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1. Introduction

Most of the Earth's land surface has been changed as a result of human use, with large environmental consequences and both positive and negative impacts on human well-being (Ellis *et al.*, 2010; Schmitz *et al.*, 2012). With limited resources of land and water, a large societal challenge consist of meeting the increasing demand for food and living space for growing populations in the context of climate change. These challenges are especially significant for the Mediterranean, a dynamic and densely populated region with severe constraints on land and water resources (Giorgi & Lionello, 2008; Giannakopoulos *et al.*, 2009; García-Ruiz *et al.*, 2011; Fader *et al.*, 2016). The Mediterranean has a long history of land use, resulting in valuable cultural landscapes created throughout centuries (Blondel *et al.*, 2010; Tieskens *et al.*, 2017), and is one of the most rich areas in terms of biodiversity (Cuttelod *et al.*, 2009). On the other side, human activities in the region have resulted in significant degradation of soil and water resources (García-Ruiz *et al.*, 2011; Karamesouti *et al.*, 2015).

Resulting from its cultural and environmental characteristics and its long land use history, the Mediterranean Basin hosts a diversity of land systems of varying intensities and levels of (multi)functionality. Intensive systems have higher yields and produce most of the crops in the region, a large part of them being exported. These systems however also have high water demands (Daccache et al., 2014) and can negatively affect the quality of soil contributing to land degradation (Karamesouti *et al.*, 2015). Traditional mosaic systems represent landscapes, where human activities and environmental conditions are intricately linked. An example is the *dehesa* / *montado* system of Spain and Portugal, where different activities such as livestock grazing, cereal production, and forestry occur simultaneously (Joffre *et al.*, 1999). Although these areas have lower yields, they contribute significantly to total regional food production (Blondel, 2006; McAdam *et al.*, 2008). Many of the traditional mosaic systems are associated with high biodiversity values (Médail & Quézel, 1999). These landscapes are particularly vulnerable to global change, threatening their supply of not only food, but a number of ecosystem services (Zamora *et al.*, 2007; Guiot & Cramer, 2016).

The Middle Eastern and North African part of the Mediterranean region is characterized with high population pressures and increasing dependence on food imports (Wright & Cafiero, 2011). Depending heavily on food imports makes the region more vulnerable to fluctuations in food supply and prices (Sowers *et al.*, 2010). The region hosts a considerable portion of cropland with relatively low yields, meaning that future cropland expansion and intensification will play a crucial role in satisfying the demand for food (Mueller *et al.*, 2012). This can however exacerbate soil and water degradation, and appropriate land management will be needed to reduce these consequences, or restore soil and water resources (Cerdan *et al.*, 2010; García-Ruiz, *et al.*, 2011). Moreover, water and land grabbing are also significant issues in the region, leading to conflicts (GRAIN, 2012; Houdret, 2012). The European Mediterranean area hosts high-input intensive agricultural systems significant for regional food production and global commodity markets. However, recent socio-economic development, such as the Greek financial crisis, have influenced the steadiness of supply of agricultural products (Pfeiffer & Koutantou, 2015). Other global change effects are the abandonment of traditional livestock grazing systems due to low economic competitiveness and reduction of livestock productivity (de Rancourt *et al.*, 2006; Bernués *et al.*, 2011). In summary, future global change, particularly changes to climate and population, could significantly impact the potential food supply of the Mediterranean region (Evans, 2008; Sowers *et al.*, 2010).

Published global land change scenarios suggest significant intensification of crop production and grazing, together with urban expansion in the Mediterranean region (Hurtt *et al.*, 2011; Letourneau *et al.*, 2012; Souty *et al.*, 2012; van Asselen & Verburg, 2013). These global studies often do not consider specific regional characteristics that could affect these processes, such as the existence of a large share of permanent crops and traditional mosaic systems, and severe water limitations. Water limitation also affects intensification and cropland expansion, feedback loops which are currently not possible to study with land use models in which water availability is represented by a proxy, such as precipitation (NRC, 2014). Simplified proxies can only influence the spatial distribution of intensive systems and do not limit cropland expansion or intensification based on available water resources. Land use modeling studies that do take into account water scarcity are often unable to generate land use patterns with the spatial detail of most biophysical models (see for example Lotze-Campen *et al.*, 2010).

In this study, we determine the impact of two potential future scenarios on land management in the Mediterranean region to study environmental consequences of increasing food production in the Mediterranean for the year 2050. We advance from the existing knowledge by combining global outlooks of socio-economic and climate change in a land system change model with regional spatial characteristics and configuration of land use. We are particularly interested in how global change might affect traditional Mediterranean landscapes and water resources. We also demonstrate how water resources limitations can be represented in land system models.

2. Future challenges for land management in the Mediterranean region

2.1 The Mediterranean region

We focused on the Mediterranean ecoregion defined by the approximate extent of representative Mediterranean natural communities from a biogeographical study (Olson *et al.*, 2001). We expanded the ecoregion by also including the Nile Delta, the Po floodplain and numerous “islands” of similar ecoregions within the Mediterranean ecoregion (Fig. 1). Thematically, we divided the region into two parts, North and South, which, based on land use characteristics and biodiversity trends (Galewski et al., 2011), were subdivided into two sub-regions each (Fig. 1). In addition, this subdivision accounted for more uniform markets that need to fulfil their own demands for food and living space and took into account socio-economic disparities between the Northwest and South. In total, the study area covers 2.3 million km^2 in

27 countries with around 420 million inhabitants in 2015 (CAPMAS, 2015; EUROSTAT, 2016c; IIASA, 2016).

