Government Office for Science

Foresight

Migration and Global Environmental Change

DR8a: Quantifying change in ecosystem services and exposure to hazards in the Mediterranean basin over the next 50 years that might be relevant to migration

Sophia M. Burke[1], Mark Mulligan[2], Katherine Parks[2] and Arnout van Soesbergen[2]

[1] AmbioTEK CIC

[2] King's College London, London, UK

October 2011

This review has been commissioned as part of the UK Government's Foresight Project, Migration and Global Environmental Change. The views expressed do not represent the policy of any Government or organisation.

Contents

Introduction

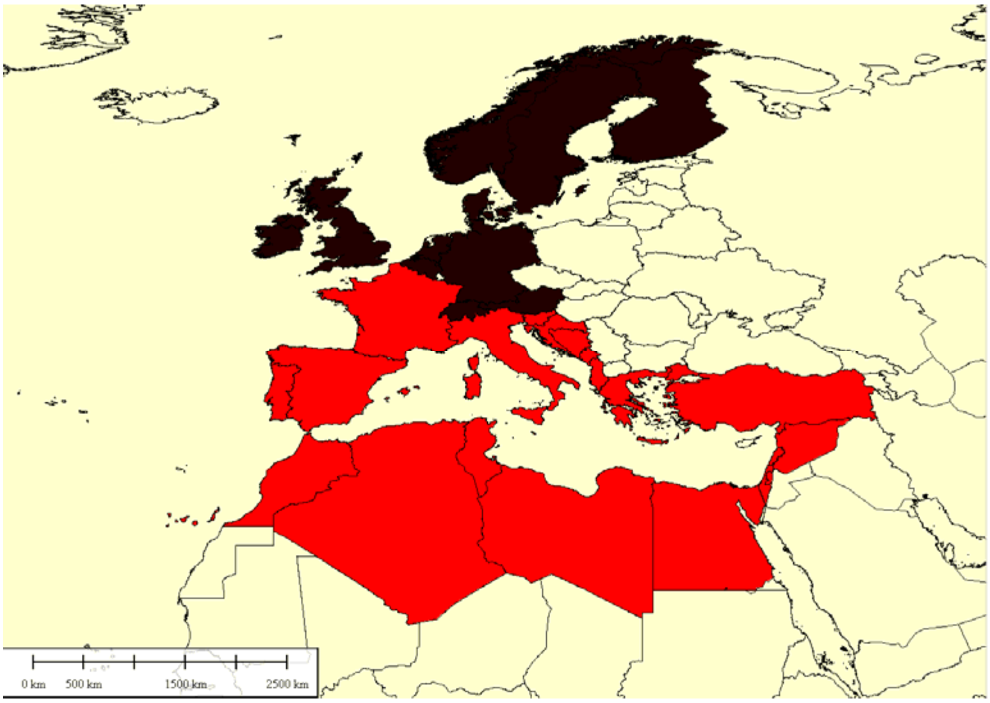
This report examines the environmental drivers of migration in the Mediterranean, with particular focus on the role of ecosystem services and the impact of environmental hazards as potential push and pull factors. Environmental drivers are just one set of potential drivers for migration described in the Foresight 'drivers of migration' pentagon alongside demographic, social, political and economic drivers. In the complex and diverse Mediterranean political, social and economic landscapes, environmental drivers rarely work in isolation of the other drivers, except in rare cases of migration forced by hazard. Nevertheless, environment plays a part and so we must consider how environmental drivers help to define the ecosystem services and disservices (such as hazards) that might combine with political, social and economic factors to provide push or pull conditions which then encourage migration. Moreover, the environment is rarely static and, given pressures on the global environment in general and the Mediterranean environment in particular, we need to analyse how ecosystem service provision and hazardscapes might change in the future and what the potential implications of such change might be for encouraging particular types of migration. The substantial role of non-environmental drivers (i.e. politics, social, cultural and economic factors) is covered by a separate report (DR8b).

Understanding the migration-relevant status and trends in biophysical drivers for the Mediterranean requires both a *quantitative* data-based analysis and a broad *review* of relevant published and grey literature in this area. We start with a quantitative analysis and review of the current status of environment, ecosystem services and hazards in the Mediterranean, and then review the published future climate change scenarios for the region. Finally, we assess the probable impact of these scenarios on ecosystem services and exposure to hazards in the Mediterranean and their potential implications for driving migration. We provide data-based geographic information systems (GIS) analysis and modelling across the Mediterranean in order to characterise the diversity of states and changes expected across the region rather than rely on extrapolating the outcomes of location-specific studies. We present the results as a series of maps rather than summarising the data by country. This is important because there are significant within-country variations in the drivers and context which might often lead to internal rather than international migration. Moreover, some of these drivers operate only in small areas of a national territory. Summary by country would focus the analysis on international differences only. We make efforts to include the uncertainty associated with the future scenarios and their impacts on the drivers of migration. We close with a set of broad conclusions based on both the data analysis and the literature review.

The geographical area of study includes the Mediterranean countries defined below as well as the potential migratory 'pull' countries of northern Europe since climate change will impact both push and pull areas and thus the interaction between them. The Mediterranean as defined here comprises the following Mediterranean Basin countries [each followed by its United Nations (UN) country code]: Morocco (169), Algeria (4), Libya (145), Tunisia (248), Egypt (40765), Israel (121), West Bank (267), Lebanon (141), Syria (238), Turkey (249), Greece (97), Albania (3), Montenegro (2647), Bosnia and Herzegovina (34), Croatia (62), Slovenia (224), Italy (122), France (85), Sardinia (122), Malta (156), Cyprus (97), Sicily (122), Spain (229) and Portugal (199); see Figure 1.

While environmental changes in these countries might act to increase the 'push' factors for migration out of them, we should understand that the pull factors for migration into specific countries are also subject to the impacts of environmental change. We thus also analyse changes in 'pull' factors as a result of environmental change by replicating our analysis in those countries that we consider as being potential European destination countries for migrants from the Mediterranean. We are considering the northern European 'pull' countries outside the Mediterranean as the UK (256), Ireland (119), Belgium (27), Netherlands (177), Germany (93), Switzerland (237), Austria (18), Denmark (69), Sweden (236), Norway (186) and Finland (84); see Figure 1.

Figure 1: Mediterranean and Northern European countries as defined for this analysis.



Current environmental status of the Mediterranean and northern Europe

We begin by analysing the current environmental status of these Mediterranean and northern European countries with a specific emphasis on differences both within and between countries. This analysis sets the context for environmental change and the potential biophysical drivers for migration.

Climate and recent climate variability

The climate of the Mediterranean region is characterised by hot, dry summers and cool, wet winters (Conacher and Conacher, 1998). It is a region of significant climate variability, both spatially and temporally, with extremes of drought and of torrential rainfall varying seasonally, inter-annually and in the long term. The observed climate variability in the Mediterranean is a function of the mixture of climate influences upon it (Lionello *et al*., 2006). The high mountain ridges surrounding the Mediterranean Sea and the complex coastal and island morphologies of the region produce distinct climatic features spatially, and the Mediterranean countries have strong latitudinal precipitation and temperature gradients. Precipitation decreases from north to south and from west to east and temperature increases along the same gradients (Figures 2 and 3). These strong gradients mean that regions of the Mediterranean are very sensitive to small shifts in climate. There are also significant montane and coastal effects on temperature and precipitation, with mountain and coastal areas generally being cooler and wetter. Precipitation for large southerly areas of the southern Mediterranean national territories is close to zero, rising steeply towards the southern Mediterranean coast and further increasing in the northern Mediterranean.

Figure 2: Mean annual precipitation (mm). Source: Hijmans *et al*. (2005). Areas shown in purple are zero and in white are greater than the legend maximum or outside of the region of interest.

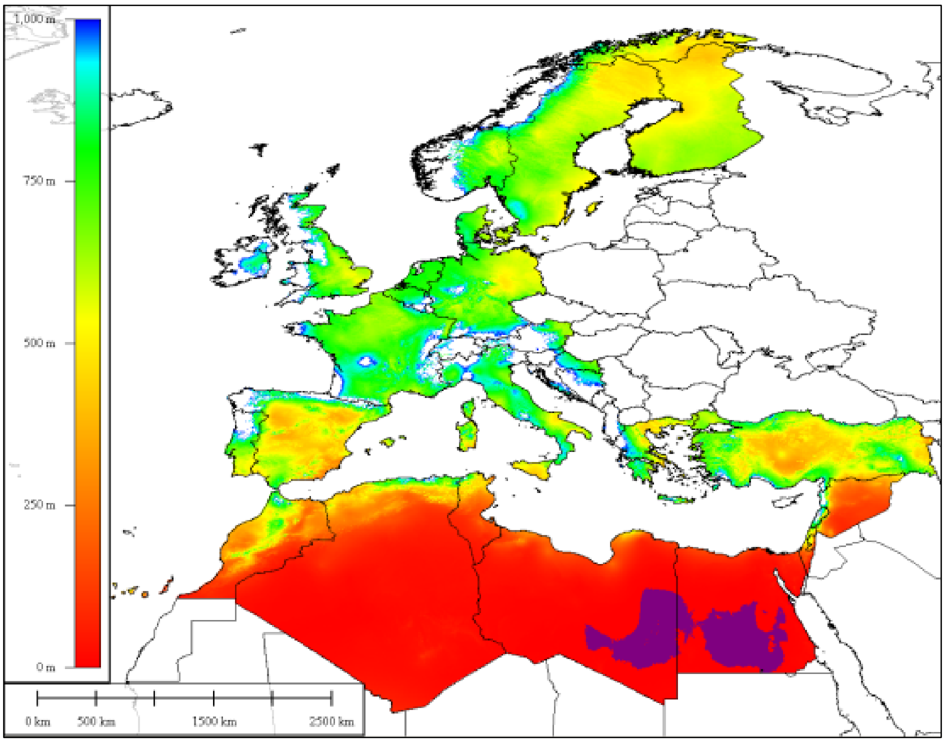
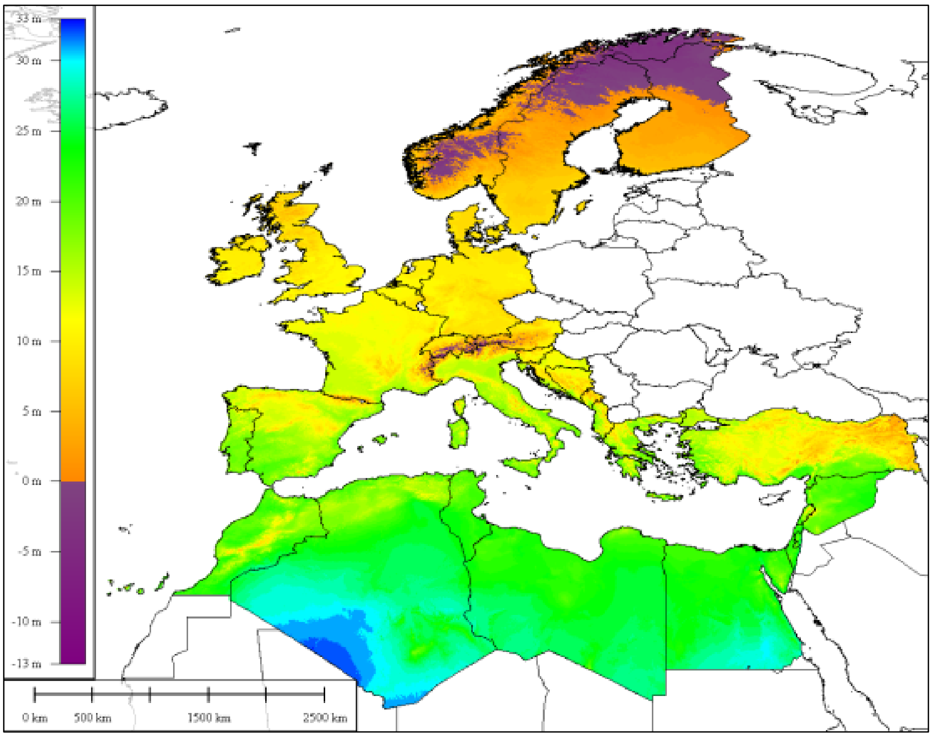


Figure 3: Mean annual temperature (ºC). Source Hijmans *et al*. (2005). Areas shown in purple are less than zero and in white are greater than the legend maximum or outside of the region of interest.



Land use and productivity

According to the best available satellite assessments, dryland agriculture dominates the European Union Mediterranean countries as well as the non-Scandinavian northern European countries (Figure 4). Significant areas of dryland agriculture are present, especially in the northern Mediterranean and in coastal and deltaic areas of Morocco, Algeria, Tunisia and Egypt. These dry-cropping areas may be more vulnerable to the effects of drought than those areas supporting irrigated cropland.

Figure 4: Dry crops in Mediterranean and northern European countries according to GlobCover continuous fields (Mulligan, 2009).

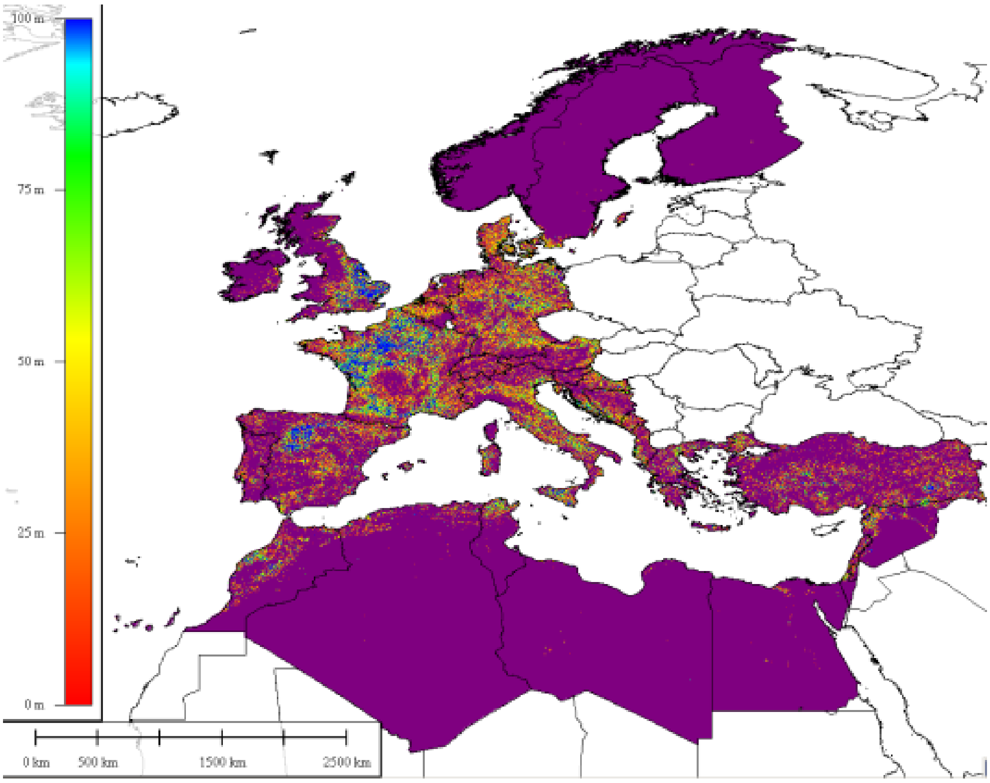


Figure 5 shows satellite-derived annual mean dry matter productivity (as a mean for the period 2000–10) for the Mediterranean and northern Europe. This measure is for all plant systems, not only for crops, and shows strong gradients, with the highest observed values in the northern Mediterranean (Italy, Sardinia, northern Spain, Greece) and a strong decline towards the southern Mediterranean and northern European land masses. Towards the south and east, water becomes limiting because of the observed gradient in precipitation (Figure 2) towards the north solar radiation and temperature become limiting (Figure 3), especially in the winter.

Figure 5: Dry matter productivity (Dg/ha/day) for the Mediterranean and northern Europe. Source: Mulligan (2009). Areas in purple are zero and in white are outside of the area of interest.

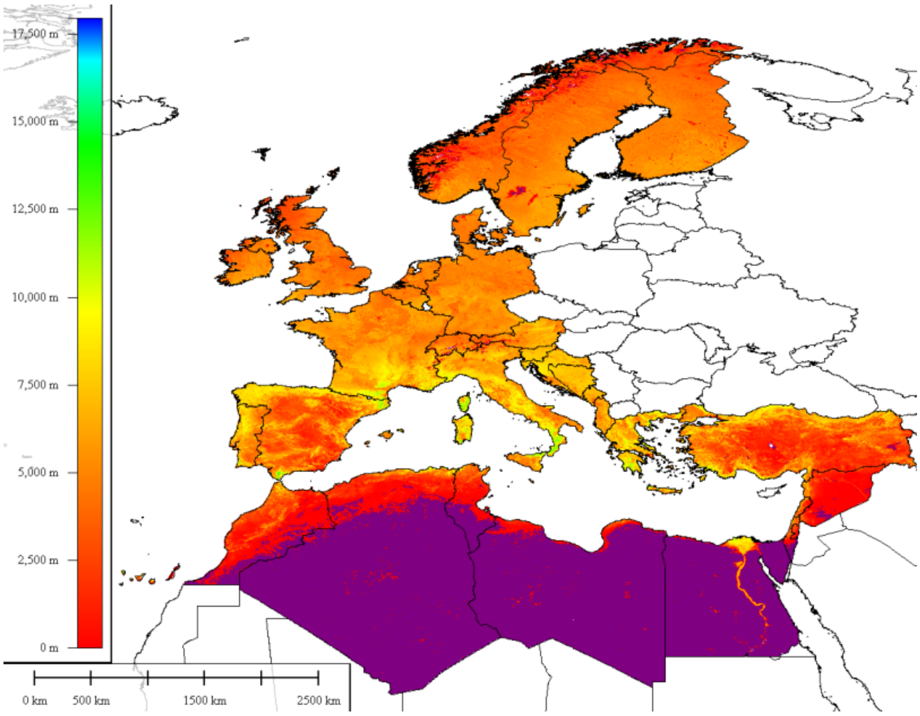


Figure 6 Percentage of land irrigated. Source: Siebert *et al*. (2007). Areas in purple are zero and in white are outside of the area of interest.

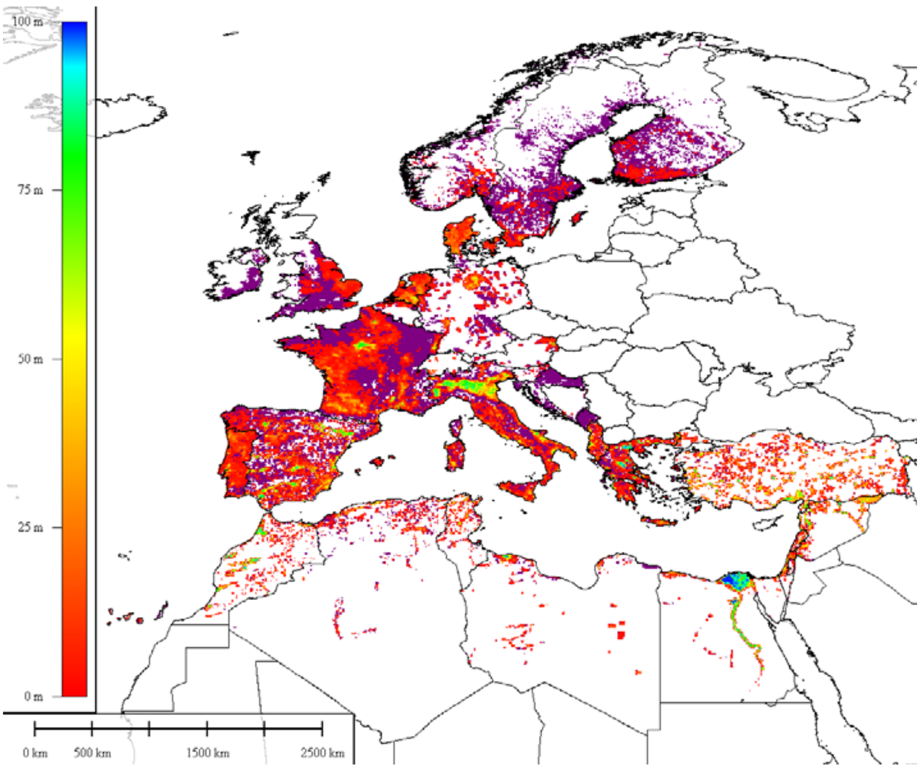


Figure 6 indicates the extent of agricultural irrigation in the study area. Irrigation is clearly highly localised with areas of intensive irrigation in the Nile Delta, northern Italy, parts of Greece, France, Spain, Morocco and Turkey. Extensive (rather than intensive) irrigation occurs throughout the northern Mediterranean and parts of lowland northern Europe. Heavily irrigated areas are clearly less vulnerable to short-term drought (if irrigation water is available) and can sustain higher productivity but are more vulnerable to degradation of soil and water resources if evapotranspiration rates are maintained at values consistently greater than the groundwater recharge rates or water supply capacity.

Major crops of the Mediterranean and recent change

The main crops in the Mediterranean partner countries (MPCs) according to Eurostat (Montgomery, 2009) include cereals, rice, fresh vegetables, fresh fruit, grapes, olives and dates. Vegetables (mainly tomatoes, potatoes and onion) account for nearly 40% of total production, with 38.9 million tonnes produced on average per year over the period 2000–06. The second largest crop is cereals, which account for 33%, with 32 million tonnes, followed by fruits, with 13.6 million tonnes. Egypt is the largest producer of vegetables, cereals and fruit.

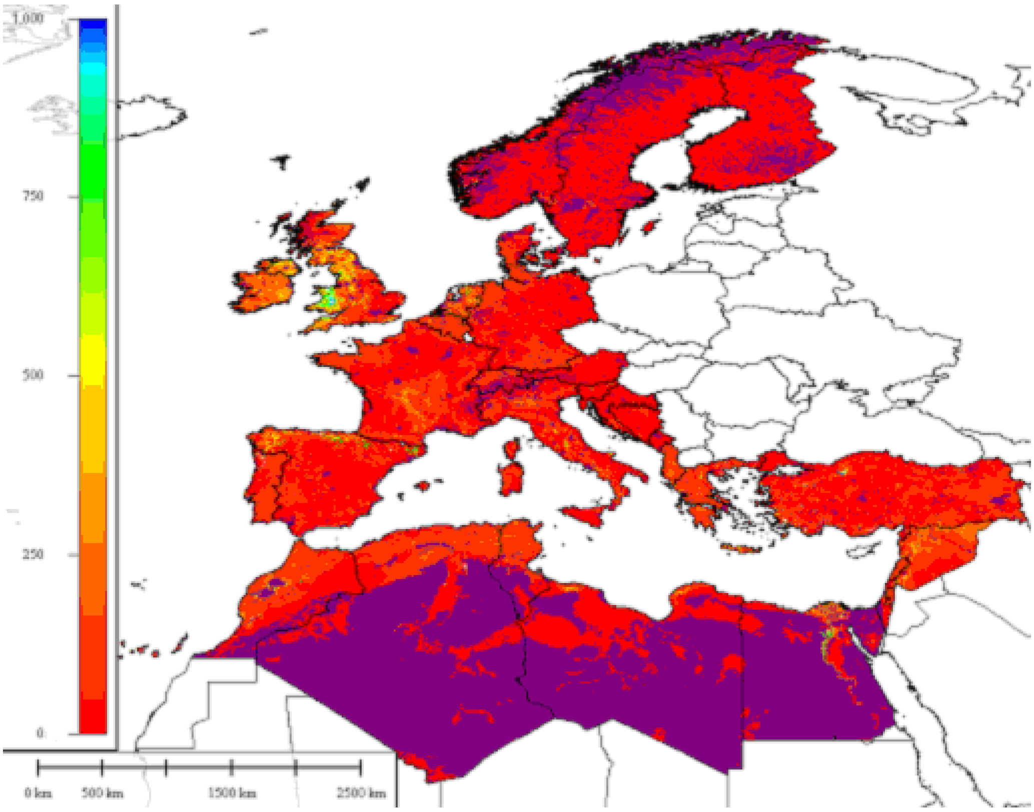
Cereals are the major crop in Europe, mainly wheat but also barley, maize, rice and oats. In 2007, the highest cereals producers in the European Union (EU) were France (59.4 million tonnes), Germany (40.6 million tonnes) and Poland (27.1 million tonnes). These are followed by Spain (23.8 million tonnes), the UK (19.4 million tonnes) and Italy (18.8 million tonnes). However, cereal production is sensitive to annual fluctuations in weather conditions and prices. For example, cereal production rose sharply in 2004 (29% higher than 2003), then fell between 2004 and 2007 (–20%). Then, in response to the very high cereal prices in 2007, production in 2008 increased by 19% but dropped by 6% in 2009, probably because of the unusually high temperatures and water shortages in southern and eastern Europe, and the persistent rains during the harvest in northern Europe (Eurostat, 2010a).

According to Eurostat (2010a), the other major crops grown are sugar beet, field peas, sunflower seed and rape seed. Most fruits and vegetables are concentrated in the EU Mediterranean countries as, in general, the climate is more conducive to such production.

