Postel
- 712 Mulligan, M. (2009b). *Global mean dry matter productivity based on SPOT-VGT (1998–2008)*.  
713 <http://www.ambiotech.com/dmp>
- 714 Mulligan, M. (2009c). Integrated environmental modelling to characterise processes of land  
715 degradation and desertification for policy support. In J. Hill & A. Roeder (Eds.), *Remote*  
716 *sensing and geo information processing in the assessment and monitoring of land degradation*  
717 *and desertification*. UK: Taylor and Francis.
- 718 Mulligan, M., Burke, S. M., & Ramos, M. C. (2004). Climate change, land use change and the  
719 ‘desertification’ of Mediterranean Europe. In S. Mazzoleni, G. di Pasquale, M. Mulligan, P. di  
720 Martino, & F. Rego (Eds.), *Recent dynamics of the Mediterranean vegetation and landscape*  
721 (pp. 259–279). Chichester: Wiley.
- 722 Mulligan, M., Saenz, L., & van Soesbergen, A. (2011). Development and validation of a  
723 georeferenced global database of dams. Available online: <http://www.ambiotech.com/dams>
- 724 Oxley, T., Winder, N., McIntosh, B. S., Mulligan, M., & Engelen, G. (2004). Integrated catchment  
725 modelling & decision support tools: A Mediterranean example. *Environmental Modelling and*  
726 *Software*, 19(11), 999–1010.
- 727 Patterson, L. A., & Josling, T. E. (2005). *Mediterranean agriculture in the global marketplace:*  
728 *A project comparing policy approaches in California and the Southern EU States*. Report on  
729 Stage 1. European Forum Institute for International Studies, Stanford University. Available  
730 online at [http://aic.ucdavis.edu/research1/patt\\_jos\\_med\\_ag\\_glob\\_mkt.pdf](http://aic.ucdavis.edu/research1/patt_jos_med_ag_glob_mkt.pdf)
- 731 Peleg, N., Bartov, M., & Morin, E. (2014). CMIP5 predicted climate shifts over the East  
732 Mediterranean: Implications for the transition region between Mediterranean and semi arid  
733 climates. *International Journal of Climatology*. Early View.
- 734 Perry, A. (2006). Will predicted climate change compromise the sustainability of Mediterranean  
735 tourism? *Journal of Sustainable Tourism*, 14(4), 367–375.
- 736 Petit, M. (2007) *Interactions between the Euro/Med liberalization process: World markets and*  
737 *International negotiations*. Deliverable D25 of Impacts of agricultural trade liberalization  
738 between the EU and Mediterranean countries (EU-MED AGPOL), Project no.  
739 SSPE-CT-2004-502457. Available online at: [http://eumed-agpol.iamm.fr/html/publications/](http://eumed-agpol.iamm.fr/html/publications/prj_report/d25.pdf)  
740 [prj\\_report/d25.pdf](http://eumed-agpol.iamm.fr/html/publications/prj_report/d25.pdf)
- 741 Puigdefàbregas, J., & Mendizabal, T. (1998). Perspectives on desertification: Western  
742 Mediterranean. *Journal of Arid Environments*, 39(2), 209–224.
- 743 Ramankutty, N., et al. (2008). Farming the planet: 1. Geographic distribution of global agricultural  
744 lands in the year 2000. *Global Biogeochemical Cycles*, 22, GB1003. doi:10.1029/  
745 2007GB002952.
- 746 Ramos, M. C., & Mulligan, M. (2005). Spatial modelling of the impact of climate variability on  
747 the annual soil moisture regime in a mechanized Mediterranean vineyard. *Journal of*  
748 *Hydrology*, 306(1–4), 287–301.
- 749 Riedel. (2007) Dairy goat grazing systems in Mediterranean regions: A comparative analysis in  
750 Spain, France and Italy. *Small Ruminant Research*, 85(1), 42–49.
- 751 Robinson, T. P., Wint, G. W., Conchedda, G., Van Boeckel, T. P., Ercoli, V., Palamara, E., ... &  
752 Gilbert, M. (2013). Mapping the global distribution of livestock. *PLoS ONE*, 9(5).
- 753 Roeder, A., Udelhoven, Th, Hill, J., et al. (2008). Trend analysis of Landsat-TM and -ETM+  
754 imagery to monitor grazing impact in a rangeland ecosystem in Northern Greece. *Remote*  
755 *Sensing of Environment*, 112(6), 2863–2875.
- 756 Rubió, J. L., & Recatalá, L. (2006). The relevance and consequences of Mediterranean  
757 desertification including security aspects. In *Desertification in the Mediterranean region.*  
758 *A security issue* (pp. 133–165). Netherlands: Springer.