We identified four major challenging trends for the region based on various documents on the future of the Mediterranean (Appendix A): 1) increasing population and continuous urban sprawl; 2) agriculture and food production; 3) threatened biodiversity, and 4) significant climate change impacts and increasing water scarcity.

2.2 Population and urban expansion

The total population in the southern (Fig. 1) Mediterranean countries is expected to increase by 43% until 2050, and by 16% in the North (Fig. 1, including Western Balkans and Turkey) following the Shared Socioeconomic Pathways 2 (SSP2) scenario (Kc & Lutz, 2014; IIASA, 2016). Urban population in the South is expected to increase even more by 82% (Jiang & O'Neill, 2015). Urban expansion in the Mediterranean region is defined by dispersed and poorly managed urban sprawl (Benoit & Comeau, 2012; Salvati *et al.*, 2012). Significant portions of Mediterranean coasts are being transformed to built-up coastal landscapes (Munoz, 2003; Parcerisas *et al.*, 2012). Agriculture is pushed further into wetlands where surface water is available (MWO, 2012). As fertile areas in the region are limited to river plains and coastlines, a large extent of cropland is lost due to soil sealing (Mediterranean 2030 Consortium, 2011). Future population increase will undoubtedly result in further pressure on coastal urban areas, especially near existing large urban agglomerations (European Commission, 2011).

2.3 Agriculture and food production

Agriculture in the region reflects its socio-economic disparities. The northern part hosts high-input intensive agricultural systems, with most of the crops being exported. In contrast, the Southern Mediterranean hosts a considerable portion of cropland with low yields and less efficient agricultural management (Mueller *et al.*, 2012). Trade regulations, protection of the European market and food safety requirements pose serious constraints to the Southern Mediterranean countries to export commodities such as fruit and vegetables (Larson *et al.*, 2002; Cioffi & dell'Aquila, 2004; García Martinez & Poole, 2004). Access to agricultural technology, subsidies and loans is unequally distributed in the region and is more accessible to farmers in the north-western part. Pasture based systems are becoming less competitive, due to high labour costs – on-farm resources are being substituted with external inputs, promoting intensive livestock systems near urban areas (Steinfeld *et al.*, 2006; Bernués *et al.*, 2011). This has resulted in the increase in landless livestock systems in the Mediterranean region (Steinfeld *et al.*, 2006).

2.4 Biodiversity

The Mediterranean ecoregion was identified as one of the world's biodiversity hotspots, as it hosts a large number of plant and animals species, numerous among them endemic (Cuttelod *et al.*, 2009). The presence of these species is closely related to extensive Mediterranean landscapes, particularly agro-silvo-pastoral mosaic systems (Médail & Quézel, 1999) and wetlands (Cuttelod *et al.*, 2009). The transformation of these systems into intensive, single function cropland systems, or their abandonment into woodland can have a significant impact on the biodiversity of the region, including changes in landscape and plant community structure (Médail & Quézel, 1999). Only 5.5% of the region's area is protected, with 90% of protected areas in the Mediterranean North (Benoit & Comeau, 2012; FAO, 2013). Among the main threats to the region's biodiversity are also urban concentration and expansion in coastal areas (FAO, 2013). Human activities have also affected Mediterranean wetlands, through increased water extraction or livestock grazing (Houérou, 1993; Ayache *et al.*, 2009).

2.5 Climate and water constraints

The region is projected to experience warming exceeding global trends, with most climate change scenarios also resulting in reduced water availability (Chenoweth *et al.*, 2011; Keenan *et al.*, 2011; Guiot & Cramer, 2016). Climate change and water scarcity have even been proposed as potential contributors to conflicts in the region (e.g. Gleick, 2014; Kelley et al. 2015). Water scarcity is likely to pose severe limitations to the agricultural sector in the future, as numerous countries risk not being able to meet irrigation requirements (Fader *et al.*, 2016). Already today, freshwater resources in the region are being extracted at unsustainable rates, not allowing for natural replenishment (FAO, 2016). However, improved irrigation efficiency and a shift to crops with lower irrigation demands could considerably lower the requirement for irrigation water withdrawal in the region (Daccache *et al.*, 2014; Fader *et al.*, 2016).

3. Methods

3.1 Land system change simulation

Land systems characterize human-environment interactions in landscapes and are defined as combinations of land use and land cover, livestock and management type and intensity (van Asselen & Verburg, 2012; Turner *et al.*, 2013). The use of land systems is a particularly suitable approach for the Mediterranean region with its diverse mosaic landscapes that may not be easily disentangled into separate land cover classes. Moreover, land systems allow a clear quantification of goods and services provided by each land systems unit, necessary to simulate future change. To simulate future land system change until 2050, we applied the CLUMondo model (Fig. 2). CLUMondo simulates land system changes driven by defined demands for specific goods or services provided by land systems, taking into account the local spatial characteristics (van Asselen & Verburg, 2013). As a baseline, we used the Mediterranean land systems map for 2010 (Fig. 3, Malek & Verburg, 2017a). Each land system is characterized by an average cropland and urban extent (% of the land system unit area of 4 km2), and livestock density (livestock units in nr. per unit). In the land systems map, irrigated cropland systems are present on areas equipped with irrigation. Intensive rain-fed cropland was identified on areas where fertilizer application, field size or yields indicate intensive agriculture. The remaining rain-fed cropland was identified as extensive (for details on the method see Malek & Verburg, 2017a). Every land system provides annual and/or permanent crops, livestock and consists of a certain fraction of built-up area (Appendix B). The land systems' output of crops (annual and permanent) is a value specific to each land system. These values were calculated based on crop production statistics to land systems and are described in Appendix B.