Grazing lands

Figure 7 shows that grazing is much more extensive than intensive in the Mediterranean and occurs throughout the northern and eastern Mediterranean and in mountains, coastal areas and river margins in the southern Mediterranean. Cattle are clearly intensive in parts of northern England, Scotland, Wales and the Netherlands.

Figure 7 :Total grazers (head count/km²). Source: Wint and Robinson (2007). Areas in purple are zero and in white are outside of the area of interest.



Overall, the north and east Mediterranean are both productive and extensively used for dryland or irrigated agriculture or for grazing. In the southern Mediterranean, only coastal, mountainous and river valley locations are extensively used, with agriculturally unproductive areas covering large parts of these countries. Both agriculture and grazing are much more intensive in northern Europe, especially outside Scandinavia.

Drivers of recent agricultural change

Agricultural production in the Mediterranean has significantly increased over the past 50 years. Since 1961, production has increased 3-fold for cereals, 2.5-fold for vegetables and 5-fold for citrus fruits, all of which account for over 85% of the total agricultural production in the Mediterranean (Plan Bleu, 2009a). Northern Mediterranean countries (NMCs) are particularly significant agricultural producers.

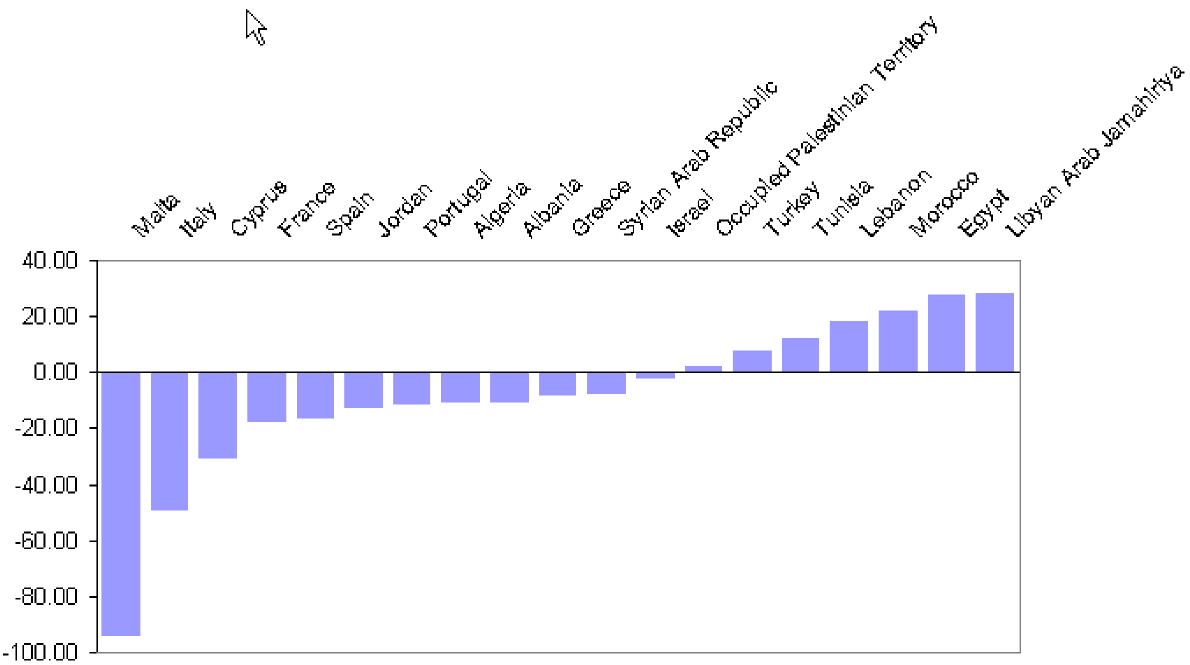
However, the growth rate in agricultural production has started to fall in recent years in all Mediterranean countries with the exception of Egypt, which showed remarkable increases in the period 1961–83 and still grew, but at a much slower growth rate, in the period 1984–2007 (Plan Bleu, 2009a). This has affected trade balances, and Mediterranean countries are becoming increasingly dependent on foreign food imports. Nevertheless, southern Europe still exports much of its produce. From 1999 to 2005, non-EU Mediterranean countries were, overall net importers of food from the EU-27, spending over €50 billion in total over the 6 years. Fruit (predominantly citrus), vegetables and olive oil were key export crops for the EU Mediterranean, with a total value of €14.1 billion and a net value of €12.1 billion for the region over the 6 years (European Commission, 2005).

The southern Mediterranean clearly suffers from a shortage of natural resources for agricultural production (water, cultivable land, etc.), but owing to the increase in irrigation of land, there has been remarkable increases in productivity in the region. Although rain-fed agriculture still predominates in terms of areal coverage in the Mediterranean, it is on irrigated land that the greatest productivity gains have been achieved in recent years (Montgomery, 2009). The total irrigated area in the Mediterranean countries doubled in 40 years to exceed 26 million hectares in 2005, now representing over 20% of the land under cultivation (Plan Bleu, 2009a). Access to irrigation has therefore become the main driver for recent agricultural change in the North African countries, and irrigation technology and experience has accumulated in this area. There are sound economic drivers for the increase in irrigation in North Africa according to Awwad (2003), including 'out-of-season' production of vegetables and fruits, which is cost-effective because of high market prices and low labour costs in North Africa.

Recent agricultural intensification and land degradation

The area under arable and permanent cropping has not increased alongside annual agricultural production, indicating a trend for intensification rather than extensification. In fact, since 1961, arable land per capita in the Mediterranean has halved (Plan Bleu, 2009a). Figure 8 shows the percentage change in absolute area under agriculture between 1961 and 2007. Although some countries have increased their agricultural area, notably the southern countries, a significant area of agricultural land has been lost elsewhere. Plan Bleu (2009a) indicates the changes are due to either land abandonment resulting from land degradation or the land being built upon as a result of increasing urbanisation.

Figure 8: Percentage change in agricultural area between 1961 and 2007. Reproduced using data sourced from FAO Statistics Division, database accessed 05 May 2010.



As farming shifts to more intensive practices, yields may increase in the short term but poor land management can eventually lead to land degradation in some areas. Land degradation is said to affect 80% of the arid and dry areas of the south and east Mediterranean, especially pasturelands and rain-fed croplands (Plan Bleu, 2005), and even irrigated land is sometimes under threat (Thivet, 2007). The EU MEDALUS (Mediterranean desertification and land use) programme has studied changes in land use across the NMCs and found that extensive deforestation of hilly areas and intensive cultivation with rain-fed cereals has already led to accelerated erosion and degradation (Kosmas, Kirkby and Geeson, 1999). Land suitable for food production is abandoned every year as a result of erosion, loss of fertility, salinisation and urbanisation, overgrazing, poor soil management and poor drainage on irrigated land. Land degradation 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 used for wheat cultivation and are said to be degrading (Kosmas *et al*., 1999). However, the Mediterranean region has a long history of intensive use by humans resulting in biological adaptations that provide high ecosystem resilience to human impact, and there is increasing recognition that Mediterranean-type ecosystems should not be regarded as fragile, degraded landscapes but rather as disturbance adapted (Allen, 2003).

Drivers of degradation

The shift towards intensively farmed cereals and towards intensive grazing systems in the northern Mediterranean is driven by (i) market drivers and regional agricultural policies, in particular subsidies (Roeder *et al*., 2008); (ii) rural labour restrictions in the face of significant rural–urban migration; and (iii) increasing mechanisation. Young farmers find the harsh working conditions unattractive compared with urban livelihoods; taking animals to graze is a hard and time-demanding job (Ruiz *et al*., 2001) with low economic rewards compared with many other careers. Intensive measures such as mechanised self-feeding systems that ensure balanced diets provide scope for substantial reduction of the workload (Riedel, 2007) and increased production efficiency.

In the southern Mediterranean, cultivation has encroached onto rangelands, driven by population growth and national policies, and has sometimes resulted in land degradation (Safriel, 2009). In the south and the east (from Morocco to Turkey), despite rural–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 substantially, from 46 million to 12 million (Thivet, 2007). This depopulation or ‘desertification’ has led to profound changes in the nature of rural landscapes and the balance between farming and natural systems.

Ecosystems, forests and protected areas

As well as significant human populations, the Mediterranean supports some important ecosystems which sustain various ecosystem services. The varied climate and landscape of the Mediterranean countries has generated a wide range of ecosystem types. The southern Mediterranean is predominantly a desert ecosystem, with agro-ecosystems present in northern Morocco, Algeria, Tunisia and the Nile Valley. NMCs have higher tree cover, associated with the major mountain chains. In the northern Mediterranean, the lowlands are primarily agro-ecosystems, interspersed with open *‘Matorral’* shrubland, some *Quercus*- and *Pinus*-dominated forests and crop/natural vegetation mosaics (see, for example, Hansen *et al*., 1998) which are water-stressed in the dry summer months (Petit *et al*., 2005). Mediterranean ecosystems rival tropical ecosystems in terms of plant biodiversity (Allen, 2003); the Mediterranean Basin itself hosts 25,000 plant species, half of which are endemic (Vogiatzakis *et al*., 2006).

We attempt here to indicate the most important of these areas in terms of conservation priority and ecosystems services using analysis of a range of GIS datasets. Figure 9 shows conservation priority as calculated by the overlap of a set of international conservation priority schemes. Datasets used to assess conservation priority were biodiversity hotspots (Myers *et* *al*., 2000), last of the wild (LOTW; Sanderson *et al*., 2002), global 200 ecoregions (G2; Oleson and Dinerstein, 1998) and important bird areas (IBAs; Birdlife International, 2008). These assessments include measures of biological importance and representation (BH, G2, LOTW, IBAs), threat (BH, G2) and lack of threat (LOTW) and should provide a reasonable representation of overall conservation priority.

Figure 9: Conservation priority. Combined prioritisations for protected areas of World Wildlife Fund for Nature, Conservation International and Birdlife International (not UK – no data available). Purple means not a priority area for any, orange is priority area for one of these organisations, yellow is priority area for two organisations and green is priority for all three organisations. Areas in white are outside the area of interest.

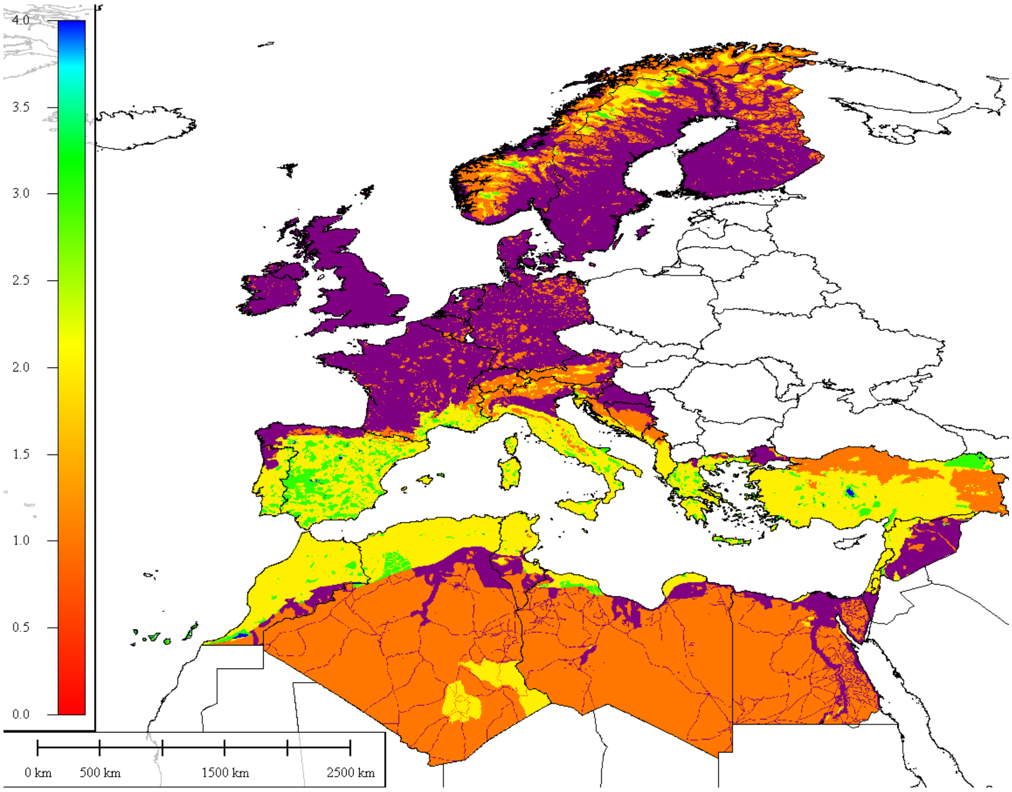


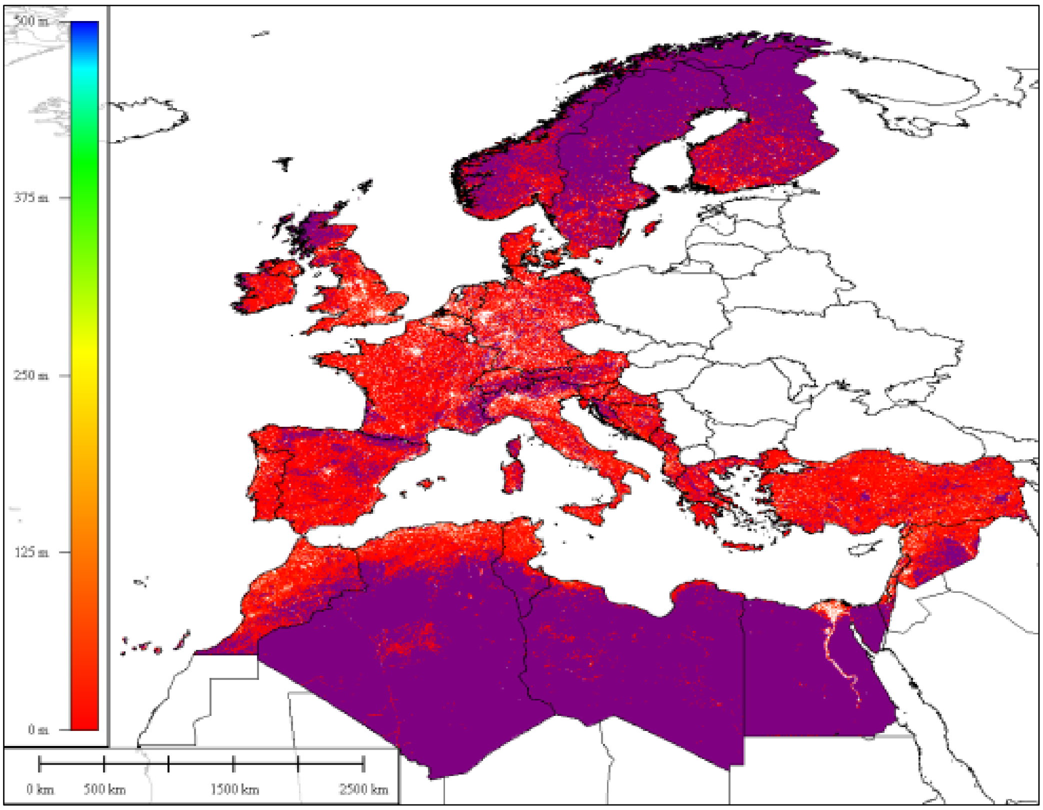
Figure 9 shows the overlap of these four conservation priority areas. Clearly, the Mediterranean itself is a priority, representing one of Myers *et al*.'s (2000) biodiversity hotspots. In general, coastal areas of north, south and east Mediterranean are important from a biodiversity conservation perspective, while large areas of lowland northern Europe are of low priority under these schemes. While not a driver of migration, conservation priority is an indicator of the importance of ecosystems in terms of at least some of the ecosystem services that contribute to quality of life (notably the cultural, aesthetic and recreational).

Socioeconomic context

It is the role of report DR8b to provide the political and socioeconomic context for migration in the Mediterranean, but to be consistent with the spatial biophysical context discussed, we provide a brief spatial analysis of some key socioeconomic variables for the Mediterranean and northern Europe. Figure 10 shows the distribution of population density. There is a clear spatial association between high populations, climate and agricultural productivity. In the southern

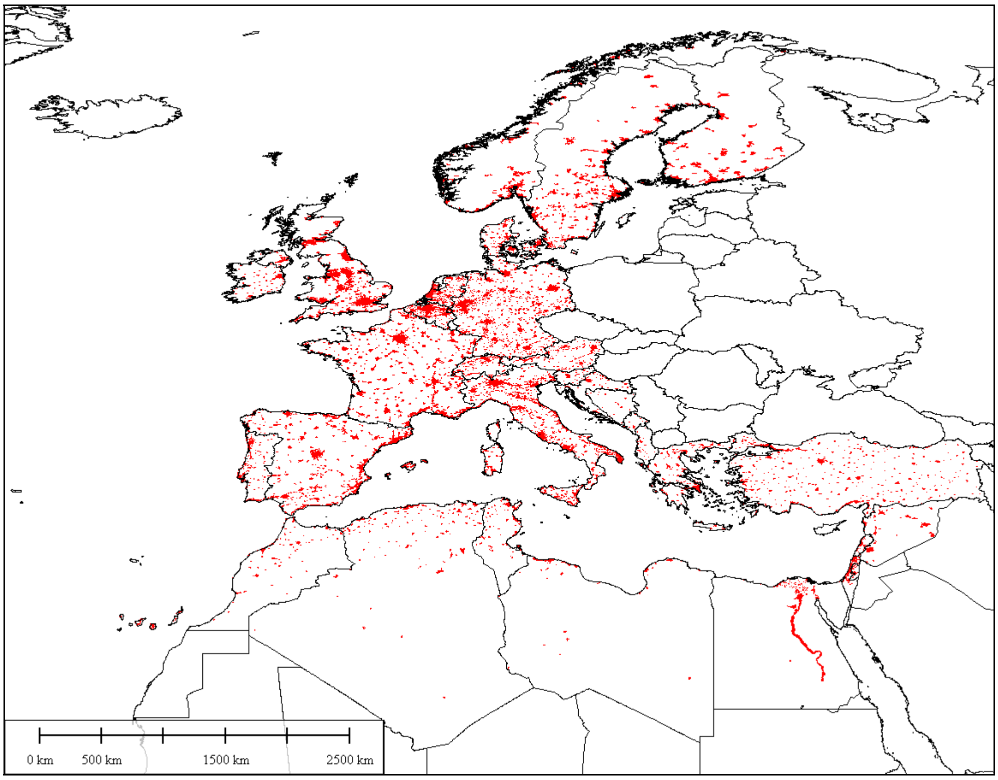
Mediterranean there are large areas of low rainfall and agricultural production and thus very low or no human population. Populations in the southern Mediterranean are concentrated in the highlands, coastal fringes and in the major river valleys which provide more amenable climates and access to markets, water and more fertile soils.

Figure 10: Population density (persons/km^2). Source: Landscan (2007). Areas in purple have no population and in white are outside of the study area or with a population greater than the legend maximum.



These populations are also clearly highly concentrated in some areas. The northern Mediterranean is highly urbanised (Figure 11), with these urbanisations being dense (in population terms). Population densities are highest in non-Scandinavian northern Europe, with contiguous highdensity urbanisation throughout the UK, the Netherlands, Belgium and Germany. Lower populations in the Scandinavian countries correspond with the very low temperatures and the resulting low productivity and challenging environments observed there.

Figure 11: Urban areas. Source: CIESIN *et al.* (2004).



There are few quantitative measures of socioeconomic context available at the subnational scale and in a comparable form for all the countries of this analysis. Two such datasets produced by the Center for International Earth Science Information Network (CIESIN) are infant mortality (a measure of poverty) (Figure 12) and gross domestic product (GDP) (Figure 13). These maps show that there is a link between socioeconomic development and the climatic limits of temperature in the north of Europe and precipitation in the south and east of the Mediterranean. Infant mortality is highest in rural parts of the south and east Mediterranean and much lower throughout northern Europe. GDP is highly concentrated in urban areas, especially the financial and industrial centres of northern Europe and the northern Mediterranean, and is low in parts of north Africa and the eastern Mediterranean as well as Scandinavia. Low rural GDP may indicate vulnerability and a low adaptive capacity.

Figure 12: Infant mortality rate (per 1,000 live births). Source: CIESIN (2002). White is outside the area of interest or greater than the legend maximum value.

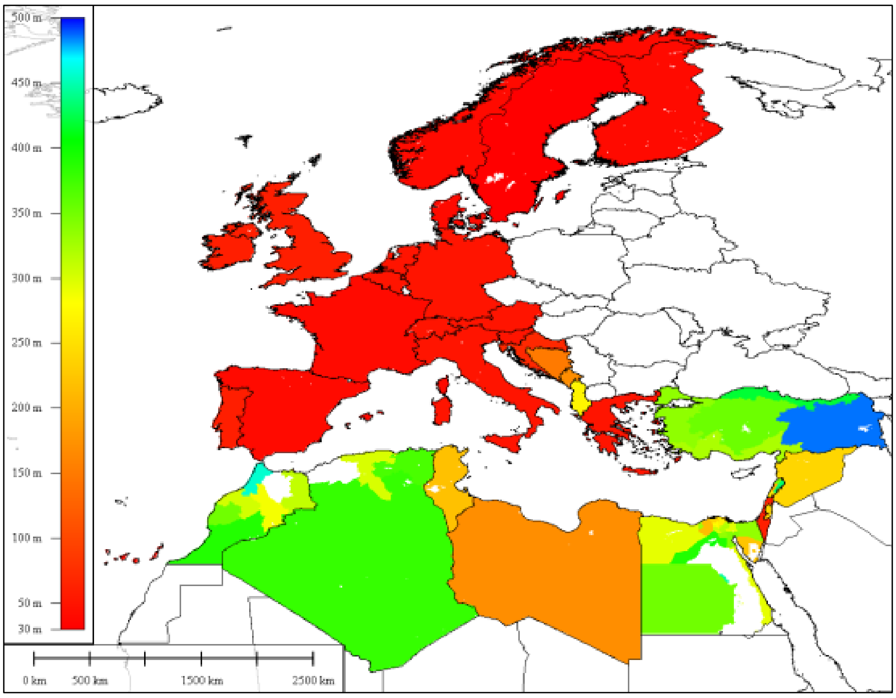
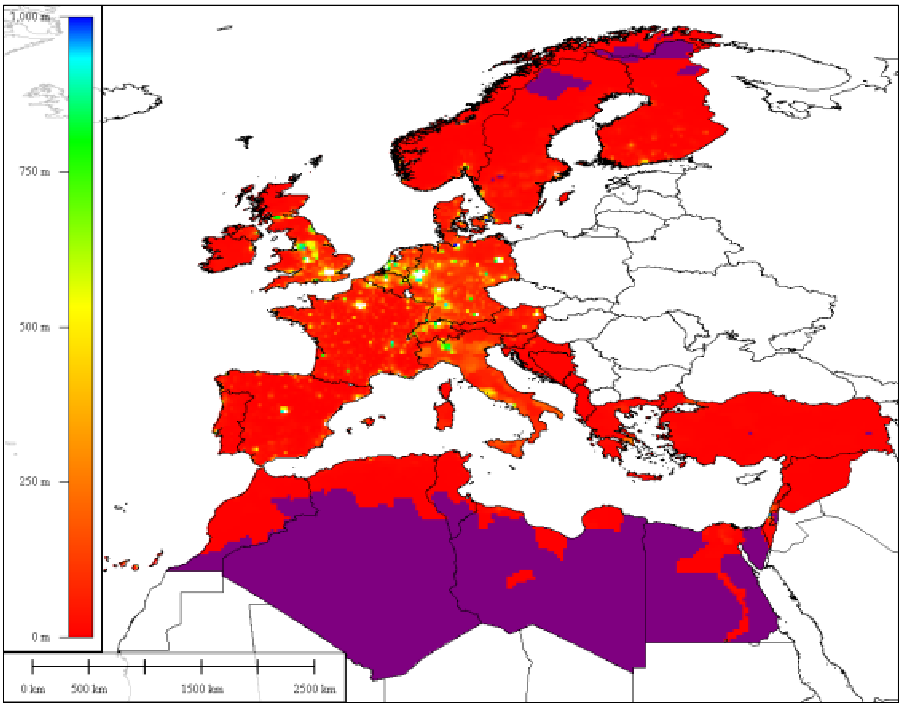


Figure 13: Gross domestic product (millions of USD). Source: CIESIN (2002). Purple represents zero and white is outside the area of interest or greater than the legend maximum value.