- 759 Ruecker, G., Schad, P., Alcubilla, M. M., & Ferrer, C. (1998). Natural regeneration of degraded  
760 soils and site changes on abandoned agricultural terraces in Mediterranean Spain. *Land*  
761 *Degradation and Development*, 9(2), 179–188.
- 762 Ruiz, F. A., Mena, Y., Castel, J. M., Guinamard, C., Bossis, N., Caramelle-Holtz, E., et al. (2001).  
763 Typology of cereal-sheep farming systems in Castile-La Mancha (South-Central Spain). *Agr.*  
764 *Syst.*, 68, 215–232.
- 765 Safrieli, U. N. (2009a). Status of desertification in the mediterranean region. In J. L. Rubio, U.  
766 Safrieli, R. Daussa, W. Blum & F. Pedrazzini (Eds.), *Water scarcity, land degradation and*  
767 *desertification in the mediterranean region* (pp 33–73). Proceedings of the NATO Advanced  
768 Research Workshop on Water Scarcity, Land Degradation and Desertification in the  
769 Mediterranean Region DEC 10-11, 2007 Valencia, SPAIN. Book Series: Nato Science for  
770 Peace and Security Series C—Environmental Security.
- 771 Safrieli, U. N. (2009b). Status of desertification in the Mediterranean region. In *Water scarcity,*  
772 *land degradation and desertification in the mediterranean region* (pp. 33–73). Netherlands:  
773 Springer.
- 774 Schar, C., Vidale, P. L., Lüthi, D., Frei, C., Häberli, C., Liniger, M. A., & Appenzeller, C. (2004).  
775 The role of increasing temperature variability in European summer heatwaves. *Nature*, 427,  
776 332–336.
- 777 Schröter, D., Cramer, W., Rik Leemans, I., Prentice, C., Araújo, M. B., Arnell, N. W., et al.  
778 (2005). Ecosystem service supply and vulnerability to global change in Europe. *Science*, 310  
779 (5752), 1333–1337.
- 780 Serra, P., Pons, X., & Sauri, D. (2008). Land-cover and land-use change in a Mediterranean  
781 landscape: A spatial analysis of driving forces integrating biophysical and human factors.  
782 *Applied Geography*, 28(3), 189–209.
- 783 Shucksmith, M., Thomson, K. J., & Roberts, D. (Eds.). (2005). *The CAP and the regions: The*  
784 *territorial impact of the common agricultural policy*. CABI.
- 785 Siebert, S., Burke, J., Faures, J. M., Frenken, K., Hoogeveen, J., Döll, P., & Portmann, F. T.  
786 (2010). Groundwater use for irrigation—a global inventory. *Hydrology and Earth System*  
787 *Sciences Discussions*, 7(3), 3977–4021.
- 788 Siebert, S., & Döll, P. (2010). Quantifying blue and green virtual water contents in global crop  
789 production as well as potential production losses without irrigation. *Journal of Hydrology*, 384  
790 (3), 198–217.
- 791 Siebert, S., Döll, P., Feick, S., Frenken, K., & Hoogeveen, J. (2007). *Global map of irrigation*  
792 *areas version 4.0.1*. Germany, and FAO, Rome, Italy: University of Frankfurt (Main).
- 793 Somot, S., Sevault, F., Déqué, M., & Crépon, M. (2008). 21st century climate change scenario for  
794 the Mediterranean using a coupled atmosphere-ocean regional climate model. *Global and*  
795 *Planetary Change*, 63, 112–126.
- 796 Thivet, G. (2007). *Towards rural revival in the Mediterranean*. Blue Plan Notes No. 5. United  
797 Nations Environment Programme—Mediterranean Action Plan, Plan Bleu.
- 798 Thornes, J. B., Shao, J. X., Diaz, E., Roldan, A., Hawkes, C., & McMahon, M. (1996). Testing the  
799 MEDALUS hillslope model. *Catena*, 26, 137–160.
- 800 Turner, B. L., Lambin, E. F., & Reenberg, A. (2007). The emergence of land change science for  
801 global environmental change and sustainability. *Proceedings of the National Academy of*  
802 *Sciences*, 104(52), 20666–20671.
- 803 UNEP (United Nations Environment Programme). (1997). *World atlas of desertification* (2nd ed.).  
804 London: UNEP.
- 805 USGS. (2006). *Shuttle radar topography mission water body dataset*. Available online at: [http://](http://edc.usgs.gov/products/elevation/swbd.html)  
806 [edc.usgs.gov/products/elevation/swbd.html](http://edc.usgs.gov/products/elevation/swbd.html)
- 807 van Delden, H., Luja, P., & Engelen, G. (2007). Integration of multi-scale dynamic spatial models  
808 of socio-economic and physical processes for river basin management. *Environmental*  
809 *Modelling and Software*, 22(2), 223–238.
- 810 van Meijl, H., Van Rheenen, T., Tabeau, A., & Eickhout, B. (2006). The impact of different policy  
811 environments on agricultural land use in Europe. *Agriculture, Ecosystems & Environment*, 114  
812 (1), 21–38.