The actual output of annual and permanent crops was based on agricultural production statistics for 2010 (EUROSTAT, 2013; 2016a, 2016b). We used subnational statistics to exclude non-Mediterranean parts of countries (France, Spain, Italy, Turkey), where a significant share of crops is produced. For countries in the Southern Mediterranean, we looked at national statistics on cropland areas and production in subnational units within the Mediterranean ecoregion. In most countries, virtually all crops were produced in the Mediterranean part (for example, 99% in Algeria and Morocco). The only exception was Egypt, where 65% of the crops are produced in the Nile delta, which we used to adjust national crop production statistics (FAO, 2016; Mohamed, 2016). Crop production was aggregated for each sub-region, and all land system output values present a mean for a specific sub-region. We used the SPAM database to identify the shares of crops produced in irrigated, intensive rain-fed and extensive rain-fed systems (You et al., 2014). Total crop production was then scaled according to these shares and calculated for the appropriate land system type (e.g. irrigated systems were associated with crops produced on irrigated cropland, intensive rain-fed with crops produced in intensive cropland). We used agricultural statistics for 2010 for two reasons. First, the year 2010 presents the most recent year where crop production statistics were consistently reported for subnational units in our study area. Secondly, the reported national crop production for 2010 deviates the least from the average national crop production of the last 20 years (less than 2%).

Annual crops consist of cereals (wheat, maize, barley and rice), and vegetables (fresh vegetables, potatoes and tomatoes). In the Mediterranean, wheat, maize and barley present the majority of cereals, with rice having a significant share in Egypt and Italy (EUROSTAT, 2013, 2016a, 2016b). Permanent crops consist of fruit , olives and dates. Olives, grapes and citrus alone amount to over 20% of total crop production in the Mediterranean region (Daccache *et al*., 2014). Livestock output is based on the values derived from a global livestock database, with values for bovines, goats and sheep calculated to livestock units (Robinson *et al.*, 2014).

CLUMondo allocates changes to land systems based on spatial preference, spatial restrictions and competition between land systems (van Asselen & Verburg, 2013). Spatial preference or local suitability describes the probability of each location (grid cell) to host a specific land system, based on its biophysical and socioeconomic conditions. CLUMondo allocates future land change in locations with highest preference for a defined land system. To calculate spatial preferences the relationships between the spatial occurrence of a specific land system and location factors (explanatory biophysical and socioeconomic variables presented in Appendix C) are investigated using logistic regression. This results in maps presenting the likelihood of occurrence of different land systems as a function of local environmental and socio-economic conditions (Appendix D). Spatial preference maps are updated annually to account for population and climate change, as described in later sections. Spatial restrictions are constraints for changing specific land systems, such as protected areas. Spatial restrictions can either completely constrain land change, or allow predefined changes to land systems (e.g. woodlands can change into forests in a protected area). To achieve a solution, CLUMondo iterates different land system allocation combinations until it fulfils all demands for a specific year for a specific scenario. Although the model can handle the provision of numerous crops and livestock units by land systems, it will promote the most competitive (while accounting for both the occurrence likelihood and competitiveness in terms of the services delivered towards the demand) system for that demand. The model is described in more detail by (van Asselen & Verburg, 2013) and is available (as open-source) at http://www.environmentalgeography.nl/site/data-models/data/clumondo-model/.

3.2 Limiting water resources

Besides achieving the most likely land system allocation under the defined demands, CLUMondo can take into account the limitations of the allocated land systems in terms of resource use. In this study, use of water resources was constrained, by applying a threshold on the total irrigation water withdrawal. This situation is implemented using physical limitations as a maximum level of resource use which cannot be overshot. If the demand cannot be satisfied fully with irrigated land systems under the given constraints, CLUMondo has to fulfill it with rain-fed land systems. This limits the allocation of irrigated land systems with high water requirements, although they have the highest crop output (Appendix B) and are therefore promoted by the model if irrigation is not limited. To satisfy the demand for annual and permanent crops, CLUMondo needs to consider other land systems without irrigation demands, but also with lower output for these crops, having a tradeoff on the conversion of (semi-)natural areas.

To associate irrigated land systems with irrigation water withdrawal, we used spatially explicit irrigation data on areas equipped with irrigation (Siebert *et al.*, 2005, 2013). Irrigation demand values for irrigated land systems were based on the extent of irrigated areas, which we linked to national and subnational irrigation water withdrawal statistics (EUROSTAT, 2013, 2016a, 2016b; FAO, 2016). This resulted in mean values of irrigation water withdrawal per cell of irrigated land system for each region (Appendix B). The available water resources, that served as a limit for irrigation water withdrawal, are based on water resource statistics on the national (Mediterranean South: FAO, 2016) and subnational level (Mediterranean North: EUROSTAT, 2013, 2016a, 2016b; Egypt: FAO, 2016; Mohamed, 2016).