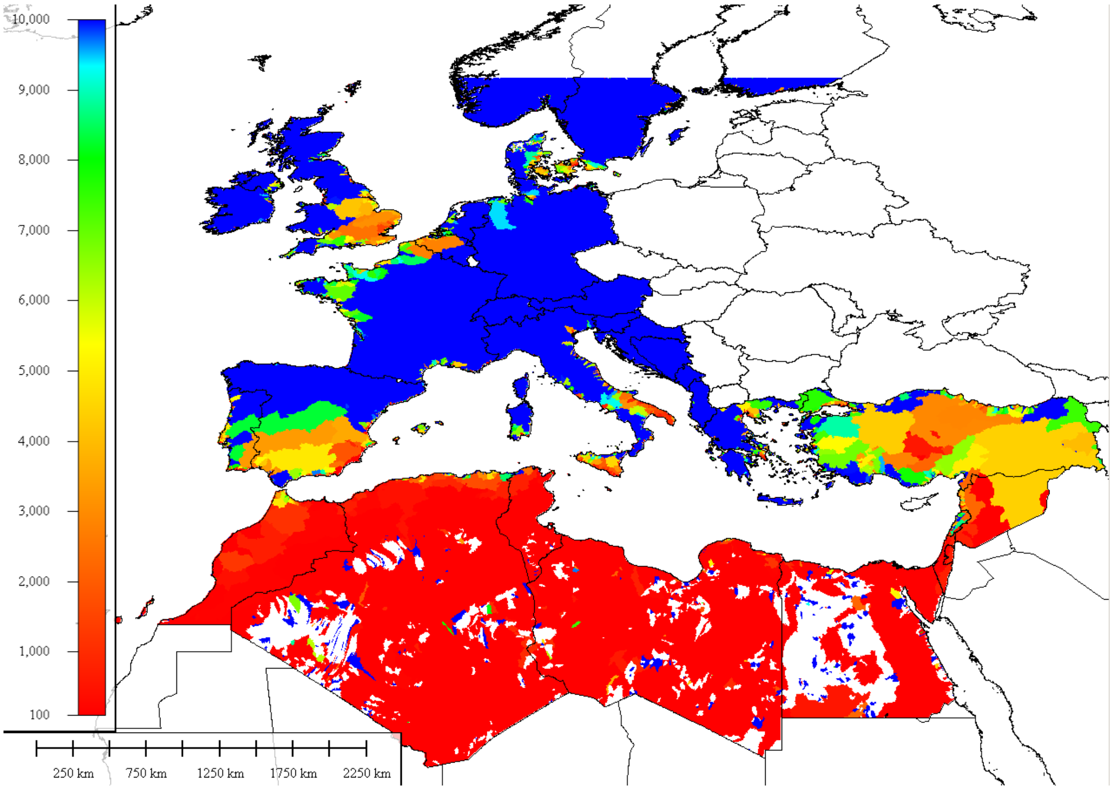


Stressors: water

The availability of sustainable water resources is perhaps the main environmental driver for population growth and development in arid areas. This is exemplified by the distribution percentage of land area flowing into dams for the region (Mulligan *et al*., 2009): Morocco (29.1), Algeria (12), Libya (0.1), Tunisia (10.3), Egypt (15.8), Israel (1.1), Lebanon (33.4), Syria (83.3), Turkey (68.2), Greece (15.4), Albania (29.0), Bosnia and Herzegovina (24.2), Croatia (13.1), Slovenia (20.8), Italy (20), France (18.3), Malta (0), Cyprus (9.8), Spain (73.4) and Portugal (28.9). Water resources are limited and highly unevenly distributed in line with rainfall (Figure 2). There are 180 million people classified as water poor, and 27 million with no access to an improved sanitation system, mainly in the southern Mediterranean (Plan Bleu, 2009a). Water quality is also considered to be decreasing owing to chronic pollution from untreated agricultural, domestic and industrial discharges, especially from pesticides and nitrates (Plan Bleu, 2009a). Water constrains productivity (Figure 5), especially in the south and the east, leading to the adoption of intensive and extensive irrigation in the region (Figure 6) which is sometimes unsustainable, drawing more water from fossil groundwater than is replenished by groundwater recharge on an annual basis.

Figure 14 shows the catchment average water balance per person, which indicates the capacity of sustainable water resources for supporting the population and agriculture. We have calculated water balance as rainfall (*Rf*; Hijmans *et al.* 2005) minus potential evapotranspiration (*PET*; Zomer *et al*., 2008) on a 1-km resolution basis with negative water balances (*PET>Rf*) set to zero. Note that this analysis does not include inflows of water from rivers (which sustains some areas, e.g. the Nile) nor stores of fossil water but focuses on the locally produced renewable water resources since these will be critical for sustainable agricultural production in water-scarce areas. The water balance has been combined with a dataset for hydrological watersheds (Lehner *et al*., 2008) and population (Landscan, 2007). Areas in blue have plenty of water per person on a catchment average basis, whereas those in green, yellow and red show progressively lower per capita water resources. The most water-stressed catchments are in the southern Mediterranean because of lack of water, in the eastern Mediterranean because of lack of water combined with high population and in coastal northern Mediterranean because of small catchments with high populations living near the coast and a low water balance. This map is an indicator of environmental stress and it is interesting to note that some densely populated parts of northern Europe are also potentially water stressed on this measure.

Figure 14: Catchment average water balance (rainfall minus evapotranspiration) per person (m^3 per person per year).



On a national basis, according to Plan Bleu (2009a), per capita resources of available renewable water are highest for Croatia, Montenegro and Albania (over 10,000 m^3 per person per year), while Algeria, Tunisia, Libya and Israel have the lowest levels (less than 500 m^3 per person per year). This results in greater water stress in the southern Mediterranean countries, putting these countries at higher water deficit risk in the future (Plan Bleu, 2010), which is further exacerbated by a high level of wastage and generally inefficient water use (Vidal *et al*., 2001). With regards to per capita water-use footprints within the Mediterranean, only Algeria, Egypt and Albania fall below the global average (Hoekstra and Chapagain, 2007). Spain, Italy and Greece are in the highest consuming category, with a national average per capita water footprint between 2,300 and 2,400 m^3 of water per person per year, lagging behind only the USA. This water footprint was calculated using overall volume of consumption within the country, product composition of that consumption, agricultural water efficiencies in the country and climatic evaporative demand (Hoekstra and Chapagain, 2007).

Hazards: flooding

In addition to water stress, the Mediterranean populations and landscapes are subject to a range of natural hazards. In addition to the earthquakes, volcanoes and other geological hazards outside the scope of this work, the key migration-relevant hazards influenced by environment and environmental change are river flooding, wildfires and sea-level rise.

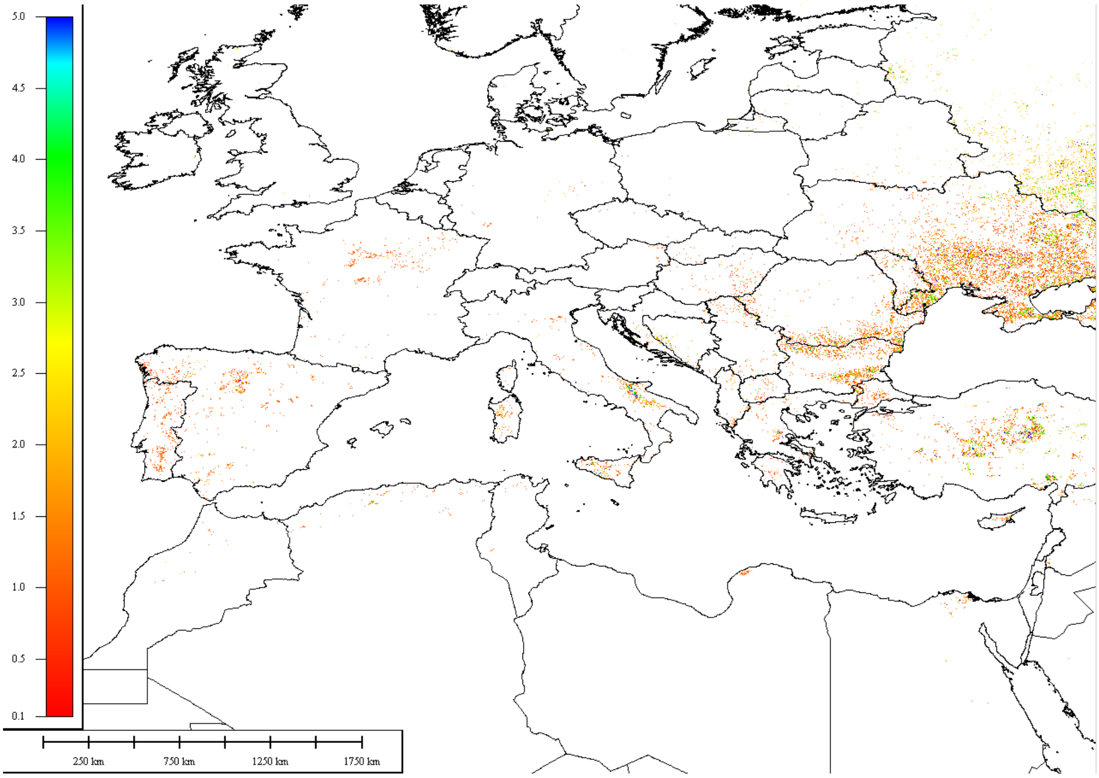
Flooding causes sudden human displacement. Llasat *et al*. (2010) reviewed a total of 185 flood events for 18 countries across the Mediterranean for the period 1990–2006 and calculated a reported material damage that exceeded €29 billion. In Llasat's study, Italy was the country with the greatest material damage, followed by France, Romania, Turkey and Spain. Flood frequency is highest in Spain and Italy, although there are also more available data there. The number of cases that affected Spain, Italy and France together amount to 59% of the 185 Mediterranean-wide events considered. The distribution of floods is neither homogeneous across the region nor stationary over time, although most floods seem to occur in the western half of the Mediterranean.

Floods are less frequent in the southern Mediterranean countries (northern Africa), but are usually catastrophic with a very high number of casualties. The total number of casualties over the whole area and time period studies by Llasat was 4,500 and was highest in the African countries bordering the Mediterranean. The highest number of casualties for a single recent flood event was the Algeria event of November 2001, followed by events in Morocco, Egypt and Italy. In 2001, extreme rainfall and windstorms triggered mudslides where the Atlas Mountains rose steeply above the densely populated coastal plain. Over 600 people were killed and there was significant urban unrest. There is also serious flood risk in some of the urban areas of southern Mediterranean owing to inadequate storm drainage infrastructure (World Bank, 2007). The impact of climate change on flooding is very difficult to anticipate given the extreme nature of generating events and the significant of local geomorphological, land-use and infrastructural contexts, but sensitivity to increased flooding will clearly equate with proximity of infrastructure to major rivers, climte change impacts, and land and water management contexts. There is also serious flood risk in urban areas worldwide owing to inadequate storm drainage infrastructure (World Bank, 2007).

Hazards: wildfires

Mediterranean forests are regularly subjected to a large number of fires; 600,000 ha burn every year according to Cemagref (2009), some of which are started deliberately. Figure 15 shows the mean observed frequency of fire burn events between 2001 and 2010, compiled by Mulligan (2010) from the MODIS burned-area product (Roy *et al.,* 2008). Clearly the north and east Mediterranean are currently subject to significant fire risks which lead to significant burn areas and, in places, repeat burns. This hazard may be exacerbated by hotter, drier summers and by changes in population, land management and infrastructure. Burns in the southern Mediterranean are much less extensive.

Figure 15: Mean observed frequency of fire burn events (2001–10) (% of MODIS observations). From Mulligan (2010).



Current migration due to environmental drivers

We have – so far – described the state of context for ecosystem service provision, hazards and thus potential drivers for economic well-being, quality of life and thus migration in the Mediterranean. The GIS analysis has shown there is a strong environmental variability between the populous, agriculturally and infrastructurally complex and highly urbanised northern Mediterranean and the southern Mediterranean, developing gradients which may contribute to 'push' and 'pull' for migration. However, estimates of numbers of environmentally forced migrants and projections of future numbers in the Mediterranean are divergent and controversial. Many studies have pointed to the difficulties of linking environmental change and migration (for example, Myers and Kent, 1995; Black, 2001; Barnett, 2003; Smit and Pilifosova, 2001; McLeman and Smit, 2006), and providing firm future projections of numbers of environmentally forced migrants is extremely difficult. The relationship between migration and environment is complex because of the many other social, economic and political factors that play a role in the relationship (Jäger *et al.*, 2009). Migration should not be considered as a simple or automatic response to a singular risk, climate related or otherwise. Many factors combine to influence human behaviour, and migration sensitivities and options vary greatly among regions and social groups. In order to assess migration due to these drivers in the future, we need to combine a spatially explicit understanding of the probable trajectories for environmental change (the focus of Dr8a) with an assessment of the agricultural, economic and social vulnerability of a community to environmental change and likely human responses, taking into account past migration events (the focus of DR8b).

Conclusions – the environmental context of the Mediterranean

The biophysical conditions of the Mediterranean are highly spatially and temporally variable. The region has areas of highly intensive, extensive and productive agriculture, particularly for high-value crops and for extensive cattle grazing. Irrigation is both intensive and extensive in different parts of the region as a means of supporting agriculture in dry climates or through the dry season, and this irrigation is sometimes unsustainable in the long term, drawing more water from fossil groundwater than is replenished by groundwater recharge on an annual basis. The Mediterranean region supports significant human populations, especially in the north and east, and is highly urbanised and industrialised in these areas. The southern countries are significantly more agricultural, with much lower and more dispersed populations and GDP and most activity focused on the wetter Mediterranean coastal region away from the arid interior. The Mediterranean is an ecologically important region with important conservation priority areas and a clear dependence on ecosystem services (especially provisioning services for food production, water quantity and quality, regulating services including water regulation, erosion control and supporting services for soil production) for agricultural production under sometimes climatically marginal conditions. Environmental hazards such as flooding and wildfire are an important factor in parts of the Mediterranean (especially the east for wildfires) and for urban populations on the floodplains of major rivers for flooding.

Scenarios for change

Here we move forward from the current context of the Mediterranean and its spatial variability and examine the probable changes in some of these key characteristics in the future. Clearly one never knows what the environmental future holds, so in examining projections for the Mediterranean we use an ensemble modelling approach wherever possible and examine the differences between the members of ensemble projections as a measure of the uncertainty in the projections offered. Although climte change projections are available for a range of scenarios, we only have access to downscaled data for multi-model A2a at present, although single-model results are also available for other scenarios including the A1 scenario. In many cases, the differences between models within a given scenario are greater than the differences between scenarios for a single model. In all cases, results should be treated as scenarios or possible/plausible futures, not as predictions, and the analysis carried out here focuses on spatial variability of change expected within and between countries rather than the exact magnitude of change expected. The A1 scenario available to us at the time that the spatial analysis was undertaken was the A1B scenario and this is used in the analysis presented below.

The Intergovernmental Panel on Climate Change A1 scenario family

The A1 scenario family from the Intergovernmental Panel on Climate Change (IPCC) (Nakicenovic and Swart, 2000) is characterised by:

- rapid demographic transition with declining mortality and fertility rates;
- very high productivity and economic growth in all regions; and
- rapid technological change.

There are three variants within this family that make different assumptions about sources of energy for this rapid growth (Arnell, 2004): fossil intensive (A1F), non-fossil fuels (A1T), a balance across all sources (A1B)

Owing to these variations in energy systems, emission pathways for this family are the most diverse of all Special Report on Emissions Scenarios (SRES). The A1B 'marker' scenario assumes a balanced mix of technologies and supply sources with no single source of energy being dominant. Table 1 shows the key characteristics of this scenario for 2030, 2060 and 2100.

Table 1: Key characteristics of A1 scenario globally.

World – A1B scenario	Unit	2000	2030	2060	2100	%
Population	Million	6,117	8,182	8,538	7,056	15.35
Energy use (EJ)	EJ	314	669	1,180	1,741	454.46
Energy available	EJ	424	895	1,574	2,226	425.00
Cumulative resources	ZJ					
Coal		1.1	5.4	10.5	15.9	1345.4
Oil		1.7	8.2	14.4	20.8	1123.5
Gas		0.9	6.3	18.2	42.2	4588.8 9
Cumulative CO_2	GtC	75.3	422.8	892.5	1492.	1881.5
Land use	Million ha					
Cropland		1,466	1,454	1,436	1,420	–3.14
Grasslands		3,404	3,458	3,525	3,576	5.05
Energy biomass		0	158	484	495	
Forest		4,237	4,164	4,194	4,204	–0.78
Others		3,842	3,715	3,299	3,253	–15.33
Total		1,294	1,294	1,294	1,294	0.00

Source: IPCC Data Distribution Centre. Available from: http://sres.ciesin.org/final_data.html.

Climate change projections for the Mediterranean

The Mediterranean climate may respond significantly to global climate change (Giorgi and Lionello, 2008) since it is a transition area between the temperate climates of central Europe and the arid climates of northern Africa, and has significant gradients of precipitation (Figure 2) and temperature (Figure 3). Therefore, projected changes in global climate could modify the climate characteristics of the Mediterranean profoundly.

Figures 16 and 17 show the difference in mean temperature and mean precipitation between 1900–2050 and 2041–60 for the HADCM3 SRES A1B scenario averaged by watershed. Figure 16 shows that warming may occur throughout the region, with a strong north–south gradient, the warming being greatest in coastal areas and to the south.

Figure 17 shows that precipitation decrease may occur throughout the Mediterranean and European countries except the extreme south and the north, which may become wetter.

Figure 16: Mean temperature change by basin (1900–2050 to 2041–60) for HADCM3 SRES A1B (ºC * 100).

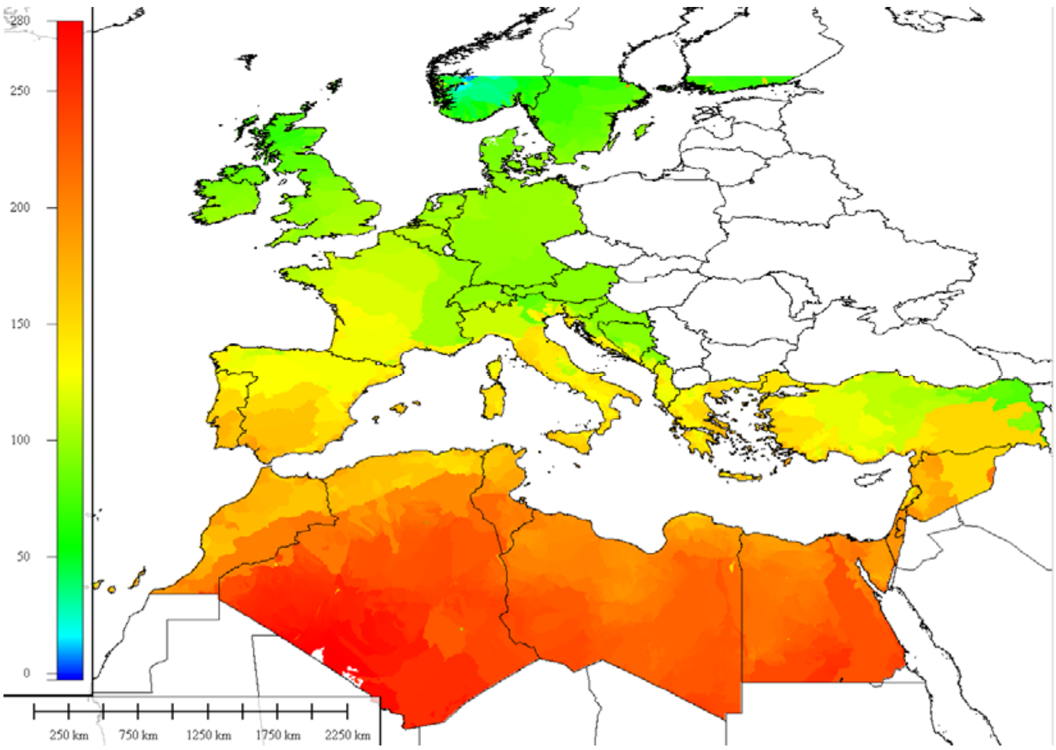
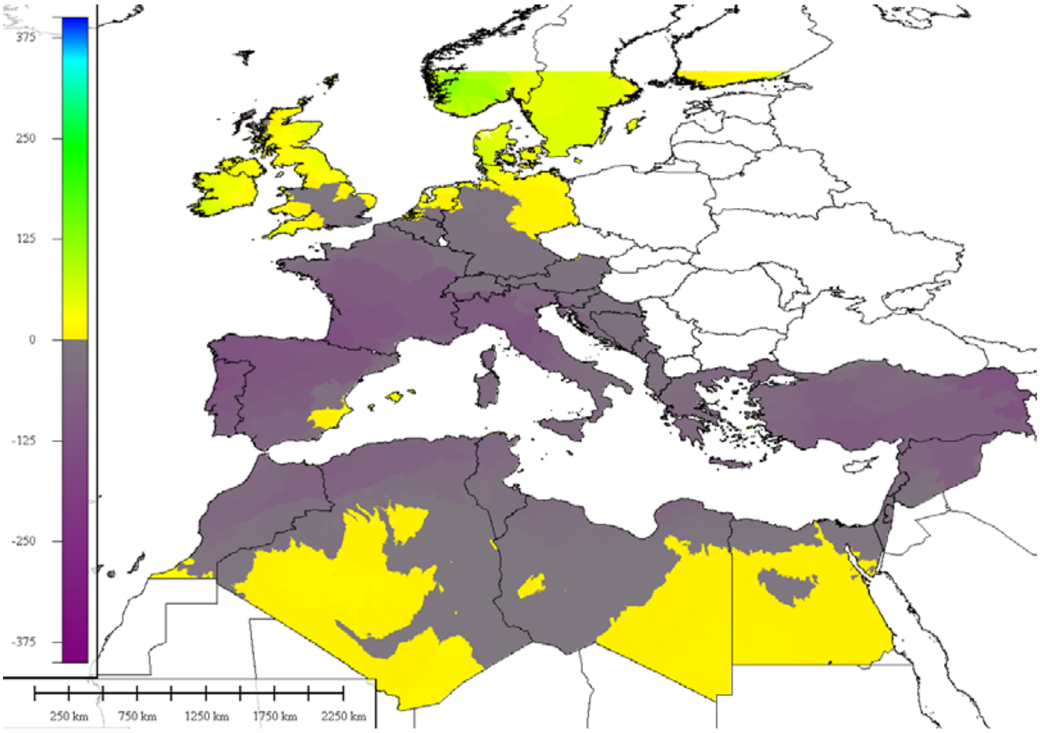


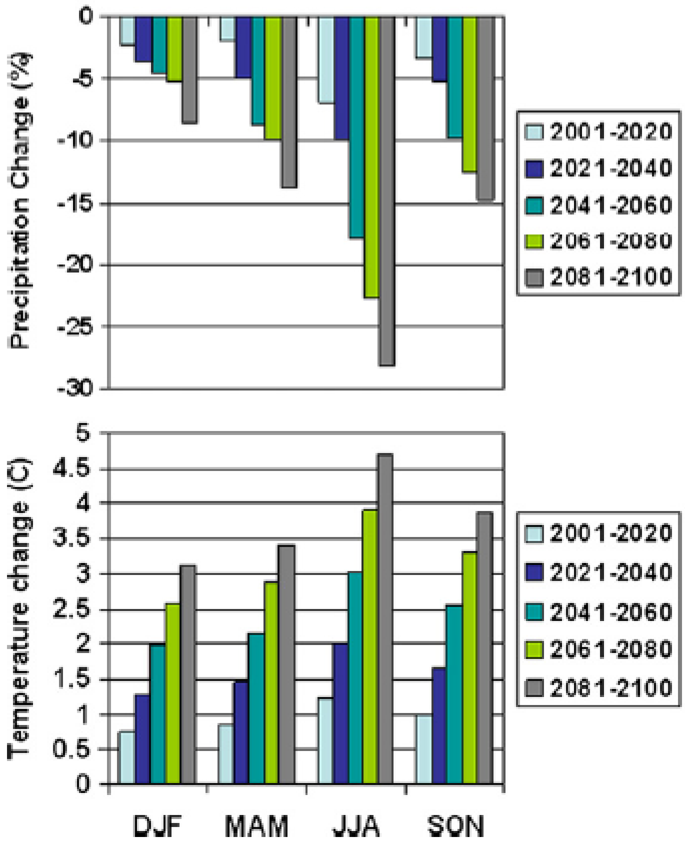
Figure 17: Mean precipitation change by basin (1900–2050 to 2041–60) for HADCM3 SRES A1B (mm per year).



Using the A1B marker scenario, Giorgi and Lionello (2008) analysed changes in temperature and precipitation for the Mediterranean basin with output from 17 general circulation models (GCMs) from the IPCCs 4th Assessment Report (IPCC, 2007). 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. 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 as also shown by HADCM3 SRES A1B above. Figure 18 shows the projected changes in precipitation and temperature for the Mediterranean region for different seasons and time periods. This region (between 2–48°N and 9.5°W–38.5°E) covers 20 countries fully or partially with climatic types ranging from the north-African desert to the Alps.