- 813 van Wesemael, B., Rambaud, Xavier, Poesen, Jean, Mulligan, Mark, Cammeraat, Erik, & Stevens,  
 814 Antoine. (2005). Spatial patterns of land degradation and their impacts on the water balance of  
 815 rainfed tree crops: A case study in South East Spain. *Geoderma*, 133, 43–56.
- 816 Verburg, P. H., Eickhout, B., & van Meijl, H. (2008). A multi-scale, multi-model approach for  
 817 analyzing the future dynamics of European land use. *The Annals of Regional Science*, 42(1),  
 818 57–77.
- 819 Walsh, P. D., & Lawler, D. M. (1981). Rainfall seasonality: Description, spatial patterns and  
 820 change through time. *Weather*, 36, 201–208.
- 821 Willaarts, B. A., Volk, M., & Aguilera, P. A. (2012). Assessing the ecosystem services supplied by  
 822 freshwater flows in Mediterranean agroecosystems. *Agricultural Water Management*, 105,  
 823 21–31.
- 824 World Database on Protected Areas. (WDPA). Annual Release. (2013). (web download version),  
 825 November 2013. Available online at: <http://www.protectedplanet.net>

# Author Query Form

Book ID : **213902\_1\_En**  
 Chapter No.: **15**



Please ensure you fill out your response to the queries raised below and return this form along with your corrections

Dear Author

During the process of typesetting your chapter, the following queries have arisen. Please check your typeset proof carefully against the queries listed below and mark the necessary changes either directly on the proof/online grid or in the ‘Author’s response’ area provided below

Query Refs.	Details Required	Author’s Response
AQ1	References Muller (2004), Plan Bleu (2009), Weib et al. (2007), Wint and Robinson (2007), CIESIN (2004) and UNEP (1997) are cited in the text but not provided in the reference list. Please provide the respective references in the list or delete these citations.	
AQ2	Kindly note that the cross citation of references Safriel (2009) and Mulligan (2009) have been changed to Safriel (2009a, b) and (Mulligan 2009a, b, c) respectively, so that this citation matches the list.	
AQ3	Reference Robinson et al. (2013) is given in the list but not cited in the text. Please cite in text or delete from the list.	

# MARKED PROOF

## Please correct and return this set

Please use the proof correction marks shown below for all alterations and corrections. If you wish to return your proof by fax you should ensure that all amendments are written clearly in dark ink and are made well within the page margins.

<i>Instruction to printer</i>	<i>Textual mark</i>	<i>Marginal mark</i>
Leave unchanged	... under matter to remain	Ⓟ
Insert in text the matter indicated in the margin	∧	New matter followed by ∧ or ∧ <sup>Ⓢ</sup>
Delete	/ through single character, rule or underline or ┌───┐ through all characters to be deleted	Ⓞ or Ⓞ <sup>Ⓢ</sup>
Substitute character or substitute part of one or more word(s)	/ through letter or ┌───┐ through characters	new character / or new characters /
Change to italics	— under matter to be changed	↵
Change to capitals	≡ under matter to be changed	≡
Change to small capitals	≡ under matter to be changed	≡
Change to bold type	~ under matter to be changed	~
Change to bold italic	≈ under matter to be changed	≈
Change to lower case	Encircle matter to be changed	≡
Change italic to upright type	(As above)	⊕
Change bold to non-bold type	(As above)	⊖
Insert 'superior' character	/ through character or ∧ where required	Υ or Υ under character e.g. Υ or Υ
Insert 'inferior' character	(As above)	∧ over character e.g. ∧
Insert full stop	(As above)	⊙
Insert comma	(As above)	,
Insert single quotation marks	(As above)	ʹ or ʸ and/or ʹ or ʸ
Insert double quotation marks	(As above)	“ or ” and/or ” or ”
Insert hyphen	(As above)	⊞
Start new paragraph	┌	┌
No new paragraph	┐	┐
Transpose	┌┐	┌┐
Close up	linking ○ characters	⸸
Insert or substitute space between characters or words	/ through character or ∧ where required	⸣
Reduce space between characters or words		⸤