3.3 Scenarios

3.3.1 Scenario introduction

To study potential pathways to fulfill the growing food production and the demand for living area in the Mediterranean region, we have developed two contrasting scenarios: ‘growth’ and ‘sustainability’. The scenarios follow different assumptions in terms of production of annual and permanent crops, and livestock, and the demand for built-up area up to 2050 (Table 1). Both scenarios are based on global SSP2 projections for the region in terms of regionally produced food, however modified to fit the storyline of each scenario as described in Table 2 and Appendix E. The production values for annual and permanent crops, and livestock are based on the SSP2 marker scenario projections for food production (Fricko *et al.*, 2016; Riahi *et al.*, 2016; Popp *et al*., 2017). These projections are a result of integrated assessment models, where the remaining consumption is satisfied with imports. In the projections, the Mediterranean North maintains producing more than it consumes in 2050, whereas the dependency of the Mediterranean South on food imports increases despite significant crop and livestock production growth (Alexandratos & Bruinsma, 2012). The Mediterranean South imported 56% of its total crop consumption in 2007 (Wright & Cafiero, 2011), which is projected to increase to 73% in 2050 (World Bank, 2009; Alexandratos & Bruinsma, 2012). The demand for built-up areas is based on the population growth rate of the SSP2 scenario (Kc & Lutz, 2014). The scenarios differ from each other significantly regarding the handling of major challenges the Mediterranean region will be facing in the future. In particular, in the sustainability scenario, freshwater is explicitly regarded as a limited resource for irrigation, while in the growth scenario, it is not. Technical details of translating the scenario storylines to the CLUMondo land system model are described in Appendix E.

3.3.2 Growth scenario – Production maximization through growth

Under the growth scenario the current economic disparities between the sub-regions are assumed to remain unchanged. Each sub-region follows its own goals, aiming to satisfy its own demands. Environmental issues, such as freshwater resources depletion are not considered.

Urban expansion. Urban expansion has priority to any other land process. Low density peri-urban systems are promoted, continuing urban sprawl. Rural abandonment continues in the North of the Mediterranean Basin. In the South, rural population increases until 2020, followed by a gradual decrease (Jiang & O’Neill, 2015).

Agriculture and food production. Agricultural intensification has priority – extensive areas are promoted to convert to intensive ones, achieved by higher use of fertilizers, irrigation and herbicides. Yield improvement technology remains unequally distributed in the region. Yield gaps are not closed, however achieve 75% of the attainable yield for irrigated systems. Landless livestock systems are promoted – indoor breeding systems on intensive cropland or near urban areas are subject to 15% intensification. No food waste reduction efforts are made.

Biodiversity. The extent of protected areas in the Mediterranean does not increase, but existing protected areas are conserved. Cropland and livestock activities with low intensity (extensive cropland and mosaic systems) are allowed in protected areas. Wetlands continue to be used for cropland and used for intensive livestock grazing. Grazing in arid areas is uncontrolled.

Climate and water constraints. Same crops are being grown as today which, given the reduction in precipitation and increases in evaporation, results in lower suitability for rain-fed intensive systems occurring in semi-arid areas due to climate change. Water resources can be exploited without limitations.

3.3.3 Sustainability scenario – Fulfilling the Mediterranean sustainable development goals

The sustainability scenario describes a future, where the future Mediterranean region is characterized by prosperity, solidarity and stability. Throughout the region, national governments and other actors agree to follow shared environmental and development goals.

Urban expansion. Urban sprawl is limited and well planned. A new type of a Mediterranean compact city emerges, denser urban areas are promoted. Rural population remains stable.

Agriculture and food production. A common Mediterranean market involving all countries around the Mediterranean sea (Fig. 1) is established. It results in a liberalization of agricultural trade, with improved access to agricultural technology, loans and subsidies for everybody. The entire region can easier satisfy its demand through additional food with imports, and can export even more commodities such as permanent crops. Yield gaps on irrigated and rain-fed intensive cropland are closed in the North, and reach 90% (irrigated) and 75% (rain-fed intensive) of attainable yield in the South. Land based livestock systems are promoted. The efficiency of livestock production systems in terms of output is improved, for example by improving breeds or fattening of herds (Bernués *et al.*, 2011). A moderate reduction in food waste due to changed dietary habits (North) and improvement in the food supply chain (South) results in a lower increase in total regional demand for agricultural production.

Biodiversity. The entire region applied coherent and consistent environmental policies and conservation tools. The extent of protected areas in the region reaches the 17% of terrestrial ecosystems as specified by the “Aichi target” of the UN Convention for Biodiversity (http://www.cbd.int/sp/targets), being a considerable improvement for the Mediterranean South (Pouzols *et al.*, 2014) (Appendix F). Low intensity cropland and livestock grazing (extensive cropland and mosaic systems) are allowed in newly established protected areas. Wetlands use by intensive crop production system and grazing of livestock is decreased. Grazing intensification in arid areas is limited in order to combat desertification. Ecological focus areas are assigned as 5% of area set aside in all rain-fed systems. This way, landscape elements with higher biodiversity values are being protected or established.

Climate and water constraints. Due to improvement in cultivars and crop changes (for example with crops with lower water demands), intensive rain-fed areas can expand more than they do in the growth scenario (Daccache *et al.*, 2014). Improvements in irrigation infrastructure and changes to irrigation type (e.g. drip irrigation lead to a 35% improvement in irrigation efficiency . Irrigation water withdrawal is limited to 75% of current total withdrawal, to allow more water for biodiversity and ecosystems.