Figure 18 shows that the projected decrease in precipitation occurs for all seasons and is particularly pronounced in the warm season (June to August), when it can exceed 20% for the 2060–80 period and the lower decrease in winter on average. Indeed, according to Frei *et al.* (2006), the Alpine areas will receive more precipitation in winter. Temperature is projected to increase for all seasons, particularly in the summer period, with total warming expected to be between 2.5 and 4ºC for the 2060–80 period

Figure 18: Multi-model ensemble average change in mean precipitation and mean surface air temperature for the full Mediterranean region for four seasons and different time periods for the A1B scenario. Changes are calculated with respect to the 1961–80 reference period and only include land points. DJF, December to February 10-year average; MAM, March to May 10-year average; JJA, June to August 10-year average; SON, September to November 10-year average. Source: Giorgi and Lionello (2008).



Changes in temporal 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 occurrence of extremely high temperature events and heatwaves. This was also studied by Giannakopolous *et al.* (2009), who found an increase in the number of days recording more than 30°C for the Mediterranean region. A similar increase in frequency has also been described for extreme precipitation events by Pal *et al.* (2004) for large regions of the Mediterranean. Aridity is expected to increase as a result of a general warming and a decrease in precipitation, which may lead to an increase in area and northward extension of arid regime lands, especially in the southern Mediterranean area (Gao and Giorgi, 2008).

Uncertainties and sensitivities to scenario

There are significant uncertainties in the climate projections, both between models for a given scenario and between scenarios for a given model. GCM mean temperature biases for the present climate in the Mediterranean region range from –5°C to 6°C (IPCC, 2007). Simulated current precipitation varies considerably between seasons and locations, but on average autumn to spring are overestimated and summers are underestimated compared with observed values (IPCC, 2007). Regional climate models (RCMs) perform better in terms of the geographical variation of temperature and precipitation but, for south-eastern Europe, simulations for the summer are generally too warm and dry (Jacob *et al*., 2007).

A significant source of uncertainty in projections for the Mediterranean region derives from unrealistic modelling of the climatic influence of the Mediterranean Sea (Lionello *et al*., 2008; Somot *et al*., 2008). Furthermore, particularly for RCMs, uncertainties in future land-use and land-cover change adds considerably to uncertainty in climate projections. Uncertainty in RCM simulations in Europe were addressed by the PRUDENCE project (http://prudence.dmi.dk/), which found that uncertainty in the boundary forcing plays a greater role than the RCM itself, particularly for temperature (Déqué *et al*., 2007). Of all SRES scenarios, the A1 scenario family has the greatest range of future GHG emission levels resulting from the various energy systems which range from non-fossil (A1T) to fossil fuel-dominated alternatives (A1C).

In our analysis of the differences between 17 different GCMs for SRES, the SRES A2a scenario (the only multi-model ensemble available to us at the time) indicates a very large variation in projected impacts between the 17 different GCMs for some parts of the Mediterranean and north Europe but greater consistency between models elsewhere (suggesting greater certainty in projections). For temperature (Figure 19), there are very significant differences between projections for different GCMs for the south and east of the Mediterranean (the more continental areas) but much greater agreement in the north and in coastally or oceanically influenced zones. For precipitation (Figure 20), the greatest uncertainty between models is in mountainous areas, especially those in the north (possibly reflecting the different treatment of terrain by the GCMs), but there are also differences throughout the Mediterranean and especially in northern Europe.

Figure 19: Temperature uncertainty (ºC * 10) (standard deviation of temperature between 17 GCMs A2a scenario). Source: Mulligan (2009).

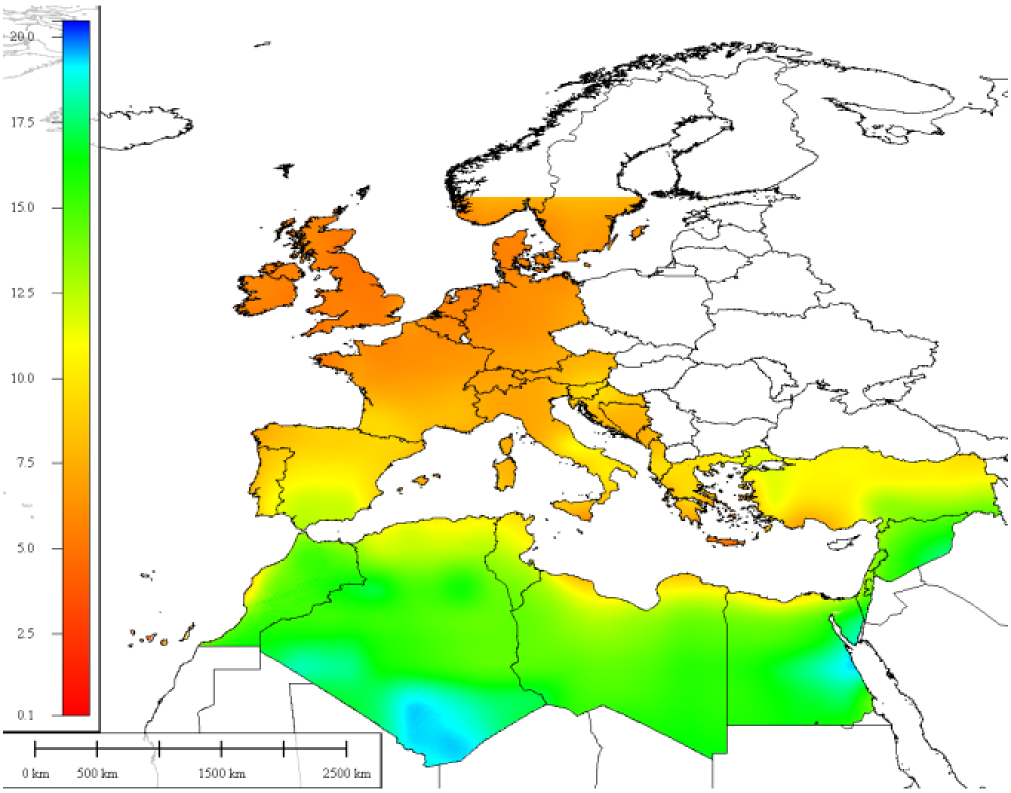
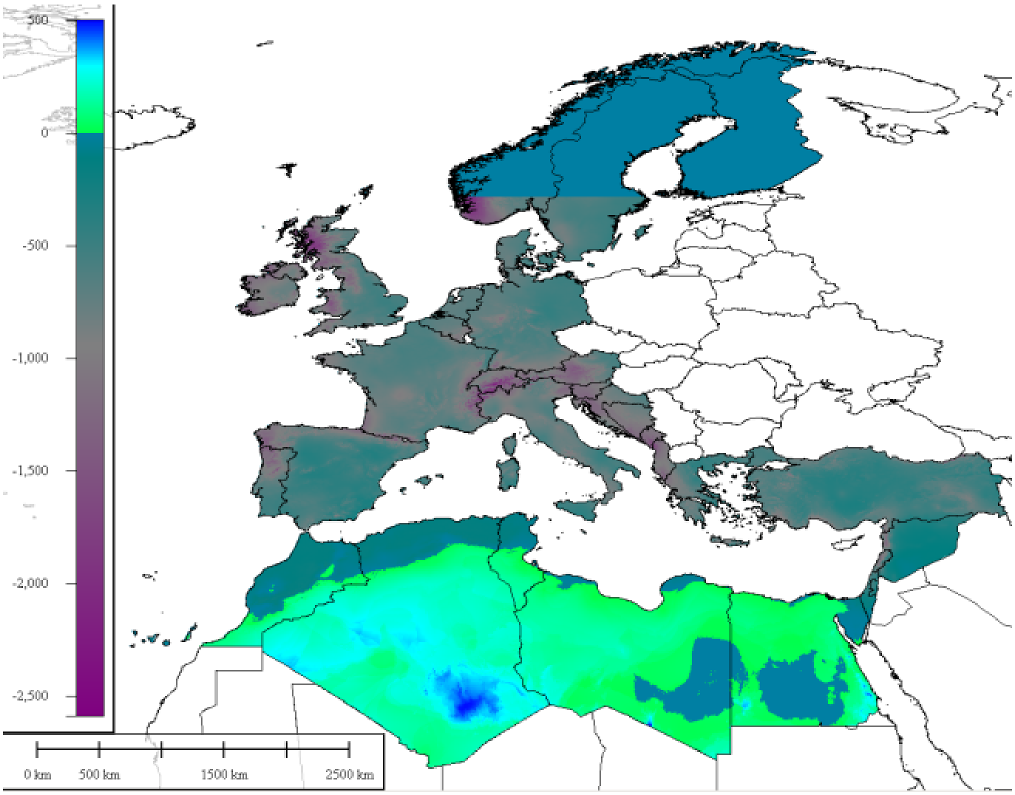


Figure 20: Precipitation uncertainty (standard deviation of precipitation between 17 GCMs A2a scenario) mm per year. Source: Mulligan (2009).

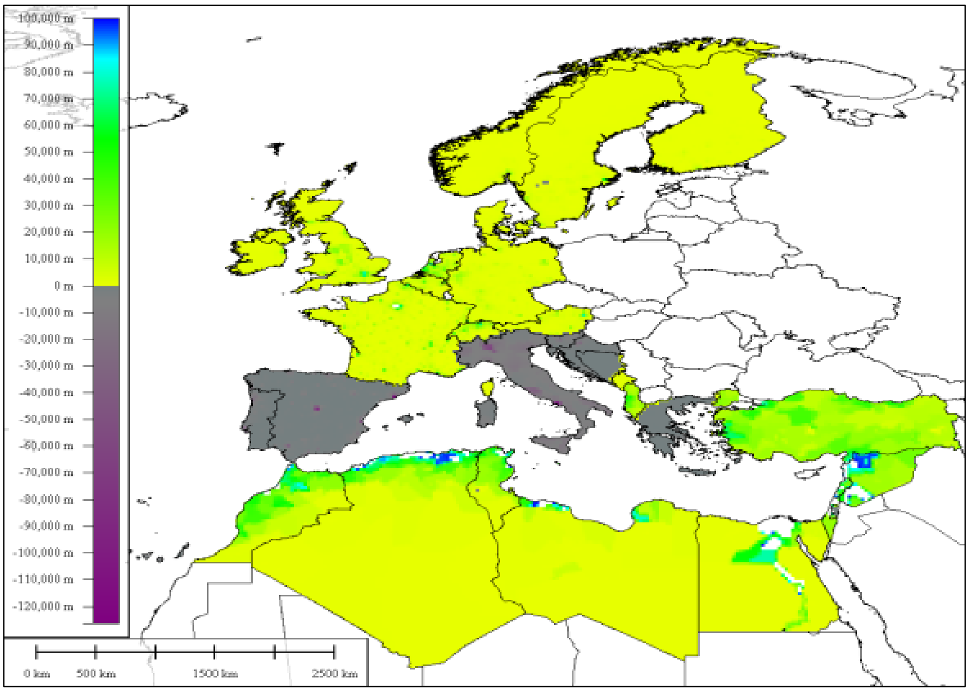


We have shown that there is significant variation in climate projections for the Mediterranean between 17 different climate models for the same scenario (Figure 16 and Figure 17) and for different scenarios (Figure 19 and Figure 20) and that these differences are highly spatially variable within and between countries. In addition to these modelling uncertainties, there are scientific uncertainties in how landscapes and ecosystems will react to climate change (see for example the section below on land-use scenarios). Of course, there are also uncertainties from non-environmental drivers, such as how humans will respond to these changes and their impacts. The impacts of climate change are thus very population, economy, politics and adaptation dependent (and these factors will change as climate changes). Although non-environmental drivers are considered in more detail in Dr8b, we cannot ignore how these factors might change spatially, and so the next section outlines the available population and economic growth scenarios for the Mediterranean.

Population growth and economic development scenarios

Spatial projections for population and GDP are publicly available only for the SRES B2 scenario. Under SRES B2, population increases by 2025 are expected to be greatest in the south and east of the Mediterranean basin and concentrated in coastal areas (Figure 21). Depopulation is expected to occur in parts of the north Mediterranean (especially Spain, Italy and Greece). Urbanisation in northern Europe is expected to continue.

Figure 21: Population projection for 2025 (persons/km², SRES B2). Source: CIESIN (2002).



Published UN population division data (from the UN population division at http://www.un.org/esa/population/) show population projections per country for the Mediterranean region as per the UN 2008 revision. These data are for the medium variant that assumes medium fertility (level converging to 1.85 children per woman), current mortality (based on life expectancy per country) and current international migration (based on past migration) for each country.

Table 2:Population projections (persons) for the Mediterranean. Source: UN population division data from the 2008 revision (http://www.un.org/esa/population/).

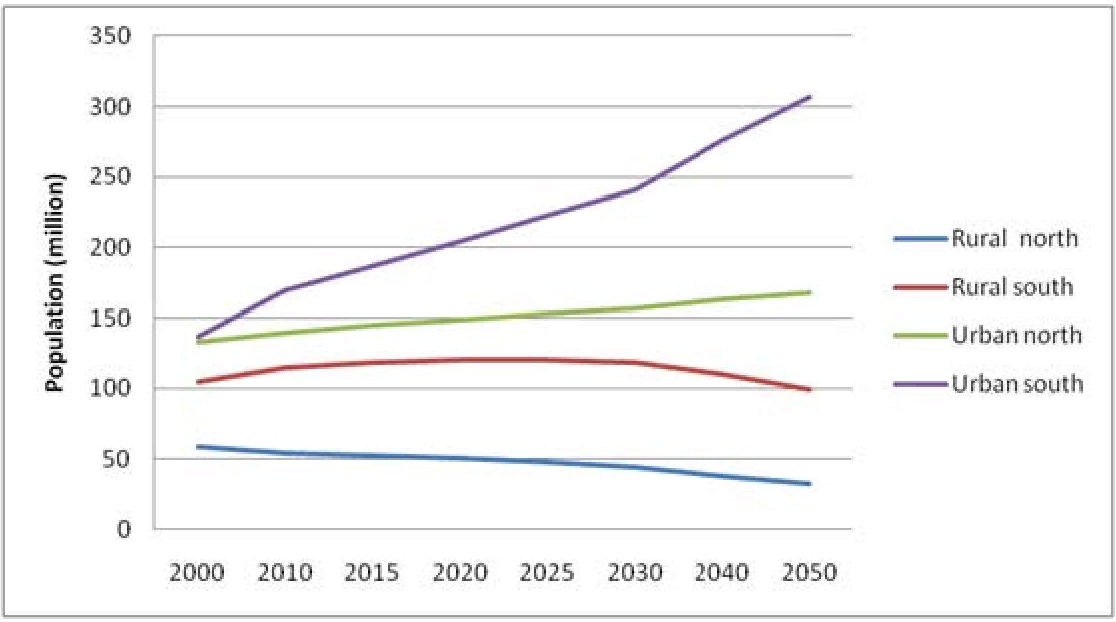
Country	2000	2010	2025	2050	% change 2000–50
Albania	3,068	3,169	3,395	3,303	7.66
Bosnia and Herzegovina	3,694	3,760	3,608	3,008	–18.57
Croatia	4,505	4,410	4,254	3,825	–15.09
France	59,128	62,637	65,769	67,668	14.44

Country	2000	2010	2025	2050	% change 2000–50
Greece	10,942	11,183	11,274	10,939	–0.03
Italy	57,116	60,098	60,018	57,066	–0.09
Malta	389	410	426	413	6.17
Montenegro	10,795	626	633	618	–94.28
Slovenia	1,985	2,025	2,050	1,954	–1.56
Spain	40,264	45,317	49,265	51,260	27.31
Northern rim	191,886	193,635	200,692	200,054	4.26
Algeria	30,506	35,423	42,882	49,610	62.62
Cyprus	787	880	1,014	1,175	49.30
Egypt	70,174	84,474	104,970	129,533	84.59
Israel	6,084	7,285	8,769	10,649	75.03
Lebanon	3,772	4,255	4,736	5,033	33.43
Libyan Arab Jamahiriya	5,346	6,546	8,144	9,819	83.67
Morocco	28,827	32,381	37,865	42,583	47.72
Occupied Palestinian Territory	3,149	4,409	6,553	10,265	225.98
Syrian Arab Republic	16,511	22,505	28,592	36,911	123.55

Country	2000	2010	2025	2050	% change 2000–50
Tunisia	9,452	10,374	11,797	12,711	34.48
Turkey	66,460	75,705	87,364	97,389	46.54
Southern rim	241,068	284,237	342,686	405,678	68.28
All countries	432,954	477,872	543,378	605,732	39.91

The total population for the region is expected to increase by 25% by 2025 and 40% by 2050. Population increase in the southern rim countries will be much greater than the growth in the northern rim countries (70% vs. 4%, respectively). This population growth is mainly the result of high fertility rates that are likely to slow down after 2030. The population in urban environments will probably increase, whereas the rural population will probably decline. Plan Bleu (2005) and the UN (2009) project that about one-third of the growth will take place in the coastal regions as depicted in Figure 21. Figure 22 shows projections for rural and urban populations for the Mediterranean northern and southern rim based on UN 2008 population data sourced from FAOSTAT (http://faostat.fao.org/site/550/default.aspx#ancor).

Figure 22: Projections for rural and urban populations for the Mediterranean northern and southern rim. Reproduced using data source from United Nations (2009).

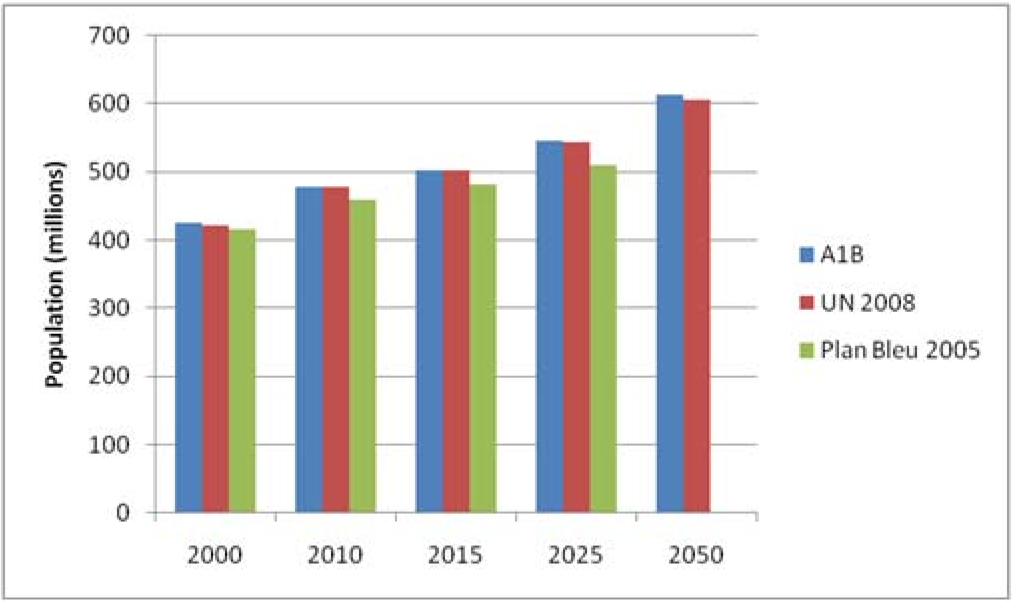


The differences in population projections published by different organisations can be observed in Figure 23. All projections are based on projections from the UN Population Division but from different base years and incorporate different assumptions concerning fertility, death and migration. For instance, Plan Bleu (2004) projections assume a slightly lower fertility rate for the future based on a much faster observed than projected slowdown in fertility rates for the south and the east of the Mediterranean.

There is clearly a great deal of uncertainty related to population projections as a result of high uncertainty of future trends of fertility and migration (Lutz, 2004, 2010). The SRES storylines are based on UN population projections from 1998. However, in its 2000 report, projections for 2050 had already risen by a further 5% (UN, 2002).

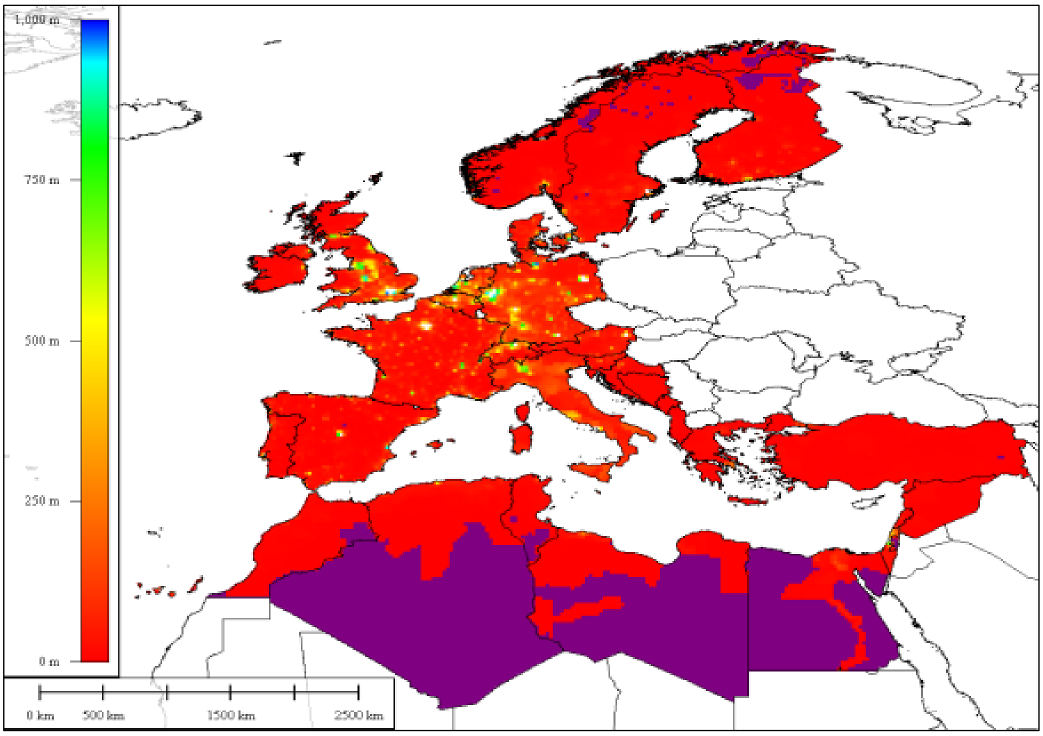
Economic projections are also uncertain. This was already pointed out in the SRES report on emissions (Nakicenovic and Swart, 2000), but more recently van Vuuren *et al*. (2008) compared the A1 scenario with more recent scenarios of change and found that economic growth projections were probably overestimated, particularly in the period up to 2025.

Figure 23: Population projections for different scenarios for the Mediterranean. Redrawn using data sourced from United Nations (2009).



It is important to indicate that these projections of GDP are highly dependent on the socioeconomic scenario used. The B2 storyline represents a world with an emphasis on local solutions to economic, social and environmental sustainability, a continuously increasing population (but lower than A2) and intermediate economic development (Nakicenovic and Swart, 2000). GDP under this scenario (Figure 24) is expected to show little change in the south and east of the Mediterranean, with growth highly concentrated in urbanised and industrialised areas of the northern Mediterranean and northern Europe. Since economic development confers adaptive capacity but also determines economic dependence on stability and on the provision of ecosystem services, and thus economic sensitivity to change, these distinct spatial patterns will have implications for the manner in which populations respond to environmental change.

Figure 24: GDP change projection for 2025 (SRES B2, GDP millions of US$). Source: CIESIN (2002).



Land-use scenarios for the Mediterranean

The impact of climate change

Potential drivers of future agricultural land-use change were discussed in relation to the Mediterranean region by Giupponi and Shechter (2003) and summarised by Rounsevell *et al.* (2005) as:

> 'world supply and demand trends, market intervention (through agricultural policy), rural development policy, environmental policy, EU enlargement, resource competition (e.g. urbanisation, recreation, bio-energy crops), the role of the World Trade Organisation (WTO) and climate change through its effect on crop productivity.'

Therefore, the impact of climate change on land use is difficult to assess given the number and influence of non-environmental drivers, as well as environmental hazards such as frosts, floods and heatwaves, which are covered below. Moreover, some production, such as milk and meat production, may be threatened by a climate-driven increase in indigenous and non-indigenous diseases (World Bank, 2009).

The response of vegetation to climate change is likely to be complex and non-linear. Generally, increasing CO_2 increases plant productivity by triggering physiological responses in the plants, resulting in more efficient resource use (Begon *et al.*, 1996). However, this is not a simple response as the climatic changes associated with elevated CO_2 also impact on vegetative responses. Increased temperature can lead to a longer growing season (and associated higher productivity), but for areas already at the edge of physiological tolerances for temperature and water availability, the increased heat and water stress will dramatically reduce productivity by increasing respiration costs (thereby diverting resources away from production) and stimulating earlier maturation (resulting in smaller yields).

An overall increase in water availability through, for example, increased rainfall is generally associated with an increase in primary productivity, but the relationship becomes far more complex when the intensity and frequency of rainfall events is considered: intense rainfall events interspersed with extended dry periods, as expected under the A1 scenario, tend to damage non-hardy plants (such as citrus fruit, grapes and olives) (Oleson and Bindi, 2002). In conclusion, although increased atmospheric CO_2 and temperature can increase total crop productivity, the expected decrease in precipitation for much of the Mediterranean, combined with greater variation in the periodicity and intensity of precipitation events, is likely to result in a net decrease in productivity in the region. High-value Mediterranean crops (fruit trees, olives and vines) are particularly vulnerable to the extreme weather events predicted to increase over the coming years (Oleson and Bindi, 2002).