3.4 Climate and population change

In both scenarios, global change was included either through a change in the location factors which underpin the spatial preference map for land system transitions, or as a land system change constraint. We used results from downscaled global climate models from CMIP5 (Hijmans *et al.*, 2005; Taylor *et al.*, 2012) forced by the RCP4.5 greenhouse gas radiative forcing representative concentration pathway. RCP4.5 is a cost-minimizing mitigation scenario, presenting a “median” and probable pathway compared to other scenarios (Thomson et al. 2011). We calculated the mean of 19 CMIP5 simulation outputs (Appendix G) for both temperature and precipitation for the years 2041-2060, referred to as year 2050. Based on these projections, we generated annual temperature and precipitation maps, which were then used to derive annual potential evapotranspiration (PET) and aridity index (AI) maps (Trabucco *et al.*, 2008; Zomer *et al.*, 2008) (Appendix H). Temperature, precipitation and PET served as location factors in the logistic regression, and AI was used to limit particular processes (Appendix E). For example, forest expansion was possible only in areas with AI>0.65 (Zomer *et al.*, 2008).

To account for population change, we updated the 2010 population density map using the SSP2 projection growth rates (CIESIN, 2015; Jiang & O’Neill, 2015). We used urban population growth rates for areas with higher population density (>250 inhabitants/km^2) for both scenarios (Appendix I). This corresponds well with population change projections for the Mediterranean region (Benoit & Comeau, 2012). Changes to rural population were applied to the rural population density map (Appendix C), and were also based on global SSP2 projections (CIESIN *et al.*, 2011; Jiang & O’Neill, 2015).

3.5 Changes to productivity of land systems

Changes to productivity were implemented by changing the output of each land system in time (Appendix B). We first studied the current average yield gap of land systems using yield gap data for major crops (Foley et al., 2011). Then, we calculated annual growth rates of land system output changes to achieve crop yields assumed attainable under the scenario conditions (Tables 2 and 3). The attainable yields were based on plausible improvements to nutrient management and irrigation as proposed by Mueller et al. (2012). Mueller et al. (2012) did not consider climate change impacts on crop yields, although the potential to close yield gaps in different regions was constrained by climate conditions.

Because the used productivity changes do not explicitly account for climate change impacts on productivity, we compared the annual productivity increases in both scenarios (Table 3), with other scenario studies that focus on future yield change in the Mediterranean region. Our assumed productivity increases are lower than in other studies, except in both climate change studies (Parry et al., 2004; Giannakopoulos et al., 2009). In these two studies, technological improvements and adaptation were however limited or not considered. In contrast to the studies mentioned in Table 3, we assumed cropland productivity will only increase in intensive rain-fed and irrigated systems, and not overall in the cropland sector. We did not improve the productivity of existing extensive cropland or traditional multifunctional mosaic systems. Moreover, we did not consider potential increases to water demands of different crops. Studies have demonstrated that improving the irrigation efficiency can help maintaining cropland productivity and allow for expansion of irrigated areas in the Mediterranean (Fader et al., 2016; Malek & Verburg 2017b; Saadi et al., 2015).

4 Results

4.1 Changes to management of Mediterranean land systems

In both scenarios, extensive cropland systems decreased most (Table 4). This is either through intensification of management, or due to abandonment and subsequent conversion to woodlands. There is also a drastic increase in urban systems in the Middle Eastern region, particularly Syria, Israel, Palestine and Jordan. The largest expansions of irrigated areas can be observed in Turkey, Tunisia and Morocco. The inclusion of water limitation for crop irrigation in the sustainability scenario impacts the way in which the demands for food are satisfied in comparison to the growth scenario (Fig. 4). In some parts of North-West Africa and Turkey, limited freshwater availability for irrigation results in more rain-fed intensive areas compared to the growth scenario (Fig. 5). In Algeria, the Western Balkans and Turkey, limited water availability does not necessarily result in more rain-fed intensive area, as a significant part of food demands is fulfilled by intensifying mosaics, higher efficiency improvement, while simultaneously the overall food demand is lower due to a decrease in food waste. Land system results for both scenarios are depicted in Fig. 4, with more detailed land system conversions shown in Table 4, Fig. 5 and Fig. 6, Appendix J and downloadable in GIS format from www.environmentalgeography.nl. Fig. 7 presents the two future scenarios in three focus areas, the Iberian peninsula, Middle East and Turkey, and in Tunisia.

4.2 Changes to traditional Mediterranean landscapes

More mosaic systems are preserved in the sustainability scenario: 60% more compared to the growth scenario. Whereas a significant share of mosaic systems remain the same, still around 58% and 32% of mosaics change in the growth and sustainability scenario respectively. Around 36% of mosaics in the growth and 21% in the sustainability scenario were changed to other mosaic systems (Table 5). Based on the level of multifunctionality, the mosaics either changed to another mosaic with the same level, or to a mosaic with a higher level. The level of multifunctionality was identified based on the number of activities defining the system. A change from a mosaic land system with 2 activities (e.g. woodland-rangeland mosaic) to another mosaic with 2 activities (woodland-cropland mosaic) was identified as a change in management on a same level of multifunctionality. The extent of mosaics, that change from another type of mosaic while keeping the same level of multifunctionality is significant in both scenarios (Table 5). Such processes were projected in southern Spain, Portugal, Western Balkans and south-western Turkey (Fig. 6). An interesting process is the increase in functionality, occurring in both scenarios. This process represents additional activities on existing land systems, such as introducing livestock to woodlands or woodland-cropland mosaics. The model transformed land systems with lower output in terms of crops and livestock such as woodlands, to land systems with higher output occurring in similar locations (similar spatial preference) such as woodland-cropland or woodland-rangeland mosaics. These processes are projected to occur on extensive areas in Algeria, Western Balkans and western Syria (Fig. 6). Differences in the extent of losses of Mediterranean agro-silvo-pastoral mosaic systems between the two scenarios are mostly a consequence of cropland expansion and intensification – more than twice as many mosaics are transformed to intensive or irrigated cropland in the growth scenario compared to the sustainability scenario (Table 5). In some areas, agro-silvo-pastoral mosaic systems expand. This is mostly caused by an increase in livestock density in extensive cropland systems, or through the introduction of livestock to cropland that was abandoned during the simulated time period. Increases in livestock density and grazing on abandoned cropland were projected mostly in NW Africa, but also in southern Spain (Fig. 6 and 7).

4.3 Water resources

As the use of water resources was constrained only in the sustainability scenario, the overall lower water extraction values are considerably lower than in the growth scenario. Clearly, the constraints on water use have influenced the model's choice of land systems. In the growth scenario, all regions demonstrate a significant increase of irrigation water withdrawal (Table 6). The highest expansions of irrigated cropland systems and consequent increases in irrigation water withdrawal are projected in the sub-regions Western Balkans and Turkey and NW Africa. We used the pressure on freshwater resources index (PFR), to describe the water stress of the sub-regions in the two scenarios (Table 6). It is defined as the share of total irrigation water withdrawal in available freshwater resources (FAO, 2016). There are considerable differences between the regions in the baseline year (FAO, 2016) (Table 6). Both sub-regions of the Northern Mediterranean have a PFR index that is below 20%, which still enables biological functioning of freshwater bodies and does not result in water stress as a limiting development factor (Arnell, 1999). This is mostly due to the more abundant freshwater resources in these regions and a lower dependence of their agriculture on irrigation (Appendix B). The Middle East and NE Africa sub-region already has unsustainable freshwater extraction rates, as some countries (e.g. Egypt and Libya) are already extracting more resources compared to their renewable water resources (Table 6).

5 Discussion

5.1 Future changes of Mediterranean land systems

Modelling the future of land use and management intensity is a central part in integrated assessment models (Wise *et al.*, 2009; Stehfest *et al.*, 2014). However, given the global character of these assessments, and the strongly simplified land cover representations, little insight into the potential changes in the specific Mediterranean land systems is acquired from these studies. While single case studies have documented the (potential) response to global change in the Mediterranean (Bugalho *et al.*, 2011; Keenan *et al.*, 2011; Nainggolan *et al.*, 2012; Parcerisas *et al.*, 2012), no earlier study specifically focused on the impacts of global change across the entire region and took into account the impacts of the limited water availability. Land systems provide highly appreciated benefits for the regional population: the region is a significant producer of highly demanded commodities, such as olives and grapes, and the region hosts vast areas of traditional multifunctional mosaic landscapes, that are well studied (Blondel, 2006; Daccache *et al.*, 2014). The region is projected to witness significant climate changes, mostly in the form of temperature increases, decreases of precipitation and more frequent climate extremes. At the same time, demographic changes and fast urbanization will pose additional challenges to land systems.

The two fundamentally different scenarios we developed, demonstrate two potential pathways of how land systems may respond to a growing population in the Mediterranean. While the future of land management of the region is more likely to be between these two scenarios, the scenarios sketch how differences in the level of technological development and the implementation of policies concerning rural development, water management and biodiversity lead to strongly different land system outcomes. Both scenarios represent a future, where the southern Mediterranean countries continue to depend on food imports for a significant part of their food demand and are based on global integrated assessment calculations of trade, demand and supply between regions. In all global level scenarios it is acknowledged that to feed the growing population of the region, significant food imports will still be needed (Wright & Cafiero, 2011). Our results indicate that already under those conditions enormous changes in land systems are needed to meet such demands for production in the region. Moreover, when looking at the changes between the two scenarios, we can identify adaptation opportunities in land management to avoid changes to mosaic land systems and cropland expansion (Fig. 8). Significantly more areas are subject to irrigation, intensification and changes to mosaics in the growth scenario compared to the sustainability scenario, suggesting the potential outcomes of successfully following common sustainable development goals. Technological improvements and nutrient management, improved irrigation efficiency, and protection of traditional land use systems were thus recognized as successful measures to increase the resilience of traditional Mediterranean landscapes. Nevertheless, the sustainability scenario also projected changes to intensity and irrigation differently from the growth scenario. These locations mostly present the tradeoffs of expanding the protected areas network (Fig. 8).

Despite a lower demand for agricultural products in the sustainability scenario, more land system transformations to intensive rain-fed cropland were projected for some areas, notably in NW Africa. In this region rain-fed intensive areas provide much less output compared to other regions and are characterized by high yield gaps (Mueller *et al.*, 2012). The lower use of irrigated cropland to meet agricultural demands therefore comes at the cost of a larger expansion of rain-fed croplands in this scenario. The intensification of rain-fed cropland was mostly projected in areas that will maintain more favorable climatic conditions in the future, such as northeast Spain. Other locations of intensifying rain-fed cropland (e.g. north of the Atlas mountains) correspond well with other research (van Asselen & Verburg, 2012; Mueller *et al.*, 2012).