Modelling results by Rounsevell *et al.* (2005) using both climate change and socioeconomic change scenarios show that the area under agriculture declines substantially by 2080, including in Spain (74%), Portugal (73%) and Greece (68%), a much greater decline than in northern Europe. However, Schröter *et al*. (2005) found that European land-use scenarios were affected less by climate change than by socioeconomic drivers. Both studies agree that the decreases in agricultural land use would be replaced in the north by small increases in bio-energy production and forests, as well as small increases in urban and protected areas.

Although area is set to decline under the A1 family of scenarios, northern Europe will likely increase its overall agricultural productivity as a result of increasing rainfall and temperature (Oleson and Bindi, 2002). In the Mediterranean, advances in agricultural technology may lead to substantial declines in agricultural area unless there is a large increase in the demand for agricultural goods, or if crop productivity declines (Rounsevell *et al*., 2005). The higher frequency of heat and drought stresses may lead to increased irrigation demand, particularly in the southern and eastern countries, and to increasing stress on water supplies, leading to a shift in crop production, especially for summer crops (Metzger *et al*., 2006; Moriondo *et al.*, 2010). Irrigated areas could increase by 38% in the south and 58% in the east by 2030, with more than half of this expansion taking place in Turkey (Plan Bleu, 2008a). The abandonment of rain-fed agricultural land is also projected to increase (Serra *et al*., 2008). In populated and farmed areas, there may be an increased risk of land degradation. Regions that are specifically vulnerable to this are considered to include Morocco, coastal Algeria, Tunisia, southern Spain and large parts of Turkey (MedSec, 2009).

In Verburg's (2006) analysis of future land-use changes for Europe under the A1 scenario, the most striking change in land use is due to further urbanisation as a result of population and economic growth. This urban sprawl is particularly expected in the southern and eastern Mediterranean region and in the coastal areas (Brauch, 2003; Plan Bleu, 2005) and will have clear implications for demand for specific ecosystem services (including agricultural production) and sensitivity to environmental hazards.

Agriculture and migration scenarios

The Scenar 2020 (Nowicki *et al*., 2009) scenario looks at projected changes in agriculture and migration. The Scenar 2020 scenario is based on analysis of trends from 1990 to 2005 projected to 2020, and projects a decline in the contribution of the agricultural sector to total income and employment in the EU27 leading to migratory pressures from rural to urban centres in the EU12 and from east to west in the EU as a whole. Productivity gains as a result of technological innovation in the agricultural sector will result in less land required for crops, even with a strong future growth in biofuel cropping.

Uncertainties with agricultural scenarios

There are still many uncertainties with agricultural and migration scenarios. The IMAGE2.2 model (Strengers *et al*., 2004) simulates land-use patterns forced by the A1B scenario and indicates that the total area of cropland in Europe might increase significantly as a result of greater food exports to regions such as China and India, and biomass crops will increase as a result of increased energy demand. These results are in contrast to earlier scenarios that assumed agricultural abandonment and a much lower growth in global food demand (e.g. FAO, 2002). The differences are mainly the result of different assumptions on population growth and food consumption rates globally as well as the development of global open markets, and the increase in global food demand as a result of rapidly developing countries leading to an increase in agricultural land, more food crop cycles and greater fertiliser use in the Mediterranean. Other uncertainties with agricultural scenarios are due to lack of detail in spatially explicit modelling of land use and crop productivity.

Climate change impacts on pull factors for potential pull countries (northern Europe)

Climte change projections for the northern European regions indicate an increase in precipitation for these areas along with a general warming that is most pronounced in eastern Europe in winter and spring. The increase in rainfall is expected to have a beneficial impact on summer and winter crops above latitudes of 55°N, leading to higher yields in these regions (Moriondo *et al*., 2010). The projected land-use changes that are most notable for northern Europe are increases in urban and forested areas and a large reduction in the areas under agriculture, particularly for food production (Rounsevell *et al.*, 2006). This potentially positive outcome of climate change may serve to strengthen the pull factors.

Population growth in the northern European countries is projected to increase by only 6% up to 2050 based on the UN population data (2008), which may also strengthen the region's pull factors relative to the Mediterranean countries in which the population growth rate is expected to be higher and the environment is expected to become less amenable to supporting the flow of ecosystem services to increased and increasingly concentrated populations. The UK and Germany are the main exceptions to this population trend with a 22% increase and 15% decrease, respectively (UN, Department of Economic and Social Affairs, Population Division, 2009). This difference is mainly the result of low birth rates and a rapidly ageing population in Germany compared with the UK, where birth rates are expected to remain high (UN Department of Economic and Social Affairs, Population Division, 2009).

Potential impacts of these scenarios

Hazards

The climte change scenario ensemble projections under consideration indicate temperature increases along with reduced precipitation and an increase the inter-annual variability of both temperature and precipitation for the Mediterranean, which could result in an increase of hydroclimatic hazards. These include floods and droughts (as a result of snowmelt or rainfall extremes), soil erosion and landsliding (again as a result of increased rainfall extremes) combined with land degradation, sea-level rise combining with storm surges (and tectonic tsunamis, leading to inundation of densely populated coastal areas) and heatwaves affecting ageing and urban populations in particular. The Mediterranean region is potentially very sensitive to climate change because it is characterised by strong cultural, economic, political and demographic gradients in already climatically stressed conditions. The strong rainfall seasonality of the Mediterranean brings periodic and often-sustained droughts as well as occasional extreme precipitation that can lead to flooding. Climate change will probably exacerbate the wet and dry extremes, and a lack of readiness and adequate adaptation strategies could result in critical situations in parts of the region. On the basis of recent migration trends, this may lead to an increased flow of people from the drier and poorer southern Mediterranean to (most likely) northern Mediterranean and northern European countries (Magnan *et al*., 2009).

However, the projections of GCMs have limitations because of their poor spatial resolution, and the projected patterns of hazards such as drought are not consistent between GCMs, especially for areas with high precipitation variability over time and space, as in the case of Mediterranean climatic regions. Drought is also highly spatially variable and unpredictable owing to its correlation with unpredictable precipitation events, as has been pointed out for Turkey (Komuscu, 1999) and Spain (Vicente-Serrano *et al*., 2004).

Impacts on droughts

Using climate projections available at the time, Jones *et al.* (1996) projected that by the end of the twenty-first century, Europe will face increases in the intensity, duration and spatial area of drought in the Mediterranean basin. The regional consequences might be severe owing to the paucity of water resources in this area coupled with the high demand for water for agricultural, industrial and tourist activities and the impact of erosion and land degradation associated with agriculture (López Bermúdez and Sánchez, 1997).

There are also significant hydroclimatic impacts originating outside the region, for example all of the population and agriculture in Egypt is concentrated in a narrow strip along the banks of the Nile and in the Nile Delta. Disruption of the Nile flow regime, whether due to climate change or human activity within the 10 African countries contributing to the flow of the Nile, may present serious consequences for the Egyptian population. Droughts could have serious impacts on water and food security with very rapid onset and difficult issues of conflict and benefit sharing around ecosystem service provision.

Impacts on heatwaves

Heatwaves in Europe have become more frequent in recent years (Della-Marta *et al*., 2007). Fischer and Schär (2010) analysed high-resolution regional climate simulations in Europe and predicted that the most pronounced changes in heatwave frequency and duration will occur in the southernmost areas of Europe, and projections of related health impacts will be most severe for low-altitude river basins in southern Europe and for the Mediterranean coasts, affecting many densely populated urban centres. Heatwaves exacerbate air pollution and can often lead to higher morbidity and mortality, predominantly in the elderly, infants and persons with pre-existing cardiovascular and respiratory disease. Substantial excess mortality has been observed during several recent heatwaves including the severe heatwave in the summer of 2003, reviewed by García-Herrera (2010), which resulted in around 40,000 deaths across Europe. An increase in frequency and intensity of summer heatwaves can have serious economic consequences, such as on agricultural yield and energy demands for cooling. Wine harvests, for example, are very sensitive to changes in the frequency and duration of extreme heat events. According to Patterson and Josling (2005), Europe saw its weakest wine harvest for the past 10 years in 2003 (USDA/FAS, 2003), primarily due to a heatwave and drought in Germany, France, Italy, Luxembourg and Austria.

Impacts on sea-level rise

Scenarios for sea-level rise are highly uncertain, with climate change-driven thermal expansion of the oceans thought to account for only a few centimetres of rise over the coming decades. Rising sea level will mainly affect coastal and deltaic regions, but in the Mediterranean most of the population live in precisely these areas. Much of the Nile Delta is already at or below sea level and is one of the world's most densely populated 'mega-deltas'. Therefore, even a marginal sea-level rise combined with storm surges could create disastrous flooding, for example in Alexandria, Egypt's second city. Increased erosion of the Nile Delta has already been attributed to upstream engineering projects such as the Aswan High Dam, and as a result the land levels of the delta are falling at the same time as sea levels are rising because of climate change (Bohannon, 2010). Water quality in Egypt is already poor because of pollution due to lack of development control (Haas, 1990).

Even if we ignore the few centimetres of sea-level rise expected through ocean warming, it is prudent to quantify the potential impact of very high and catastrophic sea-level rises and inundation as a result of storm surges, polar melting or tsunamis such as the historically documented event in eastern Mediterranean of AD365 (Shaw *et al.*, 2008). The World Bank (World Bank, 2009) estimates that a rise in sea level of 1 m would affect just under 10% of the Nile Delta population (around 6 million people) and cause a loss of 10% of arable land. Using the Space Shuttle Radar Topography Mission (SRTM) data (Farr and Kobrick, 2000), Mulligan (2007) produces a crude global analysis of inundation under a series of catastrophic sea-level rise scenarios. A 2-m rise would inundate the coastal zone areas below 2-m elevation shown in Figure 25. Some of these areas (especially in the northern Mediterranean and northern Europe) are highly populated with significant infrastructure and commercial activity, meaning this inundation could significantly affect the high level of GDP in those areas (Figure 26).

Figure 25: Inundation resulting from catastrophic 2-m sea-level rise/surge. Source: Mulligan (2007).

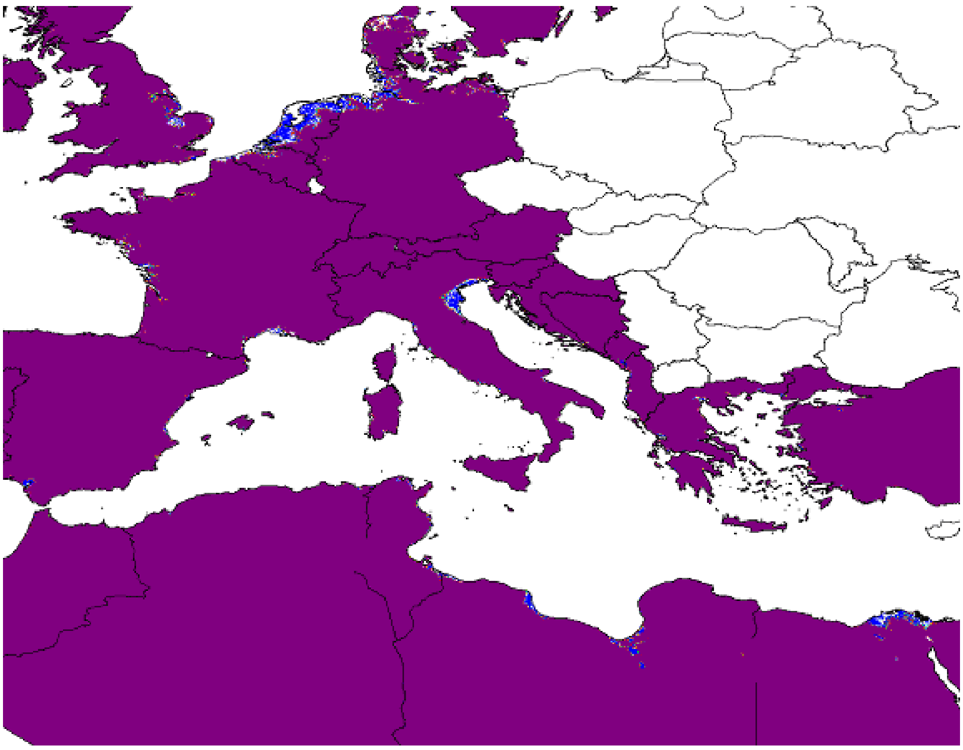
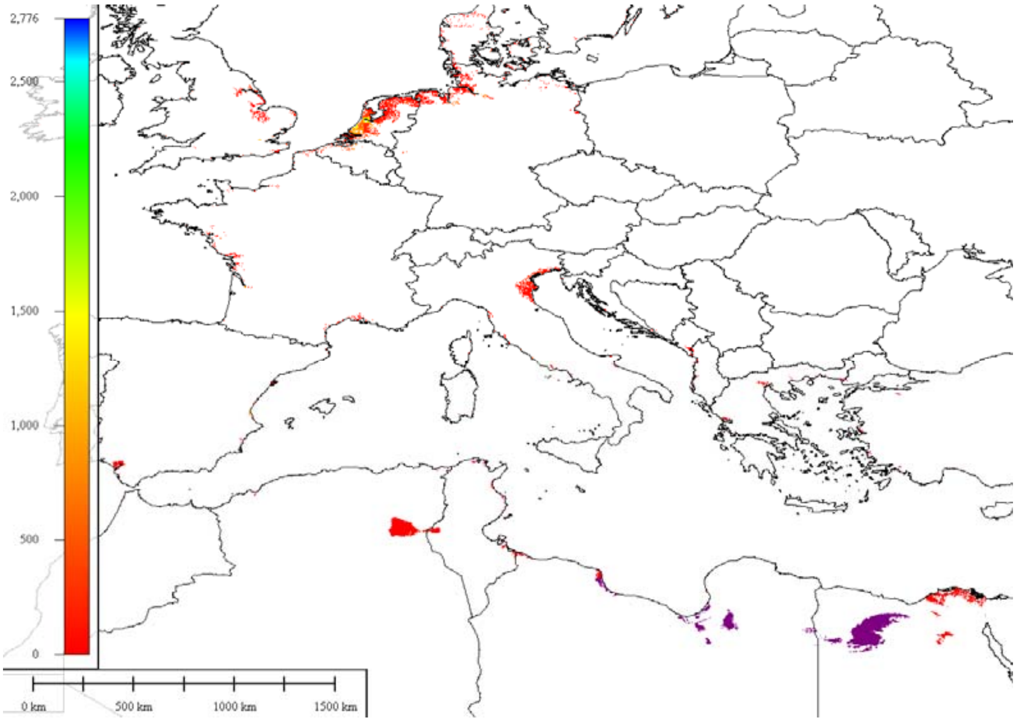
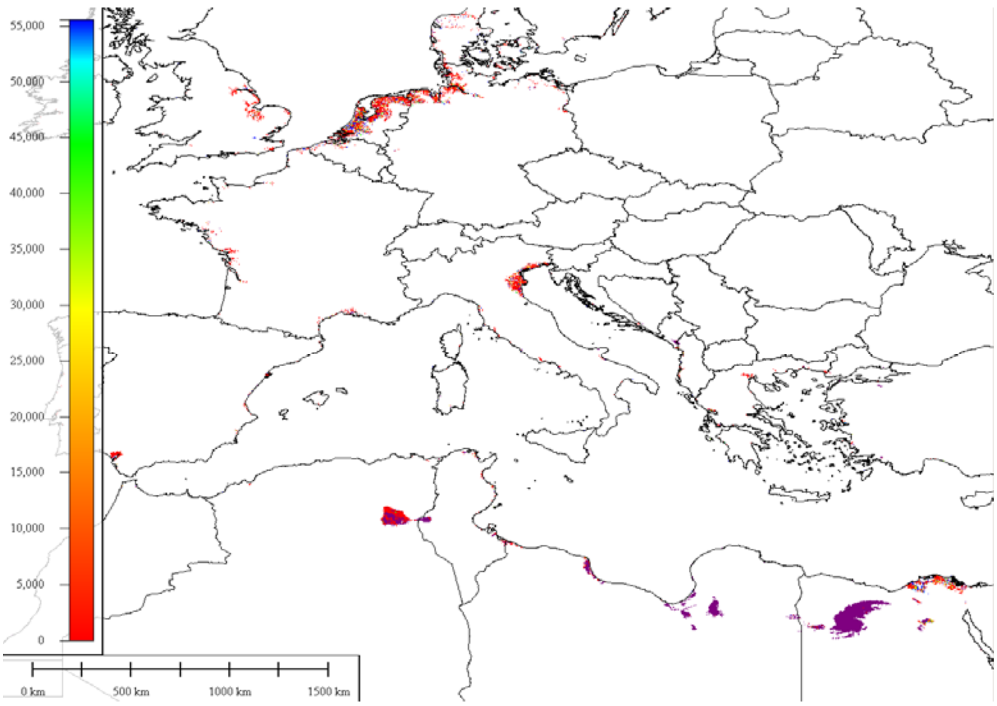


Figure 26: GDP (millions of US$ per year) loss that could result from a 2-m sea-level rise/surge.



Significant population densities are also present in some of these areas (Figure 27), such that inundation could have very serious consequences for forced migration from northern Europe (UK, Netherlands), the northern Mediterranean (Venice) and the southern Mediterranean deltaic areas (Nile). The terrain datasets used here are too crude for any more detailed analysis (90-m spatial resolution) and do not fully incorporate significant investments in sea defences made in the Netherlands for example, but nevertheless the main spatial patterns are clear.

Figure 27: Population that could be affected by a 2-m sea-level rise/surge.



Impacts on flood risk

Risk of flood may also alter as a result of climate change. It is widely acknowledged that climate change may severely alter the risk of hydrological extremes and that changes in precipitation, especially the increased intensity and frequency of rainstorms, are likely to be reflected in increased run-off.

Figure 28: Index of flood vulnerability (mean for administrative units).

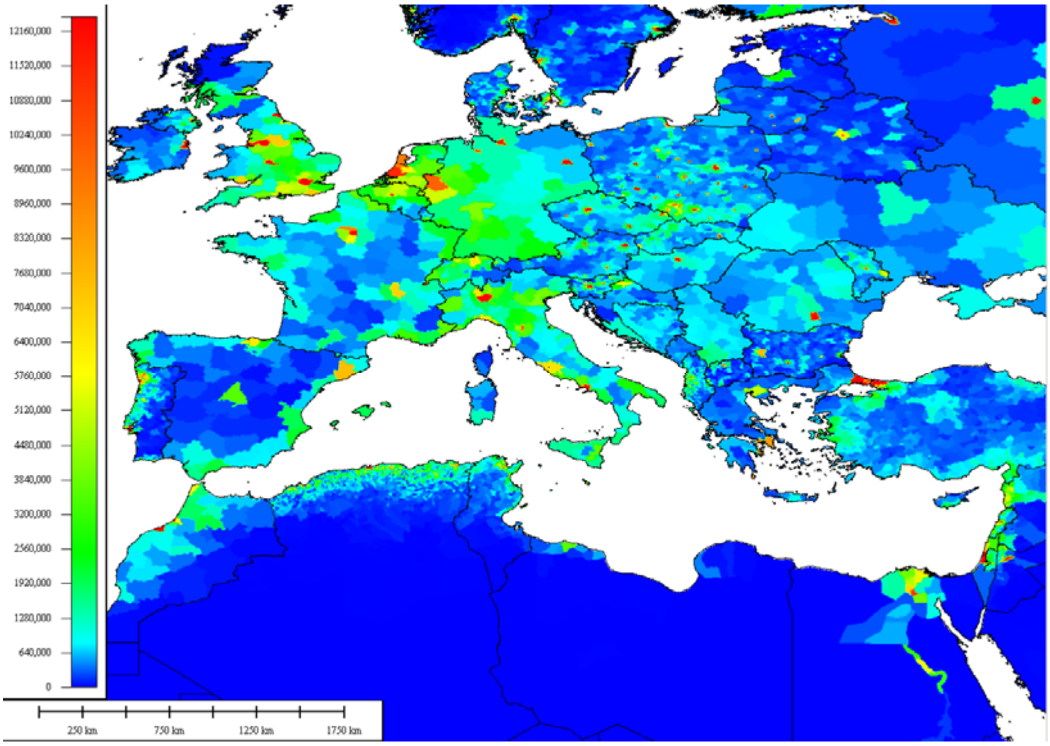


Figure 28 shows a crude index of flood risk (excluding the effects of mitigation measures that may be in place). This is an index of upstream cumulated rainfall (a measure of river system magnitude and thus hazard) and population density (a measure of exposure). The data are calculated on a 1-km pixel basis but are presented here as means for administrative units. The effects of mitigation measures are excluded, but the pattern of risk is clear (vulnerability to this risk will be reduced where investments in flood defence are made and maintained). Risks are greater in northern Europe and parts of the north and east Mediterranean because of the high population densities and large, humid catchments. Population, agriculture and economic activity in the north and east Mediterranean and parts of northern Europe are disproportionately concentrated in areas at risk for flooding. Although the flood risk is lower, flooding in the southern Mediterranean countries is of particular concern because flooding has historically been most devastating in this region in terms of casualties.

Climate change may reduce risks overall because of lower rainfall but may increase them locally if extreme rainfall and snowmelt events become more frequent or of greater magnitude (Figure 29).

Figure 29: Area of permanent snow and ice (according to GlobCover) in river basins (km^2).

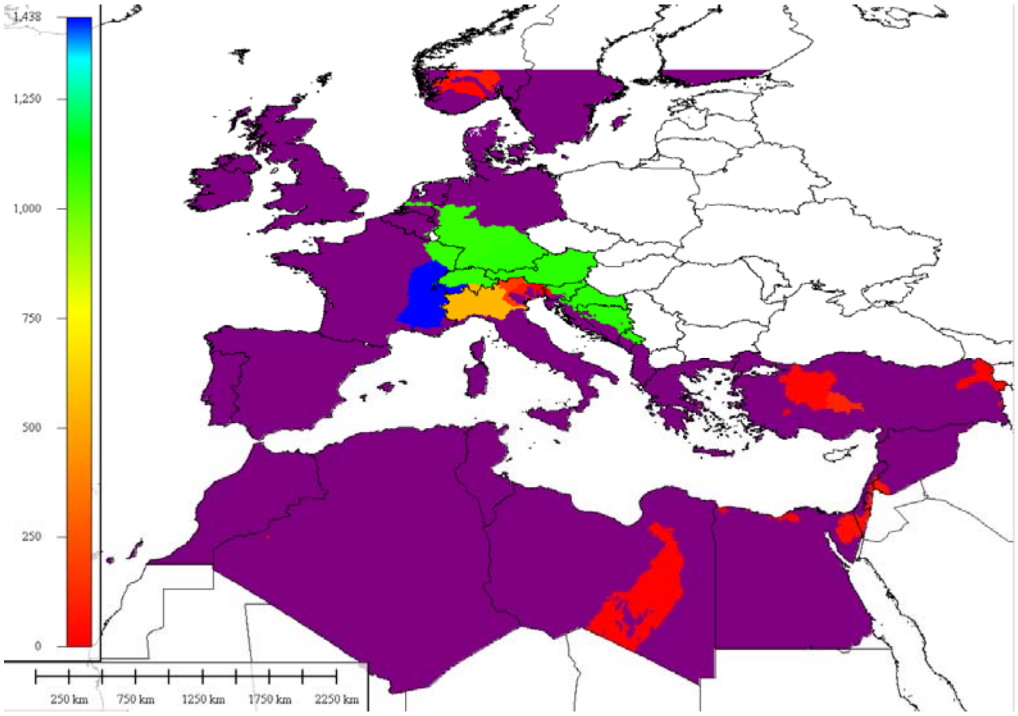


Figure 29 shows the total area covered by permanent snow and ice (according to the GlobCover remote-sensing analysis). The permanent snow and ice area is summed in hydrological basins as an indication of (a) the dependence of water resources on snowmelt and thus the potential for enhanced drought if snow were to disappear and thus no longer sustain flows in the dry season and (b) the potential for rapid-onset snowmelt leading to enhanced downstream flooding. Clearly, a number of populous basins in Italy, France, Germany and parts of Eastern Europe have significant areas of permanent snow and ice upstream and are thus vulnerable to enhanced drought and flood risk with climate warming. Case studies for the Rhine, Rhone and Danube basins reported in Schröter (2005) indicated that changes in the temperature regime will both increase winter run-off from snowmelt and shift peak flows up to 2 months earlier than at present.

Impacts on desertification and soil erosion

With aridity expected to increase under climate change, a substantial increase and northward extension of arid regime lands may take place, leading to increased desertification (Gao and Giorgi, 2008) and diminished productive capacity. Desertification is a result of both physical processes (land cover change, soil erosion, climate change) and human processes (unsustainable agricultural practices, rural depopulation). The impact of climate change on desertification will depend on a number of factors; the expected increase in storm frequency may increase soil erosion and the general decrease in rainfall will decrease vegetation cover and soil moisture impacting upon soil production, productivity, run-off and groundwater recharge.