The model projected significant increases in irrigated cropland in both scenarios, because irrigated systems in most sub-regions have the highest output of crops, and were thus promoted by the model to fulfil agricultural demands. Equipping rain-fed cropland with irrigation, particularly in semi-arid regions as the Mediterranean, is among the most implemented adaptation options to reduce risks to climate change (Smit & Skinner, 2002). Due to projected climate change, the extent of areas most suitable for rain-fed intensive cropland systems decreased. A major limiting factor for rain-fed agriculture is high aridity, and arid and hyper-arid areas are projected to expand in the NW Africa sub-region (Appendix H). Although necessary improvements in irrigation efficiency to maintain current water withdrawal with projected expansion of irrigated areas are possible (Fader *et al.*, 2016), the two southern Mediterranean sub-regions already today have unsustainable water withdrawal levels. Furthermore, the growth scenario does not consider projected decreases in water resources as may be expected due to depletion of aquifers and climate change (Vörösmarty *et al.*, 2010; Chenoweth *et al.*, 2011). Despite the efforts on finding new water resources, water reuse and desalination, the growth scenario is strongly overestimating the water availability.

The drastic expansion of irrigated areas projected in the sub-regions Western Balkans and Turkey, and NW Africa is expected under the ‘growth’ scenario. Particularly in NW Africa, irrigation is needed in order to increase the yields, as studies suggest that only improving nutrient management and mechanization will not be enough to improve cropland productivity in this area due to local climatic conditions (Mueller *et al.*, 2012). Generally, the sustainability scenario resulted in less intensive rain-fed and irrigated cropland (Fig. 8), which can also be attributed to a 5% lower demand due to a decrease in food waste. Nevertheless, our reduction in demand for agricultural products is conservative, as studies suggest higher potentials to reduce agricultural demands in case of drastic improvements in the supply chain or diet change (Parfitt *et al.*, 2010; Garrone *et al.*, 2014).

Expansion of multifunctional systems, projected by the model in both scenarios can be explained two-fold. First, these areas are subject to expansion of protected areas in the sustainability scenario, which prevents more intensive land systems to be established, but allows for the conversions into other (more) traditional extensive systems. Secondly, climatic and soil characteristics of these areas constrain rain-fed intensive agriculture. Similar transitions have already been observed at the local scale in areas such as south-eastern Spain, as a result of environmental conditions, policies favoring woodland expansion and less profitable rain-fed agriculture (Nainggolan *et al.*, 2012). This increase of multifunctional areas can be defined as sustainable intensification, where satisfying future demands for crops and livestock occurs simultaneously with meeting sustainability objectives (e.g. biodiversity protection and strengthening rural communities) (Garnett *et al.*, 2013). Multifunctional land systems have been acknowledged as a significant adaptation option to climate change, particularly for smallholder farmers (Verchot *et al.*, 2007). Although multifunctional areas contribute less to satisfying food demand as compared to intensive cropland, they can also be recognized as an effort to rehabilitate and conserve land and water resources. Such increased land productivity (in terms of crop and livestock production) with simultaneous sustainable land use follows the objectives of the United Nations Convention to Combat Desertification (UNCCD, 1994).

This study took into account competing demands for food production and living space. Traditional Mediterranean land systems are, however, providing other significant ecosystem services, such as non-timber forest products like mushrooms or cork, fire prevention, carbon storage, soil erosion prevention and landscape aesthetics (Bugalho *et al.*, 2011; Almagro *et al.*, 2013; Guerra *et al.*, 2016). These services could also act as additional demands especially if covered by environmental, rural development and tourism policies (Eitelberg *et al.*, 2016). Future studies should therefore study the effects of maintaining different benefits provided by traditional Mediterranean mosaic systems besides food. This way, the extent of mosaic systems needed to provide a certain extent of important ecosystem services can be determined, as well as potential tradeoffs in irrigation and intensification in other areas.

5.2 Water limitation as a contribution to land change modelling

Significant improvements in the modelling of future land use have been made in the recent decades, including more precise coverage of spatial, temporal and thematic resolution and moving beyond an approach based only on dominant land cover (Hurtt *et al.*, 2011; Letourneau *et al.*, 2012; Souty *et al.*, 2012; Bryan *et al.*, 2016). Land management which used to be represented in a simplified manner as a class of regional management factor (Bouwman *et al.*, 2006; Bondeau *et al.*, 2007), can now be described using different management intensity metrics, such as livestock numbers, fertilizer inputs or yield gaps (Souty *et al.*, 2012; van Asselen & Verburg, 2013). This is necessary, as often socio-economic changes are not limited to direct land cover changes, but predominantly lead to changes in management intensity or irrigation. In this study, we managed to quantify the relative changes required for both land management and land cover to fulfill future food demands. Our results show that for the growth and sustainability scenario respectively 61% and 51% of the increase of agricultural demand is met by new irrigation, 23% and 36% by cropland intensification and only 12% each by cropland expansion. Our study therefore confirms that the inclusion of changes in land management (irrigation and intensification) may be more important than land cover changes in modeling of future scenarios. This way we contribute to better understanding of land system processes leading to increased pressure on land and water resources, and consequent land degradation (UNCCD, 1994).