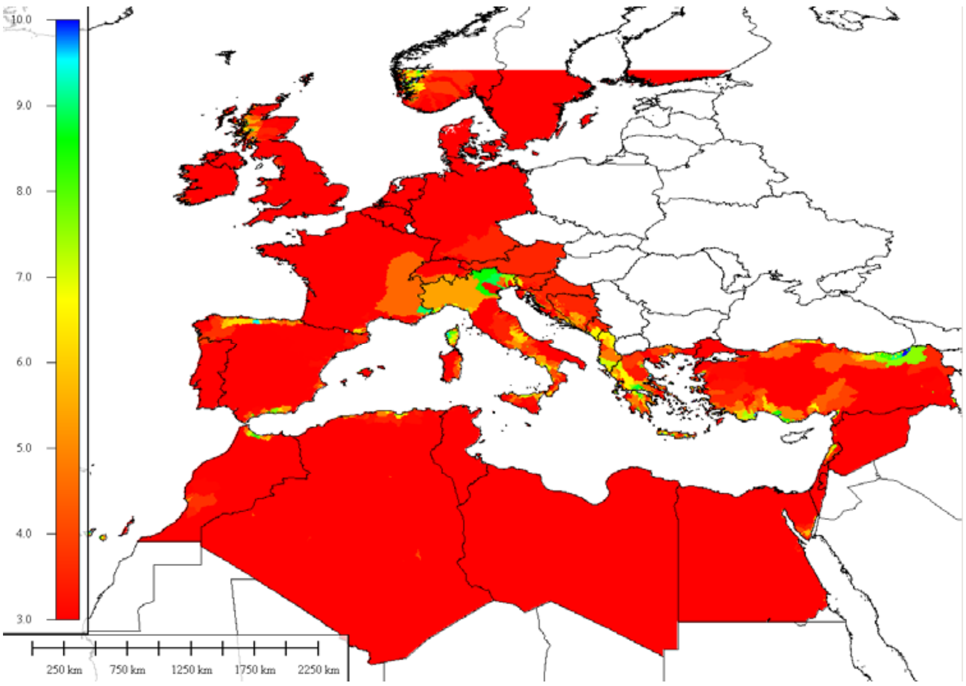
Nunes *et al*. (2009) addressed this issue by analysing the sensitivity of run-off and erosion to incremental degrees of change (from −20% to +20%) to storm rainfall and pre-storm soil moisture in two Mediterranean watersheds using the MEFIDIS model. Results are shown in Table 3.

Table 3: MEFIDIS model sensitivity analysis of run-off and erosion to rainfall soil and vegetation.

Changes in storm rainfall	High sensitivity (expected greater storm intensity and frequency – more run-off)
Soil water content	High sensitivity (higher temperatures and less precipitation – drier soils – less run-off)
Soil depth	High sensitivity (shallow soils – less soil moisture capacity – more run-off)
Changes in vegetation cover	Low sensitivity

In addition, studies indicate that bare agricultural or bare abandoned land will suffer more erosion than vegetated areas, for example see López-Vicente (2011), and so abandoned agricultural land that facilitates vegetation recovery may reduce soil erosion in the long term, although with consequences for the farm economy. Overall, Nunes' (2009) results indicate that decreasing run-off from lower soil moisture levels caused by climate change and a decrease in agricultural land could be sufficient to offset the impact of greater storm intensity in Mediterranean watersheds, although areas with shallow soils (and steep slopes) will generally experience an increase soil erosion if the expected increase in rainstorms intensity and frequency occur. Figure 30 shows the mean slope gradient (based on 90 m SRTM terrain data aggregated to 1 km; Farr *et al*., 2000) averaged over watersheds. This can be used as a broad assessment of the areas particularly at risk of soil erosion and landsliding owing to their physical environment and thus of those areas vulnerable to change in these processes with climate change.

Figure 30: Catchment mean slope gradient (degrees).



Human vulnerability to desertification as a consequence of social, political and economic variables is considered more fully in DR8b. However, given the projected combined impacts of climate change, dryland population growth and the pressure on drylands brought about by a projected global decline in good cultivable land, enhanced Mediterranean desertification may represent a risk to food security, health security and livelihood security, all of which impact on decisions to migrate. In north Africa, food security issues are particularly important. In areas of current water scarcity in north Africa there is already a dependence on cereal imports and thus international market dynamics (Yang and Zehnder, 2002). Nevertheless, desertification is usually a slow process rather than a catastrophic event and thus the direct links between desertification and migration events within the Mediterranean basin have yet to be demonstrated (Safriel, 2009).

Impacts on wildfire risk

Fire risk depends on human, ecological, biophysical and climatic factors such as whether it is a wet or dry summer, wind magnitude and direction, sources of ignition and the amount of dead wood available to propagate combustion (Pausas, 2004). Cemagref (2009) shows that fires during dry years, as in 2003 to 2008, can lead to a collapse of the biological operation of the ecosystem. A long dry period after a fire will slow or even stop plant regeneration. Similarly, the impact of a fire is greater on an environment that has recently suffered a long dry period since combustion may be more intensive than extensive. The recent trend in and projected future continuation of abandonment of land by farmers and a reduction in livestock pressure have resulted in high-fire-risk scrub species moving into the previously grazed areas. Four successive dry years would appear to constitute a critical threshold in the resistance of forests to fire. If summers become warmer and drier, forest ecosystems will become more vulnerable. To reduce fire risk, some areas have implemented scrub clearance programmes, for example in La Rioja region in Spain (Lasanta *et al*., 2009). Clearly, current burned areas are much more frequent and extensive in the east Mediterranean, and given that precipitation is projected to decline and temperature to increase in this area, wildfires may become more frequent and their consequences for landscape, air pollution and agriculture may worsen. However, some of these impacts may be manageable through vegetation management and changes to agricultural practices (reducing or better controlling the use of fire).

Ecosystem services

The Millennium Ecosystem Assessment identifies ecosystem services as ‘the benefits people obtain from ecosystems’ and defines four types (provisioning, regulating, cultural and supporting) which are closely linked to the five constituents of human well-being (Millennium Assessment, 2005). Important services include:

- provisioning services: for example crop and livestock production, freshwater, fibre and forestry, fisheries;
- regulating services: for example soil-erosion regulation, water-quality regulation, natural hazard regulation, carbon sequestration, pest regulation, flood protection; and
- cultural services, which are more difficult to quantify: for example aesthetics, recreation, ecotourism, and spiritual and religious values.

One should distinguish between environmental services and ecosystem services (Mulligan *et al*., 2010). Environmental services are a function of the environment and relatively independent of the ecosystem (e.g. water quantity services resulting from high rainfall and low evaporation in mountain regions). Ecosystem services on the other hand are fundamentally dependent on the local ecosystem present and can be managed by managing that ecosystem, an example being the high quality (low sediment concentration) water derived from intact forested ecosystems in mountain environments compared with the water quality from the same environments under agricultural land use.

Provisioning services

Key provisioning services within the Mediterranean include food production, freshwater production, soil productivity and energy production. Not all of these services originate within the region, indeed 11% of water used within the Mediterranean border countries originates outside the region (Plan Bleu, 2009b), creating external dependencies for the provision of these services.

A 2005 review of the potential impacts of climate change on a wide range of ecosystem services across Europe found that generally the A2F1 scenario led to the greatest decrease in service provision, with the Mediterranean region being most vulnerable to these decreases when compared with other European regions (see Table 4 for a more detailed breakdown) (Schröter *et al*., 2005).

Table 4: Results from Schröter *et al*. (2005) summarising, where possible, the impacts of climate change (A1F1 scenario) on various ecosystem services in the EU Mediterranean countries.

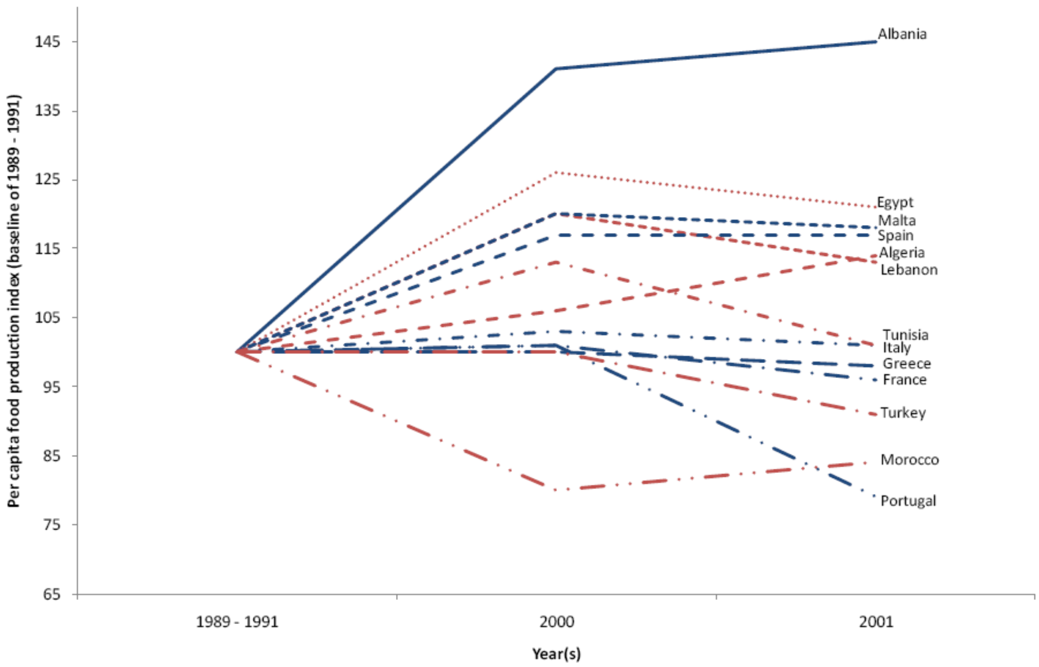
Ecosystem service	Potential implication of climate change in the Mediterranean by 2080
Provisioning services from cropland and grazing land	Decrease by 10.7% and 8.7% (not accounting for technological change)
Provisioning services from bioenergy crops	Decreases in southern Europe and increases in northern Europe
Water availability	20–38% of Mediterranean population living in watersheds with increased water stress
Biodiversity (not a service *per se*)	Impacts at species level, for example characteristic Mediterranean tree species, cork oak (*Quercus suber*), holm oak (*Q. ilex*), Aleppo pine (*Pinus halepensis*) and maritime pine (*P. pinaster*), are likely to decrease in distribution
Reliable snow line (provisioning and regulating service for water)	In the Alps, this is likely to rise by 200–400 m, thus reducing ski-tourism potential

Food provision

Food security occurs when all people, at all times, have physical and economic access to sufficient safe and nutritious food to meet their dietary needs and food preferences for a healthy and active life (FAO, 1996). Food security is a complex issue encompassing economics, agriculture and many other disciplines. A general evaluation of the probable impacts of climate change on food security within the Mediterranean region is challenging owing to the socioeconomic and policy differences within (e.g. north vs. south France) and between Mediterranean countries (Giupponi and Shechter, 2003). It is only fairly recently that the Mediterranean countries have achieved food security; NMCs generally reaching security by the mid-20th century, while most southern and eastern Mediterranean countries (SEMCs) achieved security by the 1990s.

According to Padilla *et al*. (2005), per capita food production has tended to decrease from 2000 to 2001, although most countries are producing more food than baseline (1989–91) levels (see Figure 31). In absolute terms, the southern Mediterranean countries are the least food-secure, although none are as insecure as sub-Saharan countries. Without changing current practices, the southern Mediterranean will most likely see a decrease in food security as a result of decreases in agricultural productivity and economic activity while population and food demand increases (Giupponi and Shechter, 2003). Without significantly more irrigation, there will be an increased reliance on imported food and a decrease in food export.

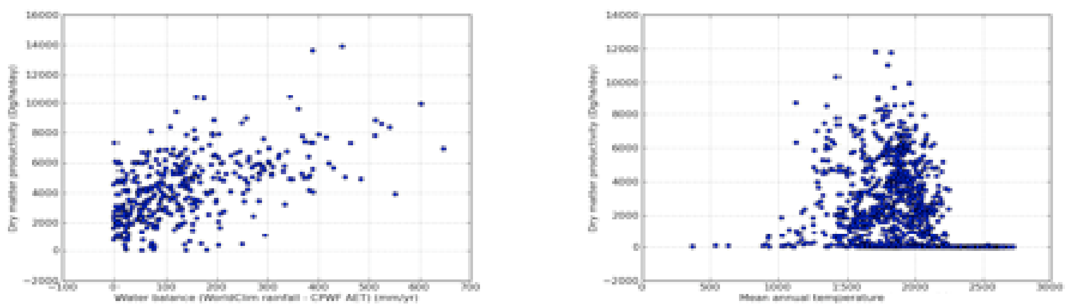
Figure 31: Per capita food production for Mediterranean EU and SEMC using 1989–91 as a baseline level (Padilla *et al*., 2005).



As discussed earlier, although increased atmospheric CO_2 (through CO_2 fertilisation) and temperature can increase total crop productivity, a decrease in precipitation, combined with greater variation in periodicity and intensity of precipitation events, may result in a net decrease in productivity in the Mediterranean (Vidal *et al.,* 2001), which will have implications for food security. Under the A2 scenario, an increase in technology combined with CO_2 fertilisation is likely to increase agricultural productivity in Europe up to 2030, but beyond 2030 the warming is likely to become limiting to crop production (van Meijl *et al*., 2006). There is less research focused on SEMCs, however, but it is likely that agricultural productivity will be limited by water availability (Vidal *et al*., 2001) and, given that agriculture makes up the greatest user of water in the Mediterranean region (Shatanawi *et al*., 2005), food security is likely to decline.

In order to further quantify the impact of climate change on productivity, Figure 32 shows that satellite-measured dry matter productivity (as a mean for the period 2000–10) from Mulligan (2009) responds strongly to annual precipitation (not shown) water balance (rainfall–ET, left) and temperature (right) in the Mediterranean region extracted from the datasets mapped in Figure 14 and Figure 3. The points represent 1,000 randomly chosen 1-km pixels covering land areas in the Mediterranean. On the basis of the existing patterns of productivity as a spatial analogue for change, we can expect decreases in water balance in the range of 600–100 mm per year and increases in temperature in the range of 20–23°C to cause significant declines in dryland plant production for fuel, fibre, cropland and grazing. Increases in rainfall and increases in mean annual temperature in the range of 15–20°C may lead to increases in productivity.

Figure 32: Measured productivity from SPOT VGT data, water balance (mm per year) and mean annual temperature (°C * 100). Data sourced from Mulligan (2009).



Water provision

The hydrological cycle provides many ecosystem services: fresh water, in-stream flows, flood mitigation, cultural services for recreation, and supporting services enabling plant growth and providing habitat. Both aquatic and terrestrial ecosystems play an important part in providing hydrological services. Key systems responsible for water purification are riparian forests, wetlands and soils ecosystems, which act to slow the flow of water through the landscape and to filter out sediment, excess nutrients and metals. A further important ecosystem service is the reduction of sedimentation, thus maintaining the economic value of hydropower and reservoir dams. The human benefits of water cycling are often received away from the location of the ecosystem service provider; for example, an upstream forest may provide fresh water for a downstream conurbation located hundreds of kilometres away (Guo *et al*., 2001; Brauman *et al*., 2007).

The hydrological cycle and associated ecosystem services are likely to be severely impacted by climate change, and the Mediterranean region has been defined as a 'hot-spot' for hydrological change (Mariotti *et al*., 2008). The dynamics of the hydrological cycle adds a further layer of complexity and uncertainty because of its dependence on GCM precipitation and the non-linear relationship between evaporation, precipitation and run-off (Nunes *et al*., 2008) as affected by topography, vegetation and landscape flow connectivity. In order to capture some of these complexities, we apply the spatially explicit, physically based WATERWORLD model (http://www.policysupport.org/links/waterworld; Bruijnzeel *et al.,* 2011;

Mulligan *et al*., 2011) to model the hydrological baseline (mean 1950–2000) and then a scenario for climate change based on HADCM3 A1B for 2050 downscaled to the baseline climate using the delta method.

Under the HADCM3 A1B scenario, precipitation is likely to decrease in the Mediterranean (as shown in Figure 17). This decrease may be particularly pronounced in the summer, as shown in Figure 33. Higher temperatures are likely to lead to higher evapotranspiration, where water is available (Figure 34). Water balance is likely to dip therefore, especially in the summer (Figure 35).

Figure 33: Modelled precipitation under HADCM3 A1B scenario for 2050 (left) and baseline 2000 (right).

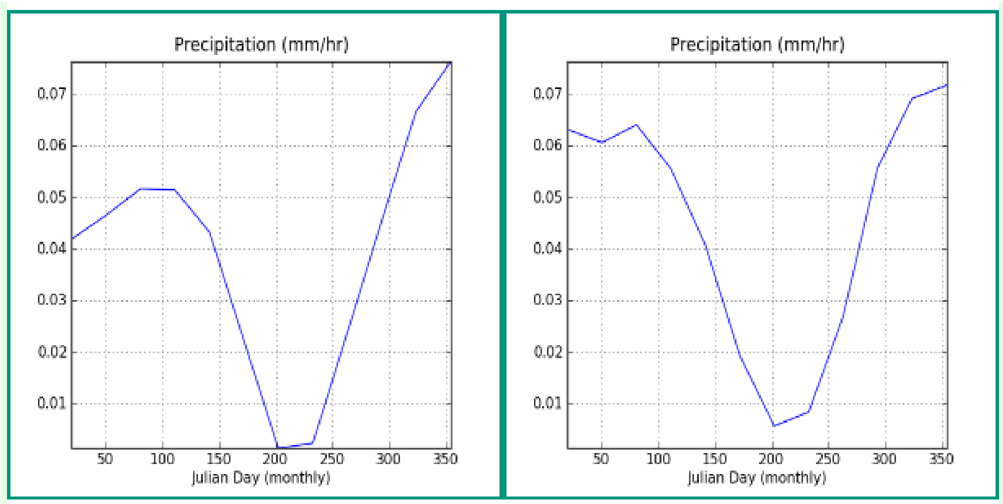


Figure 34: Modelled actual evapotranspiration under HADCM A1B scenario for 2050 (left) and 2000 (right).

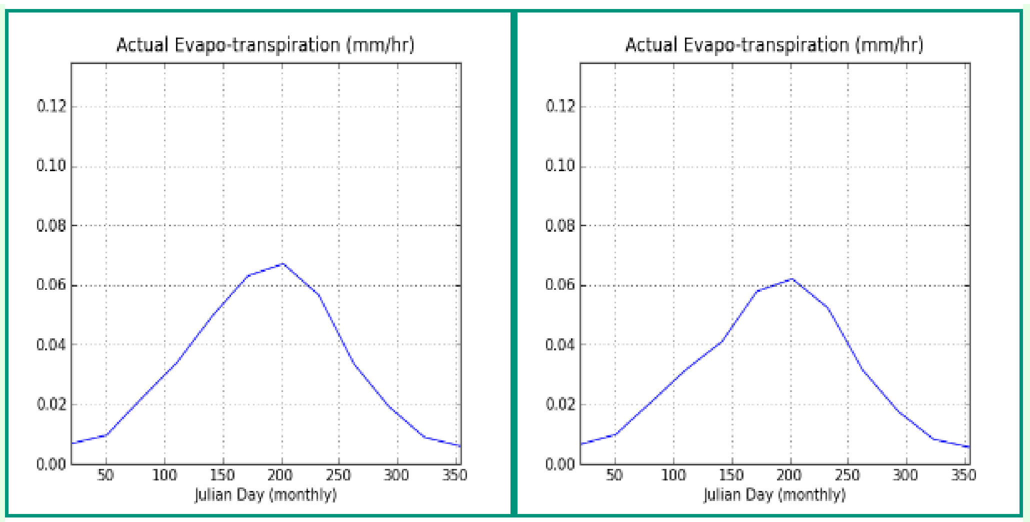
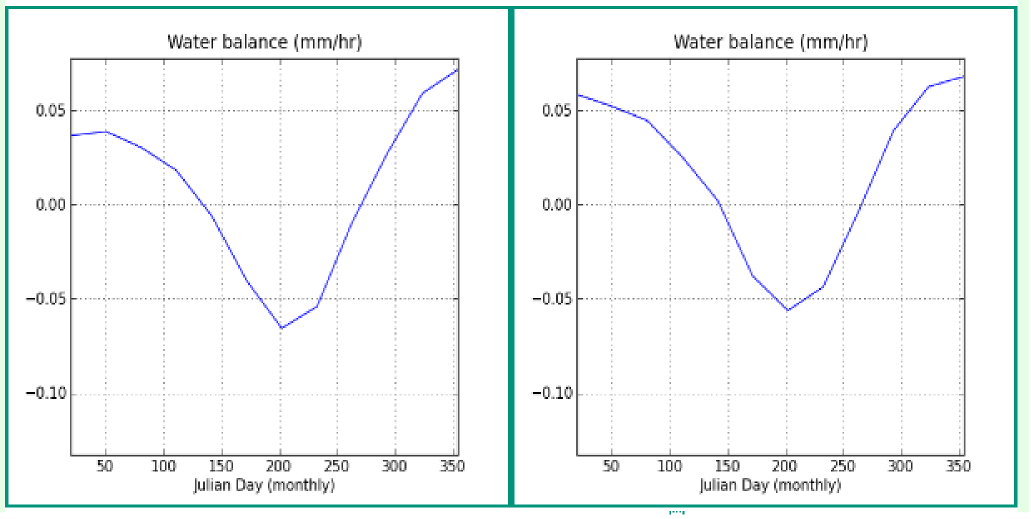
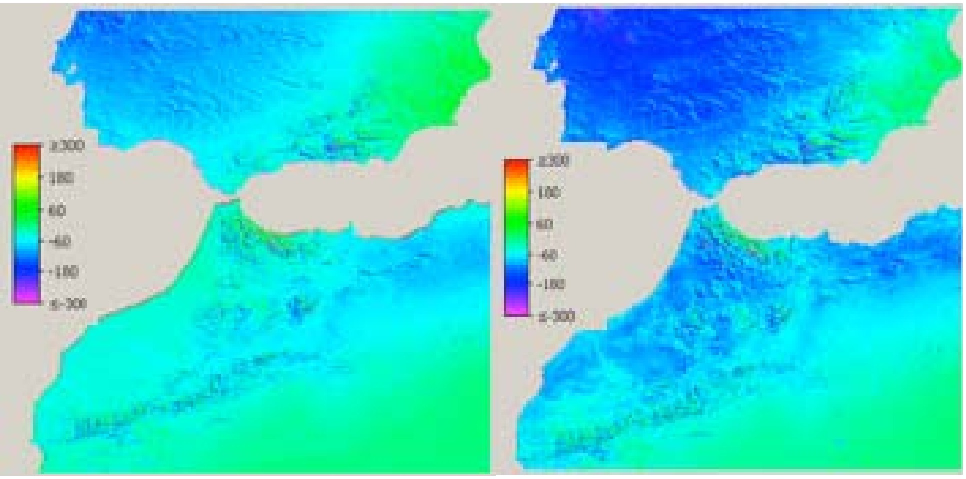


Figure 35: Modelled water balance under HADCM A1B scenario for 2050 (left) and 2000 (right).



However, the outcome will be highly spatially variable at regional and local scales and depend upon the GCM and scenario used. For example, Figure 36 shows the spatial variability of change in a single 10º tile for rainfall (left) and water balance (right).

Figure 36: Spatial change in rainfall (left) and water balance (right) under HADCM A1B scenario (mm/hour), green/red = wetter, blue = drier.



Nunes *et al*. (2008) describes hydrological modelling based on the A1B scenario in Portugal and found that increased temperature is likely to affect subsurface flows due to increased evaporation, while decreased rainfall affects both surface and subsurface flows, with water being diverted from run-off to plant use. Such changes are likely to vary spatially and temporally depending on soil properties, land-use change and population-change pressures . Under the A1F scenario, summer run-off in the Alpine region is likely to decrease by 46%, an increase in water stress occurring in the already stressed summer months (Schröter *et al*., 2005).

Water availability is fundamentally controlled by water quality as well as quantity, where water quality defines its suitability for a given purpose. Water quality is an important regulating service, often termed the water purification service and is thus discussed later under *regulating* *services*. Across all Mediterranean basin countries, it is estimated that water availability will fall from approximately 350 m^3 per inhabitant per year to approximately 300 m^3 per inhabitant per year by 2025, and still be at that level by 2050 (Shatanawi *et al*., 2005). This effect is unlikely to be spatially even across the region, with NMCs experiencing less shortage due to increased precipitation. Although consumption patterns are likely to increase under the A1 scenario, it is hypothesised that the assumed technological advances will to some extent offset the associated increase in water demand by increasing the efficiency of agricultural production and irrigation techniques. However, the proportion of urban population is likely to increase at a higher rate than that of rural population. Given that spatial and cultural separation from the source of an ecosystem service, in this case from upstream watershed ecosystems, leads to a reduced awareness of the reliance on that ecosystem, it may be difficult to bring about the changes in individual behaviour necessary to reduce water demand (Brauman *et al*., 2007). This 'disconnection' from nature is likely to be most felt in the SEMC countries owing to the high rates of projected urbanisation. These countries already suffer water shortages, and therefore face a combination of the greatest increase in water scarcity, the greatest increase in irrigation, the highest population growth and the greatest increase in urbanisation (Plan Bleu, 2009b).

Energy production – ecosystem services and power

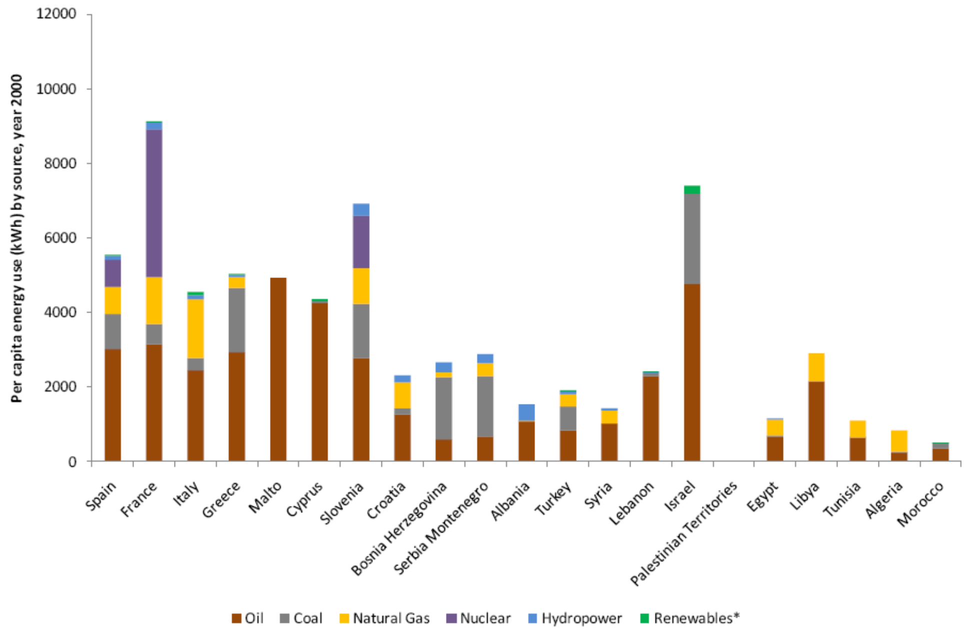
In Mediterranean rim countries, just 1% of electricity came from renewable sources in 2000, with a further 2% from hydropower and the remainder predominantly from fossil fuels. Figure 37 shows the per capita energy usage of Mediterranean countries from different supply sources for 2000 and estimates for 2025 [data sourced from the International Energy Agency, from 1971 to 2000 energy balances of the Organisation for Economic Co-operation and Development (OECD) and non-OECD countries].

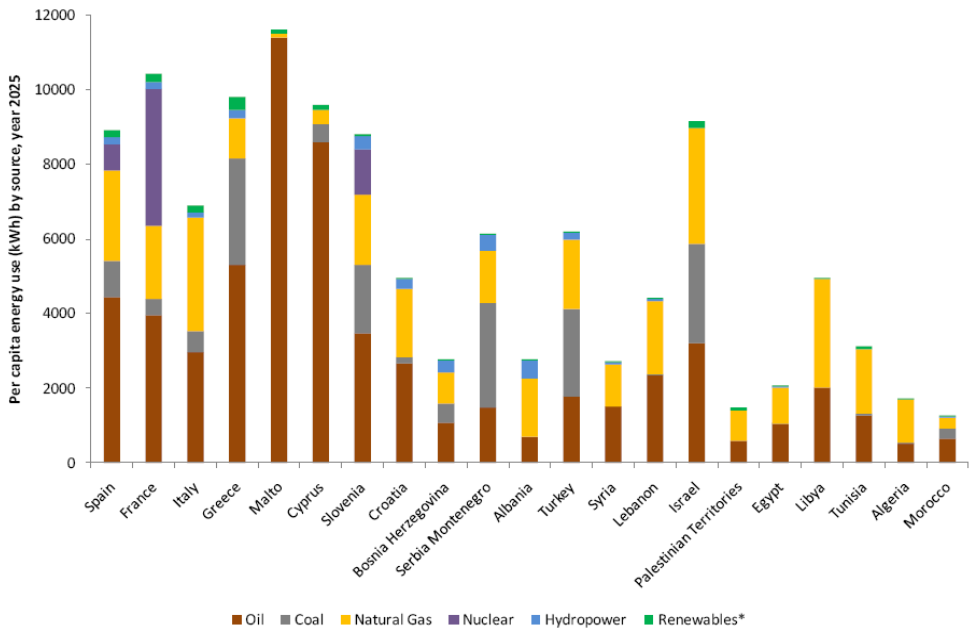
Ecosystems can provide energy services through biofuels and hydropower. Although there is a potential for up to 8,000 MW production of power from biofuels in the SEMC, the increasing pressures on agriculture in parts of the region may mean that biofuel production is not sustainable (Pimentel, 2003). Hydropower relies on run-off and, although precipitation is likely to increase, run-off is not always anticipated to do the same, meaning that future hydropower potential may decrease as a result of climate change (Harrison *et al*., 1998). Furthermore, although the potential for small-scale dams is generally high across the Mediterranean basin, some countries have little scope for further development (for example 73.4% of Spain's land area already drains into a dam). In some cases, dams might become less productive, for example Egypt currently generates 11% of its electricity from hydropower plants, but is likely to reduce to 3.5% by 2025 owing to a decrease in surface water availability and increased sedimentation in the dams (Plan Bleu, 2008b). Detailed consideration of site availability (and the robustness of that suitability under climate change), along with a cost-benefit analysis considering the pressures of hydropower production on water resources, is necessary (Plan Bleu, 2008b) as well as better understanding conflicts between upstream and downstream users and uses of water.

Regulating services

Climate regulation and carbon sequestration are important regulating services. Vegetation can act as a carbon sink by extracting CO_2 from the atmosphere and converting it to plant material through photosynthesis. When vegetation dies, carbon is stored in dead wood or the soil and eventually returns to the atmosphere; some estimates place the global soil carbon store at over 2,700 Gt (Lal, 2008). Sequestration and storage of carbon regulates the atmospheric

Figure 37: Per capita electricity use for the Mediterranean rim countries in 2000 (top) and 2025 (bottom) showing the supply sources. Renewables are classed as geothermal, solar and wind energy.





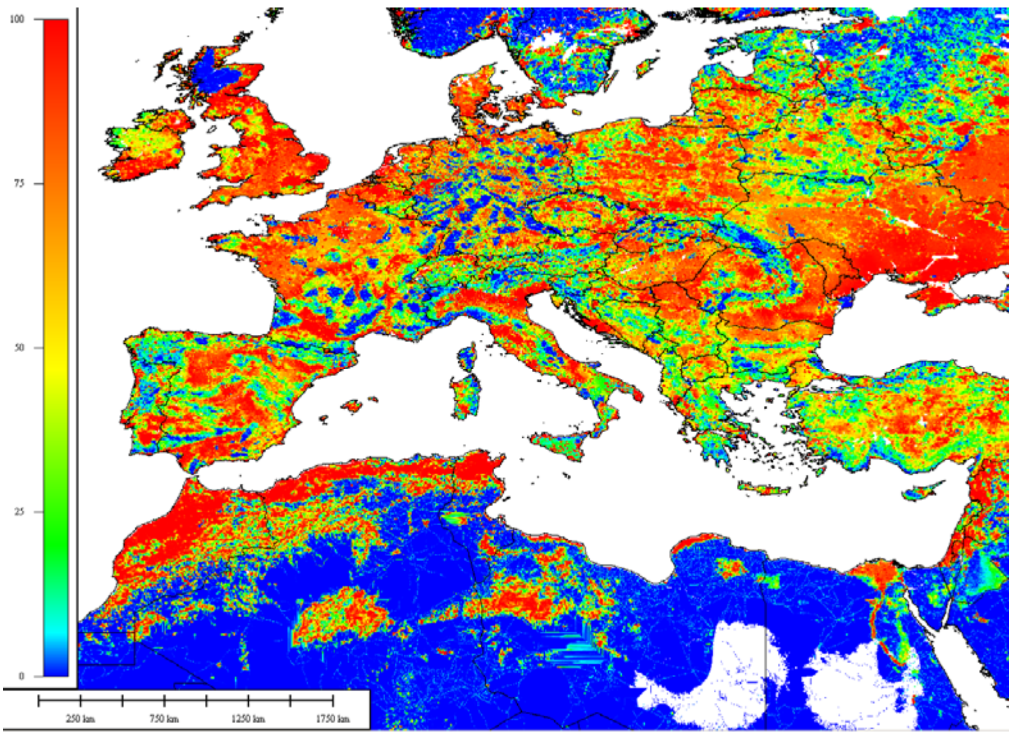
composition and thus climate and, to some extent, buffers increasing carbon emissions. Mediterranean ecosystems are currently thought to be a net carbon sink (Morales *et al*., 2007). Sequestration levels range from 0.01 to 1.08 t C/ha, the highest levels occurring in Croatia and Slovenia (Croitoru and Merlo, 2005).

Current atmospheric CO_2 limits photosynthesis and increasing atmospheric carbon in the future may enable faster photosynthesis through CO_2 fertilisation, while rising temperatures may lead to longer growing seasons in northern Europe (although limited by water stress). Faster photosynthesis and longer growing seasons both potentially increase carbon sequestration (Davi *et al*., 2008). Under the A1F scenario, by 2080 there is likely to be 1.8 Pg more carbon sequestered across the EU compared with 1990 baseline levels owing to an overall decrease in agriculture combined with an increase in forest cover (Schröter *et al*., 2005). However, in areas under water stress there will be a probable reduction in the sequestering capacity of the region due to lack of vegetative carbon uptake and increased soil carbon losses (Geeson *et al.,* 2002). Carbon uptake (even under forest land cover), when compared with emissions from fossil fuel use, is small (Schröter *et al*., 2005). Assuming some continued reliance on fossil fuels (as per A1b/A1f scenarios), increasing urbanisation of the SEMC suggests that carbon sequestration by Mediterranean ecosystems will not be sufficient to offset emissions in the region.

Water purification by ecosystems is fundamental to the provision of water quantity since the quality of supplied water determines its suitability for a given purpose (e.g. irrigation, domestic consumption, hydropower generation). The ‘human footprint on water’ is shown in Figure 38 and is a measure of the influence of cropland, pasture, urban areas, mining, roads, oil and gas on local and downstream water quality. The index is essentially the percentage of run-off in each pixel that has been influenced by non-protected areas (human influences) upstream. Rainfall is accumulated along the flow network with a weighting of 0–100 where it falls on a human-influenced area from the list above (according to the percentage cover of that influence within the pixel) and 0 where it falls on a protected or non-human-influenced area that is assumed to provide the dilution or purification service. Thus, the human footprint index sums indicate the probable effect of contaminants associated with urban, agricultural, transport and industrial processes on water quality downstream.

Northern Europe and the north Mediterranean have some of the greatest footprints and therefore require significant water treatment and diversion to retain water quality. Even in the southern Mediterranean, extensive grazing has an impact on this surrogate for downstream water quality. Increased urbanisation, agricultural mechanisation and reduced water balances will probably exacerbate the water-quality problem.

Figure 38: The human footprint on water (%). A metric of the upstream influence on water by human and natural landscapes and thus a surrogate for potential impacts on downstream water quality.



Protected areas provide a regulating service through their impact on reducing the human footprint on water and thus maintaining water quality but also by filtering out contaminants in flow. Ecosystems with intact root and ground cover are the most efficient in filtering contaminants from the water; this efficiency will be impacted by changes in land use, particularly within riparian zones (Brauman *et al*., 2007).

Cultural services

In addition to the significant provisioning and regulating services, densely populated areas receive significant cultural service, which form part of an individual's quality of life. Protected areas provide a range of provisioning and regulating services as well as a cultural service for spiritual, aesthetic and recreational benefit. The six EU Mediterranean countries contain almost 1.5 million km^2 of protected areas, accounting for 38% of the EU total (Eurostat, 2010b). Figure 9 shows the areas of conservation priority for three major conservation organisations (not UK – no data are available at the time of analysis). The Mediterranean is generally of much greater conservation value than northern Europe, so risk to aesthetic services which provide benefits to Mediterranean nationals as well as a thriving tourist industry is greater. Conversely, there is a significant need to find more space for nature in northern Europe if ecosystem services are to be sustained as economic development continues and climate changes.

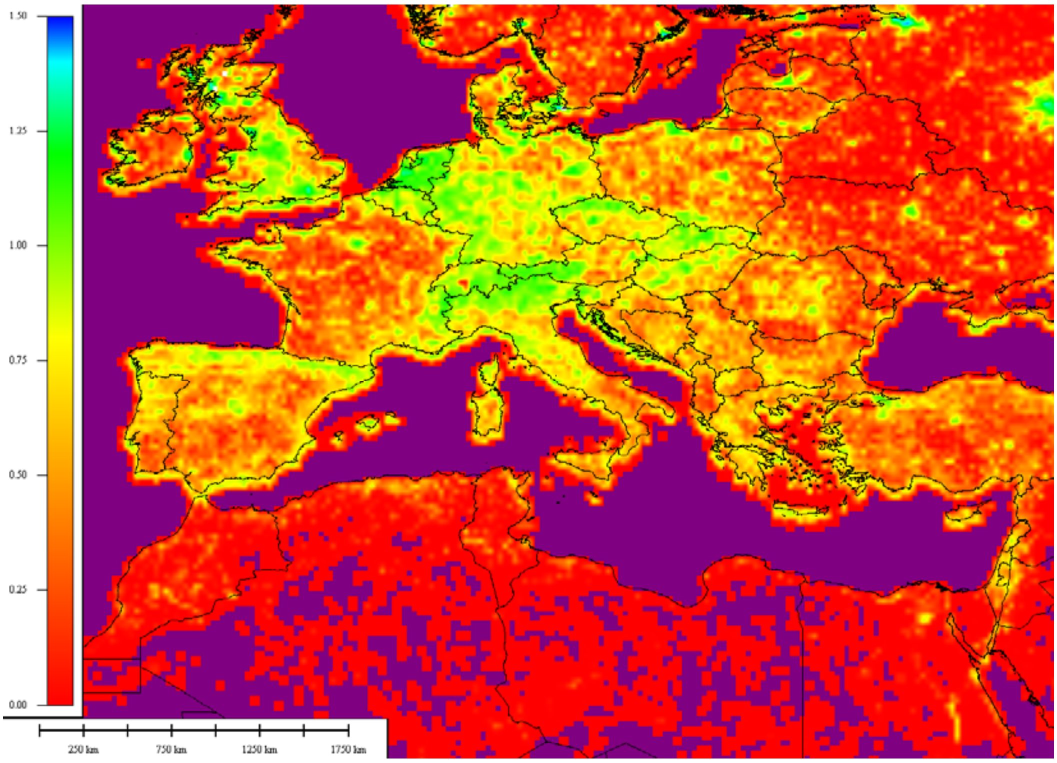
In addition to the services provided, it is important to maintain a patchwork of natural areas in order to protect threatened species and maintain a functional ecosystem. Even if land-use pressures on ecosystems in the Mediterranean reduce, climate change may impact directly on these highly heterogeneous species- and endemism-rich systems. A modelling study on forest distributions on the Iberian peninsula found a probable reduction in forest extent there under all emission scenarios, with A1 and A2 causing the greatest loss in habitat by 2080 (Benito Garzon *et al*., 2008). The intensity of land use and small size of individual protected areas, especially in the northern Mediterranean, exacerbate the difficulties of biological conservation in these systems and a much-expanded network of protected areas or efforts to increase species movement may be necessary (Loarie *et al*., 2009) to avoid the loss of important cultural services.

One of the hard economic benefits of the cultural services is tourism. This is very difficult to derive spatial data for, especially on the subnational level. An index of tourism is shown in Figure 39, which portrays the density of uploaded photos on the photo-sharing websites Panoramio and Flickr. Ignoring the clear bright spots associated with urban tourism, clearly the Alps and the Mediterranean coastline are areas of significant tourism, but are at risk of the predicted changes to snowmelt (Alps) and sea-level rise (at the coastline) and other hazards such as drought as well as degradation through intensive use. Significant temporary migration from northern Europe to the Mediterranean already occur to hotels or holiday homes in the Mediterranean and thus, as well as providing a significant economic benefit, the population concentrations associated with this tourism can lead to significant local degradation of resources, especially water.

Pull factors in northern Europe relating to ecosystem services

Generally, the provision of provisioning, regulating and cultural ecosystem services in the Mediterranean is therefore expected to decline with the onset of climate change and continued population pressure. It is likely that provisioning ecosystem services in northern Europe will improve with climate change, for example, northern Europe is likely to increase agricultural productivity owing to increasing rainfall and temperatures (Oleson and Bindi, 2002). In terms of

Figure 39: High-value tourism index. Density of online (Panoramio, Flickr) photographs as an index of tourism value. Source: compiled by Mulligan and Heinla, 2010.



energy production, biofuel crop potential in northern Europe is expected to increase by 12% between latitudes of 45° and 55°, and 32% between 65° and 71°. There is also expected to be less conflict between biofuel crops and food crops owing to the increased productivity potential for biofuels under future climates (Schröter *et al*., 2005). Regulating and cultural services may improve with continued planning, regulatory vigilance and population stabilisation. Finally, a warming of 4°C will move the optimum tourist summer climate to northern Europe, regardless of precipitation changes (Perry, 2006). Such changes may exacerbate the current gradient increasing environmental pressure from north to south on agricultural and urban populations.

Conclusions

The Mediterranean is a spatially complex region with strong international and intra-national gradients in climate, landscape and socioeconomic conditions. This enormous diversity of the region means that generalisations on climate, landscape, agriculture, ecosystem services, hazards, migrations and the impacts of environmental change upon them cannot be made. Rather, one must take a spatially explicit approach to understand the distribution of state and change in these variables within and between countries in order to better understand the interactions between environment and regional or national migrations. Most of the proximal drivers for migration are political, social, economic and cultural, and thus it is very difficult to find clear relationships with environmental factors, although environmental factors surely have a role to play in setting the context for the socioeconomic landscape to play out.

Population, GDP and infrastructure have developed over millennia in the Mediterranean and both the level of population and the magnitude of GDP are strongly conditioned by overall climate suitability. The SRES scenarios are expected to lead to significant changes in population and GDP throughout the basin, with the greatest population change in the south and east and the greatest GDP increase in the north, potentially further separating the income and well-being gradient that currently exists from north to south. Much of the population increase is expected to be urban populations, and will thus generate an increasingly spatially concentrated set of pressure on ecosystem services and exposures to hazards. Continued land degradation, agricultural intensification or abandonment, industrialisation and post-industrialisation may lead to continued rural–urban flows within and between countries. Since GDP increases are focused on the urban and industrial areas of the north Mediterranean and northern Europe, these cities may be particularly attractive to migrants from inside and outside the Mediterranean region and may also be much more open to migration given a potential surplus of employment over demand.

Climate changes will be strongly spatially variable within countries both latitudinally, continentally and altitudinally. According to an ensemble mean for 17 GCMs, climate is expected to warm throughout the basin, but especially in the south, and rainfall is expected to decrease throughout the basin but increase in the extreme south and also in northern Europe.

These changes will have a mixture of positive and negative impacts for agriculture, water resources and other ecosystem services as well as for hazards. There may be improvements in water resources and ecosystem services in parts of the Mediterranean and northern Europe. Productivity may increase in parts of the Mediterranean basin although this will be strongly limited by water availability and the impact of drought and extreme rainfall events. Short-term increases may lead to longer term declines if temperatures continue to increase. Productivity in northern Europe will probably increase with the increasing temperature, growing season length and rainfall.

Hazards can be expected to increase throughout the region but risk will probably be much greater in the northern Mediterranean and northern Europe, where populations are greater and more concentrated, where mountains are present and where existing infrastructure and GDP is greatest, thus increasing exposure. Since significant investments in mitigation and emergency planning measures exist in these countries, the resulting disasters (for all but the most extreme events) may be, as currently, less damaging to life and property than in the southern Mediterranean. The complexity of impacts of climate change on agricultural productivity, ecosystem service provision, hazard and disaster are poorly known at the regional scale, though a number of case studies within the region point to potentially serious negative impacts especially in the northern Mediterranean and some potentially positive impacts in parts of the south. Such case studies should be extrapolated with caution given the heterogeneous nature of the Mediterranean as indicated by the spatial analysis presented.

Overall, this means that while the south of the basin is clearly currently the economically poorer area, climate change may improve productivity, agriculture, water resources and ecosystem services in parts of that region while creating greater risks for natural hazards in the populous and infrastructurally sensitive north. If, as expected, population and urbanisation continue to grow in the south, risk in this region is likely to increase. The distribution of climate impacts in relation to the current distribution of population and the land that provides populations with key provisioning and regulating services will be critical. Any positive changes in the south may be cancelled out by increased human pressure on the landscape as populations grow. The areas with the greatest potentially negative impacts include those agriculturally intensive and populous regions of the northern Mediterranean, whereas areas with potentially positive impacts of climate change are currently both agricultural and population deserts, so few people will benefit unless they or the harvesters of their ecosystem services migrate to these areas.

There are significant uncertainties as to how agriculture and human behaviour will respond to these impacts since the responses are dependent upon the population density, economics, politics, culture and adaptive capacity. These characteristics are not easily mapped at the European scale and they also change over time in unpredictable ways. The wealthier Northern Mediterranean is, on the face of it, more adaptable but since these areas carry the greatest populations, intensive agriculture and are presently at the limits of environmental sustainability, these areas are also more vulnerable to loss of ecosystem services and increase in the frequency and magnitude of hazards through climate change.

In conclusion, while environmental change of one form or another is inevitable, its impact on the *status quo ante* will vary according to the complexity and magnitude of the current human infrastructure. Significant environmental change over coming decades may lead to enhanced economic or even forced migration to areas where environmental and economic conditions are more amenable. There will be significant pressures for movement within the Mediterranean, especially south to north, south to east and rural to urban, as well as potentially between rural and urban areas. Given the complexity of Mediterranean landscapes and the spatial heterogeneity of the impacts of climate change, internal migration may be a smart adaptation mechanism to make use of new agricultural and other opportunities, especially in the extreme southern Mediterranean. While push factors for migration may increase in the coastal southern Mediterranean areas and parts of eastern Europe, so some pull factors in the north Mediterranean and north Europe may also decline as a result of climate change and its impacts, particularly given the significant current flows of food from southern to northern Europe. Indeed, the populations most vulnerable to climate change impacts are likely to be those very highly urbanised and infrastructurally complex societies in parts of the northern Mediterranean that are already close to agricultural and water-resource limits and in hazard-prone environments rather than the relatively disbursed and potentially more resilient populations of the southern Mediterranean.

References

Allen, H.D. (2003). Response of past and present Mediterranean ecosystems to environmental change. *Progress in Physical Geography* 27: 359–377.

Arnell, N.W. (2004). Climate change and global water resources: SRES emissions and socioeconomic scenarios. *Global Environmental Change* 14: 31–52.

Awwad, H. (2003). Euro-Mediterranean agricultural trade policies : are they sustainable? Options Méditerranéennes, Sér. A / n°52. Available from: http://ressources.ciheam.org/om/pdf/a52/03400058.pdf.

Barnett, J. (2003). Security and climate change. *Global Environmental Change* 13: 7–17.

Begon, M., Harper, J.L., and Townsend, C.R. (1996). *Ecology* (3rd edition). Oxford: Blackwell Science.

Benito Garzon, M., Sanchez de Dios, R., and Sainz Ollero, H. (2008). Effects of climate change on the distribution of Iberian tree species. *Applied Vegetation Science* 11(2): 169–187.

Birdlife International. (2008). Key biodiversity areas. Available from: http://www.birdlife.org.

Black, R. (2001). *Environmental Refugees: Myth or Reality? New Issues in Refugee Research*. Working Paper No. 34. Brighton: University of Sussex.

Bohannon, J. (2010). The Nile Delta's sinking future. *Science* 327: 1444–1447.

Brauch, H.G. (2003). Urbanisation and natural disasters in the Mediterranean; population growth and climate change in the 21st century. In: A. Kreimer, M. Arnold and A. Carlin (eds), *Building Safer Cities: The Future of Disaster Risk*. Washington, DC: World Bank, pp. 170–183.

Brauman, K.A., Daily, G.C., Ka'eo Duarte, T., and Mooney, H. (2007). The nature and value of ecosystem services: an overview highlighting hydrologic services. *Annual Review of Environment and Resources* 32(6): 1–32.

Bruijnzeel, L.A., Mulligan, M., and Scatena, F.S. (2010). Hydrometeorology of tropical montane cloud forests: Emerging patterns. *Hydrological Processes* 25: 465–498.

Cemagref (2009). Repeated fire and drought: a menace for Mediterranean forests. *ScienceDaily*, 26 May. Available from: www.sciencedaily.com/releases/2009/05/090519080045.htm.

Center for International Earth Science Information Network (CIESIN) (2002). *Country-level Population and Downscaled Projections based on the B2 Scenario 1990–2100* [digital version]. Palisades, NY: CIESIN Columbia University. Available from: http://www.ciesin.columbia.edu/datasets/downscaled.

Center for International Earth Science Information Network (CIESIN), Columbia University; International Food Policy Research Institute (IFPRI); The World Bank; and Centro Internacional de Agricultura Tropical (CIAT). (2004). *Global Rural–Urban Mapping Project (GRUMP), Alpha Version: Urban Extents*. Palisades, NY: Socioeconomic Data and Applications Center (SEDAC), Columbia University. Available from: http://sedac.ciesin.columbia.edu/gpw/.

Conacher, A.J., and Conacher, J. (1998). Introduction. In: A.J. Conacher and M. Sala (eds), *Land Degradation in Mediterranean Environments of the World*. Chichester: John Wiley and Sons.

Croitoru, L. and Merlo, M. (2005). Mediterranean forest values. In: M. Merlo and L. Croitoru (eds), *Valuing Mediterranean Forests: Towards Total Economic Value*. Wallingford: CABI Publishing, p. 406.

Davi, H., Dufrene, E., Francois, C., *et al*. (2008). Sensitivity of water and carbon fluxes to climate changes from 1960 to 2100 in European forest ecosystems. *Agricultural and Forest Meteorology* 141: 35–56L.

Della-Marta, P.M., Haylock, M.R., Luterbacher, J., and Wanner, H. (2007). Doubled length of western European summer heat waves since 1880. *American Geophysical Union* 112: 15103. doi: 10.1029/2007JD008510.

Déqué, M.D.P., Rowell, D., Lüthi, F., *et al*. (2007). An intercomparison of regional climate simulations for Europe: assessing uncertainties in model projections. *Climatic Change* 81: 53–70.

European Commission (2005). Agricultural trade statistics. Available from: http://ec.europa.eu/agriculture/agrista/tradestats/index_sem.htm.

Eurostat (2010a). Protected Areas for biodiversity: habitats directive. Available from: http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_bio1&lang=en.

Eurostat (2010b). Agricultural statistics – Main results – 2008–09. Series: Pocketbooks. Luxembourg: Publications Office of the European Union. Available from: http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-ED-10–001/EN/KS-ED-10–001-EN.PDF.

Farr, T.G. and Kobrick, M. (2000). Shuttle Radar Topography Mission produces a wealth of data. *American Geophysical Union Eos*, 81: 583–585.

FAO (1996). *Declaration on World Food Security*. World Food Summit. Rome: FAO.

FAO (2002). *World Agriculture: Towards 2015/2030*. Summary report. Rome: FAO. ONLINE: ftp://ftp.fao.org/docrep/fao/004/y3557e/y3557e.pdf

Fischer, E.M. and Schär C. (2010). Consistent geographical patterns of changes in high-impact European heatwaves. *Nature Geoscience* 3: 398–403.

Frei, C., Scholl, R., Fukutome, S., Schmidli, J., and Vidale, P.L. (2006). Future change of precipitation extremes in Europe: intercomparison of scenarios from regional climate models. *Journal of Geophysical Research* 111: D06105. doi: 10.1029/2005JD005965.

Gao X., and Giorgi, F. (2008). Increased aridity in the Mediterranean region under greenhouse gas forcing estimated from high resolution simulations with a regional climate model. *Global and Planetary Change* 62: 195–209.

García-Herrera, R., Díaz, J., Trigo, R.M., Luterbacher, J., and Fischer, E.M. (2010). A review of the European summer heatwave of 2003. *Critical Reviews in Environmental Science and Technology* 40: 267–306.

Geeson, N., Brandt, C.J., and Thornes, J.B. (2002). *Mediterranean Desertification: A Mosaic of Processes and Responses*. Chichester: Wiley.

Giannakopoulos, C., Le Sager, P., Bindi, M., Moriondo, M., Kostopoulou, E., and Goodess, C.M. (2009). Climatic changes and associated impacts in the Mediterranean resulting from a 2°C global warming. *Global and Planetary Change* 68: 209–224.

Giorgi F., and Lionello, P. (2008). Climate change projections for the Mediterranean region. *Global and Planetary Change* 63: 90–104.

Giupponi, C., and Shechter, M. (2003). *Climate Change in the Mediterranean; Socioeconomic Perspectives of Impacts, Vulnerability and Adaptation*. Bodmin: Edward Elgar Publishing.

Guo, Z., Xiao, X., Gan, Y., and Zheng, Y. (2001). Ecosystem functions, services and their values – a case study in Zingshan County of China. *Ecological Economics* 38: 141–154.

Haas, P.M. (1990). Towards management of environmental problems in Egypt. *Environmental Conservation* 17: 45–50.

Hansen, M., DeFries, R., Townshend, J.R.G., and Sohlberg, R. (1998). *UMD Global Land Cover Classification, 1 Kilometer, 1.0*. College Park, MD: Department of Geography, University of Maryland. Available from: http://www.landcover.org/data/landcover/.

Harrison, G.P., Whittington H.W., and Gundry, S.W. (1998). *Climate Change Impacts on Hydroelectric Power*. Proceedings of 33rd Universities Power Engineering Conference (UPEC 1998), Edinburgh, September 1998, pp. 391–394.

Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G., and Jarvis, A. (2005). Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology* 25: 1965–1978.

Hoekstra, A.Y., and Chapagain, A.K. (2007). Water footprints of nations: Water use by people as a function of their consumption pattern. *Water Resource Management* 21: 35–48.

IPCC (2007). *Climate Change 2007: Synthesis Report*. International Panel on Climate Change. Available from: http://ipcc-wg1.ucar.edu/wg1/wg1-report.html.

Jacob, D.L., Bärring, O., Bøssing Christensen, J., *et al*. (2007). An inter-comparison of regional climate models for Europe: model performance in present-day climate. *Climatic Change* 81: 31–52.

Jäger, J., Frühmann, J., Grünberger, S., and Vag, A. (2009). *Synthesis Report EACH-FOR Environmental Change and Forced Migration Scenarios Specific Targeted Project Scientific Support to Policies – SSP*. Available from: http://www.each-for.eu/documents/EACH-FOR_Synthesis_Report_090515.pdf.

Jones, P.D., Hulme, M., Briffa, K.R., and Jones, C.G. (1996). Summer moisture availability over Europe in the Hadley centre general circulation model based on the Palmer drought severity index. *International Journal of Climatology* 16: 155–172.

Kadirbeyoglu, Z. (2009). *Turkey Case Study Report*. *EACH-FOR Environmental Change and Forced Migration Scenarios.* Available from: http://www.each-for.eu/documents/CSR_Turkey_090126.pdf.

Komuscu, A.U. (1999). Using the SPI to analyze spatial and temporal patterns of drought in Turkey. *Drought Network News* 11: 7–13.

Kosmas, C., Kirkby, M.J. and Geeson, N. (1999). *Manual on key indicators of desertification and mapping environmentally sensitive areas to desertification*. European Commission Publication EUR 18882.

Lal, R. (2008). Sequestration of atmospheric CO_2 in global carbon pools. *Energy and Environmental Science* 1: 86–100.

LandScan™. (2007). *Global Population Database 2007*. Oak Ridge, TN: Oak Ridge National Laboratory. Available from: http://www.ornl.gov/landscan/.

Lasanta, T., Arnaez, J., Errea, M.P., Ortigosa, L., and Ruiz-Flano, P. (2009). Mountain pastures, environmental degradation, and landscape remediation: The example of a Mediterranean policy initiative. *Journal of Applied Geography* 29: 309–319.

Lehner, B., Verdin, K., and Jarvis, A. (2008). New global hydrography derived from spaceborne elevation data. *Eos Transactions, American Geophysical Union* 89(10): 93–94.

Lionello, P., Malanotte-Rizzoli, P., and Boscolo, R. (2006). *Mediterranean Climate Variability*. Amsterdam: Elsevier.

Lionello, P., Platon, S., and Rodo, X. (2008). Trends and climate change in the Mediterranean region. *Global and Planetary Change* 63: 87–89.

Llasat, M.C., Llasat-Botija, M., Prat, M.A., *et al*. (2010). High-impact floods and flash floods in Mediterranean countries: the FLASH preliminary database. *Advances in Geoscience* 23L 47–55. Available from: www.adv-geosci.net/23/47/2010/.

Loarie, S.R., Duffy, P.B., Hamilton, H., Asner, G.P., Field, C.B., and Ackerly, D.D. (2009). The velocity of climate change. *Nature* 462(7276): 1052–U111.

López Bermúdez, F., and Sánchez, M.C. (1997). Las sequías y su impacto en el riesgo de desertificación de la cuenca del Segura. Apuntes para la gestión y sostenibilidad del agua. *Areas* 17: 155–168.

López-Vicente, M., Poesen, J., Navas, A., and Gaspar, L. (2011). Predicting run-off and sediment connectivity and soil erosion by water for different land use scenarios in the Spanish Pre-Pyrenees. *CATENA*, in press. doi: 10.1016/j.catena.2011.01.001.

Lutz, W., and Goldstein, J. (2004). Special issue on ‘how to deal with uncertainty in population forecasting?’. *International Statistics Review* 72: 1–106, 157–208.

Lutz, W., and Samir, K.C. (2010). Dimensions of global population projections: what do we know about future population trends and structures? *Philosophical Transactions of the Royal Society B* 365: 2779–2791.

Patterson, L.A., and Josling, T.E. (2005). *Mediterranean Agriculture in the Global Marketplace: A Project Comparing Policy Approaches in California and the Southern EU States Report on Stage 1.* Stanford University: European Forum Institute for International Studies. Available from: http://aic.ucdavis.edu/research1/patt_jos_med_ag_glob_mkt.pdf.

McLeman, R., and Smit, B. (2006). Migration as an adaptation to climate change. *Climatic Change* 76: 31–53.

Magnan, A., Garnaud, B., Bille, L., Gemenne, F., and Hallegatte, S. (2009). *The Future of the Mediterranean: From Impacts of Climate Change to Adaptation Issues*. Paris: IDDRI.

Mariotti, A., Zeng, N., Yoon, J.H., *et al*. (2008). Mediterranean water cycle changes: transition to drier 21st century conditions in observations and CMIP3 simulations. *Environmental Research Letters* 3: 1–8.

MedSec. (2009). *Environment and Security Issues in the Southern Mediterranean Region*. Available from: http:// www.medsecnet.org/images/stories/medsec_scr_updt.pdf.

Metzger, M.J., Rounsevell, M.D.A., Acosta-Michlik, L., Leemans, R., and Schröter, D. (2006). The vulnerability of ecosystem services to land use change. *Agriculture, Ecosystems and Environment* 114: 69–85.

Millennium Assessment (2005). *Current State and Trends Assessment*. Available from: http://www.millenniumassessment.org/en/Condition.aspx.

Montgomery, R. (2009).*Crop Production in the Mediterranean Partner Countries Continues to Increase. Statistics in Focus.* Luxembourg: Eurostat, Office for Official Publications of the European Communities. Available from: http://www.pcbs.gov.ps/Portals/_PCBS/Documents/KS-SF-09–012-EN.pdf.

Morales, P., Hickler, T., Rowell, D.P., Smith, B. and Sykes, M.T. (2007). Changes in European ecosystem productivity and carbon balance driven by regional climate model output. *Global Change Biology* 13: 108–122.

Moriondo, M., Bindi, M., Kundzewicz, Z.W., *et al*. (2010). Impact and adaptation opportunities for European agriculture in response to climatic change and variability. *Mitigation and Adaptation Strategies for Global Change* 7: 657–679.

Mulligan, M. (2007). *Global Sea Level Change Analysis Based on SRTM Topography and Coastline and Water Bodies Dataset.* (SWBD). Version 1.0. Available from: http://www.ambiotek.com/sealevel.

Mulligan, M. (2009) *SimTerra*: *A Consistent Global Gridded Database of Environmental Properties for Spatial Modelling*. Available from: http://www.ambiotek.com/simterra.

Mulligan, M. (2010). *Global Cumulative Burn Frequency Mapping*. Available from: http://www.ambiotek.com/fires.

Mulligan, M., Saenz-Cruz, L., van Soesbergen, A., Smith, V.T., and Zurita, L. (2009). *Global Dams Database and Geowiki*. Version 1. http://www.ambiotek.com/dams. Version 1. Available from: http://www.ambiotek.com/damsu.

Mulligan, M., Guerry, A., Arkema, K., Bagstad, K. and Villa, F. (2010). Capturing and quantifying the flow of ecosystem services in Silvestri S., Kershaw F., (eds). *Framing the flow: Innovative Approaches to Understand, Protect and Value Ecosystem Services Across Linked Habitats*. Cambridge: UNEP World Conservation Monitoring Centre, Cambridge, UK.

Mulligan, M., Saenz Cruz, L.L., Pena-Arancibia, J., Pandey, B., Mahé, G., and Fisher, M. (2011). 'Water availability and use across the Challenge Program on Water and Food (CPWF) basins'. *Water International* 36: 1, 17–41.

Myers, N., and Kent, J. (1995). *Environmental Exodus – An Emergent Crisis in the Global Arena*. Washington, DC: Climate Institute.

Myers, N., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G.A.B. and Kent, J. (2000). Biodiversity hotspots for conservation priorities. *Nature* 403: 853–858.

Nakicenovic, N. and Swart, R. (eds) (2000). *IPCC Special Report on Emissions Scenarios*. Cambridge: Cambridge University Press.

Nowicki, P., Goba, V., Knierim, A., *et al*. (2009). Scenar 2020-II – Update of analysis of prospects in the Scenar 2020 Study – Contract No. 30-CE-0200286/00-21. Brussels: European Commission, Directorate-General Agriculture and Rural Development. Available from: http://ec.europa.eu/agriculture/analysis/external/scenar2020ii/report_en.pdf.

Nunes, J.P., Seixas, J., and Pacheco, N.R. (2008). Vulnerability of water resources, vegetation productivity and soil erosion to climate change in Mediterranean watersheds*. Hydrological Processes* 22: 3115–3134.

Nunes, J.P., Seixas, J., Keizer, J.J., and Ferreira, A.J.D. (2009). Sensitivity of run-off and soil erosion to climate change in two Mediterranean watersheds. Part II: assessing impacts from changes in storm rainfall, soil moisture and vegetation cover. *Hydrological Processes* 23: 1212–1220.

Oleson K. and Bindi M. (2002). Consequences of climate change for European agricultural productivity, land use and policy*. European Journal of Agronomy* 16: 239–262.

Oleson, D.M., and Dinerstein, E. (1998). The Global 200: a representation approach to conserving the Earth's most biologically valuable ecoregions. *Conservation Biology* 12: 502–515.

Padilla, M., Ahmed, Z.S., Wassef, H.H., Layaida, N., and Oberti, B. (2005). *CIHEAM Analytic Note: The Mediterranean Region: Overall Food Security in Quantitative Terms but Qualitative Insecurity?* Montpellier: International Centre for Advanced Mediterranean Agronomic Studies – Mediterranean Agronomic Institute. Available from: http://portail2.reseau-concept.net/Upload/ciheam/fichiers/ANP4.pdf.

Pal, J.S., Giorgi, F., and Bi, X. (2004). Consistency of recent summer European precipitation trends and extremes with future regional climate projections. *Geophysical Research Letters* 31: L13203. doi: 10.1029/2004GL019836.

Pausas, J.G. (2004). Changes in fire and climate in the eastern Iberian Peninsula (Mediterranean basin). *Climatic Change* 63: 337–350.

Perry, A. (2006). Will predicted Climate Change Compromise the Sustainability of Mediterranean Tourism? *Journal of Sustainable Tourism* 14: 367–375.

Petit, R.J., Hampe, A., and Cheddadi, R. (2005). Climate changes and tree phylogeography in the Mediterranean. *Taxon* 54: 877–885.

Pimentel, D. (2003) Ethanol fuels: energy balance, economics, and environmental impacts are negative. *Natural Resources Research* 12: 127–134.

Plan Bleu (2004). *Demography in the Mediterranean Region: Situation and Projections*. France: UNEP/MAP-Plan Bleu, Sophia Antipolis.

Plan Bleu (2005). *A Sustainable Future for the Mediterranean: The Blue Plan's Environment and Development Outlook*. London: Earthscan.

Plan Bleu (2008a). *The Blue Plan's Sustainable Development Outlook for the Mediterranean.* France: UNEP/MAP-Plan Bleu, Sophia Antipolis.

Plan Bleu (2008b). *Climate change and energy in the Mediterranean*. France: UNEP/MAP-Plan Bleu, Sophia Antipolis.

Plan Bleu (2009a). *State of the Environment and Development in the Mediterranean*. Athens: UNEP/MAP-Plan Bleu.

Plan Bleu (2009b). *The Mediterranean has to take up Three Major Challenges to Ensure Sustainable Management of its Endangered Water Resources*. Available from: http://www.planbleu.org/publications/4p_eau_11_2009Uk.pdf.

Plan Bleu (2010). *The Foreseeable Impacts of Climate Change on the Water Resources of Four Major Mediterranean Catchment Basins*. Available from: http://www.planbleu.org/publications/impact_CC_eau_EN.pdf.

Riedel, J.L., Casasús, I. and Bernués, A. (2007). Sheep farming intensification and utilization of natural resources in a Mediterranean pastoral agro-ecosystem*. Livestock Science* 111: 153–163.

Roeder, A., Udelhoven, Th., Hill, J., *et al*. (2008). Trend analysis of Landsat-TM and -ETM+ imagery to monitor grazing impact in a rangeland ecosystem in Northern Greece. *Remote Sensing of Environment* 112: 2863–2875.

Rounsevell, M.D.A., Ewert, F., Reginster, I., Leemans, R., and Carter, T.R. (2005). Future scenarios of European agricultural land use: II. Projecting changes in cropland and grassland. *Agriculture*, *Ecosystems and Environment* 107: 117–135.

Rounsevell, M.D.A., Reginster, I., Araujo, M.B., *et al*. (2006). A coherent set of future land use scenarios for Europe*. Agriculture, Ecosystems and Environment* 114: 57–68.

Roy, D.P., Boschetti, L., Justice, C.O., and Ju, J. (2008). The Collection 5 MODIS Burned Area Product - Global Evaluation by Comparison with the MODIS Active Fire Product. *Remote Sensing of Environment* 112: 3690–3707.

Ruiz, F.A., Mena, Y., Castel, J.M., *et al.* (2001). Typology of cereal-sheep farming systems in Castile-La Mancha (South-Central Spain). *Agricultural Systems* 68: 215–232.

Safriel, U.N. (2009). Status of desertification in the Mediterranean region. In: J.L. Rubio, U. Safriel, R. Daussa, W. Blum, and F. Pedrazzini (eds), *Water Scarcity, Land Degradation and Desertification in the Mediterranean Region*. Proceedings of the NATO Advanced Research Workshop on Water Scarcity, Land Degradation and Desertification in the Mediterranean Region, 10–11 December 2007, Valencia, Spain. Book Series: NATO Science for Peace and Security Series C – Environmental Security, pp. 33–73.

Sanderson, E.W., Malanding, J., Marc, A. *et al.* (2002). The human footprint and the last of the wild. *Bioscience* 52: 891–904.

Schar, C., Vidale, P.L., Lüthi, D., *et al*. (2004). The role of increasing temperature variability in European summer heatwaves. *Nature* 427: 332–336.

Schröter, D., Cramer, W., Leemans, R., *et al*. (2005). Ecosystem service supply and vulnerability to global change in Europe. *Science* 310: 1333–1337.

Serra, P., Pons, X., and Sauri, D. (2008). Land-cover and land-use change in a Mediterranean landscape: a spatial analysis of driving forces integrating biophysical and human factors. *Applied Geography* 28: 189–209.

Shatanawi, A., Hamdy, A., and Smadi, H. (2005). Urban wastewater. Problems, risks and its potential use for irrigation. In: H. Atef (ed.), *The Use of Non-conventional Water Resources*. Bari: CIHEAM-IAMB / EU-DG Research, p. 216. Available from: http://ressources.ciheam.org/om/pdf/a66/00800299.pdf.

Shaw, B., Ambraseys, N.N., England, P.C., *et al*. (2008). Eastern Mediterranean tectonics and tsunami hazard inferred from the AD 365 earthquake. *Nature Geoscience* 1: 268–276.

Siebert, S., Döll, P., Feick, S., Frenken, K., and Hoogeveen, J. (2007). *Global Map of Irrigation Areas Version 4.0.1*. Germany: University of Frankfurt (Main), and Rome: FAO.

Smit, B., and Pilifosova, O. (2001). Adaptation to climate change in the context of sustainable development and equity. In: J.J. McCarthy, O.F. Canzianni, N.A. Leary, D.J. Dokken and K.S. White (eds), *Climate Change 2001: Impacts, Adaptation and Vulnerability – Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press, Chapter 18.

Somot, S., Sevault, F., Déqué, M., and Crépon, M. (2008). 21st century climate change scenario for the Mediterranean using a coupled atmosphere–ocean regional climate model. *Global and Planetary Change* 63: 112–126.

Strengers B., Leemans R., Eickhout B., De Vries B., and Bouwman L. (2004). The land-use and resulting emissions in the IPCC SRES scenarios as simulated by the IMAGE 2.2. model. *Geojournal* 61: 381–393.

Thivet, G. (2007). *Towards Rural Revival in the Mediterranean*. Blue Plan Notes No. 5. Valbonne, France: United Nations Environment Programme – Mediterranean Action Plan, Plan Bleu. Available from: http://www.planbleu.org/publications/4pages_rural_uk.pdf.

United Nations Department of Economic and Social Affairs, Population Division. (2002). *World Population Prospects*: *The 2000 Revision*. Volume III Analytical Report No. ST/ESA/SER.A/200. New York: United Nations. Available from: http://www.un.org/esa/population/publications/wpp2000/wpp2000_volume3.htm.

United Nations Department of Economic and Social Affairs, Population Division. (2009). *World Population Prospects*: *The 2008 Revision*. Highlights, Working Paper No. ESA/P/WP.210

USDA Foreign Agricultural Service. (2003). *Global Agriculture Information Network Voluntary Report*. GAIN Report Number: E23213, European Union 2003 Wine Production lowest in 10 years. Christine Strossman. US Mission to the European Union, Brussels. Available from: http://www.fas.usda.gov/gainfiles/200311/145986774.pdf.

van Meijl, H., van Rheenen, T., Tabeau, A. and Eickhout, B. (2006). The impact of different policy environments on agricultural land use in Europe. *Agriculture Ecosystems and Environment* 114: 21–38.

Van Vuuren, D.P., De Vries, B., Beusen, A., and Heuberger, P.S.C. (2008). Conditional probabilistic estimates of 21st century greenhouse gas emissions based on the storylines of the IPCC-SRES scenarios. *Global Environmental Change* 18: 635–654.

Verburg, P.H. (2006). Downscaling of land use change scenarios to assess the European landscapes. *Agriculture, Ecosystems and Environment* 114: 39–56.

Vicente-Serrano, S.M, González-Hidalgo, J.C., and Martín de Luis, J.R. (2004). Drought patterns in the Mediterranean area: the Valencia region (eastern Spain) *Climate Research* 26: 5–15.

Vidal, A., Comeau, A., Plusquellec, H.L., and Gadelle, F. (2001). *Case Studies in Water Conservation in the Mediterranean Region*. Rome: IPTRID secretariat, FAO.

Vogiatzakis, I.N., Mannion, A.M., and Griffiths, G.H. (2006). Mediterranean ecosystems: problems and tools for conservation. *Progress in Physical Geography* 30: 175–200.

Wint, G.R.W., and Robinson, T.P. (2007). *Gridded Livestock of the World 2007*. Rome: FAO, p. 131.

World Bank. (2007). *Development Actions and the Rising Incidence of Disasters*. Evaluation Brief 4. Available from: http://www.worldbank.org/ieg.

World Bank. (2009). Adapting to climate change in Europe and Central Asia, Washington. Available from: www.worldbank.org/eca/climate/ECA_CCA_Full_Report.pdf.

Yang, H., and Zehnder A.J.B. (2002). Water scarcity and food import: a case study for southern Mediterranean countries. *World Development* 30: 1413–1430.

Zomer, R.J., Trabucco, A., Bossio, D.A, van Straaten, O., and Verchot, L.V. (2008). Climate Change Mitigation: A Spatial Analysis of Global Land Suitability for Clean Development Mechanism Afforestation and Reforestation. *Agricultural Ecosystems and Environment* 126: 67–80.

Glossary

EU27: Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxemburg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and the United Kingdom.

EU12: Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain.

SMCs Cyprus, Turkey, Syria, Lebanon, Israel, Egypt, Libya, Tunisia, Algeria and Morocco.

Foresight
1 Victoria Street
London SW1H 0ET
www.foresight.gov.uk
11/1177