The growth scenario presented a continuation of worldwide trends, where the demands for food and living space are fulfilled by increasing more productive, monofunctional, land systems at the expense of traditional systems, as is also suggested by global scale studies (van Asselen & Verburg, 2013; Eitelberg *et al.*, 2016). In this scenario, the likelihood of spatial variables and location preferences for where irrigated systems were considered in the allocation of land systems by the model. However, the expansion of irrigated agriculture was not limited by water availability. Consequently, the growth scenario resulted in more than twice as much irrigation water withdrawal in the sub-regions NW Africa and Western Balkans and Turkey. An assumption of unlimited water availability can therefore lead to an overestimation of expanding irrigated areas. Such increases of water extraction are unlikely to happen in the Mediterranean basin, partly because of the regional expected impacts of climate change (Elliott *et al.*, 2014). On the other side, not constraining water availability is a useful scenario exercise as it demonstrates the land systems distribution that might otherwise be possible (Fig. 8). Our results show the necessity of including the reality of limited water availability when simulating future changes to land systems, particularly in (semi)arid regions. Many global studies disregard this issue and suggest significant cropland expansion and intensification in other semi-arid areas (van Asselen & Verburg, 2013; Eitelberg *et al*., 2016), which undoubtedly will have an impact on future water resources. The approach presented in this paper can, therefore, be applied in areas that face similar resource constraints, and improve the understanding of how future cropland expansion and intensification are responding to situations of water stress.

In this study we used spatially explicit irrigation data, linked to irrigation water withdrawal and freshwater resources statistics. This resulted in mean values per cell of irrigated land system, not considering areas where water withdrawal values can be considerably higher due to higher potential evapotranspiration. Incorporating water cycle processes is needed to improve the availability and constraints of water resources. One example could be to use spatially explicit data on water availability and water extraction, if such data was available on a more detailed resolution (Brauman *et al.*, 2016). A higher resolution of water withdrawal of land systems might be achieved, by operating on a catchment scale. Nevertheless, data on crop production is not available on the same scale, which would result in a mismatch of management levels - water management on catchment scale vs. agricultural management on a regional or national scale. Moreover, using spatially explicit water withdrawal data would mean additional uncertainties to our approach, related to the models used to derive such data. Using regional or national scale irrigation withdrawal data furthermore ensures a higher transferability of our approach to similar (semi)arid areas with increasing food demand and high water stress (e.g. other areas in the Middle East, south Asia, China, North America…). Another challenge would be to consider groundwater reserves, as these are often non-renewable, or their exploitation exceeds groundwater recharge rates. Although there is data on irrigation from groundwater resources, for the Southern Mediterranean it is based on national statistics (Siebert *et al.*, 2010), which makes it difficult to limit their spatial extent and occurrence. Irrigation using groundwater might also occur in the hyper-arid (desert) part in the Middle East and North Africa, outside our study area (Mediterranean ecoregion).

We only focused on water withdrawals for agriculture and did not account for the competing demands for municipal and industrial water use. Whereas in the European Union irrigation amounted for around 40% of total water withdrawals, it is the main source of water withdrawals in other sub-regions (Appendix K). Future socio-economic development particularly in the southern Mediterranean will however also likely result in increased demands for non-agricultural water use (Flörke *et al.*, 2013). Livestock water use was also not considered, mostly as the statistics in all sub-regions except the European Union equal irrigation with agricultural water withdrawals (FAO, 2016). Nevertheless, livestock also has significant water demands influencing freshwater resources (Mekonnen & Hoekstra, 2012). Further research on improving the data on water use and how different sector compete for water resources is therefore needed.

5.3 Storyline to modeling translation and uncertainties

In this study, we present a transparent and clear methodology on translating storylines to modeling, as demonstrated by detailed supplement information. Individual steps of our study are presented, ranging from preparing dynamic input files for changing temperature and precipitation, to defining model parameters reflecting the storyline. This way, we aimed at improving the presentation of the translation of specific policy assumptions to model parameters.

In analyzing global change effects on local scale land management, we went beyond applying global demand projections only. We developed two storylines that describe regional challenges on a higher detail – global SSP storylines are more broad and general (Riahi *et al.*, 2016). For example, in our study water management is one of the most crucial challenges for the Mediterranean, influencing the development of scenarios significantly.

Model studies are sensitive to uncertainties and errors in the input data. We aimed to reduce the uncertainties in our approach by relying mostly on crop production and irrigation water withdrawal statistics. Nevertheless, combining numerous spatial data can result in an aggregation of uncertainties. For example, our baseline land systems map is heavily dependent on inputs such as land cover, with the southern Mediterranean having higher observed inaccuracies compared to the northern part (Malek & Verburg, 2017a). Moreover, in this study we focused on the Mediterranean ecoregion. Irrigated systems in deserts, such as oasis like date plantations in North Africa, are also contributing to total crop production and also irrigation water withdrawals.

One of the biggest uncertainties for land system modelling are assumptions on improvements in technology and efficiency. Agreement in efficiency improvements used in different models is usually higher in developed regions, such as the European Union (Paillard *et al.*, 2014), whereas we observed relatively large variations in other regions, such as the whole Southern Mediterranean and Turkey. This could be linked to the fact that yield gaps are larger in developing countries than in developed countries (Ramankutty *et al.*, 2008; Mueller *et al.*, 2012). Yield improvement scenarios are often optimistic, not considering the expected impacts of climate change (Long, 2006). Our yield improvements were rather conservative, considering the region's socio-economic and environmental characteristics (Mueller *et al.*, 2012). We did not apply efficiency improvements to all land systems as it is the case in some similar studies (van Asselen & Verburg, 2013; Eitelberg *et al.*, 2016). For example, in NW Africa, improvements in nutrient management are needed to achieve higher yields. Improved nutrient management on extensive cropland could however also mean a transition to a more intensive cropland, resulting in higher yields. Finally, we did not consider potential new crop production systems in the future. One example of such system are greenhouses with significantly higher agricultural output. Such systems could occur on a wider spatial extent, as they are less dependent on local environmental characteristics. Assumptions on technological improvement, particularly increases of yield are significantly influencing the extent of simulated cropland expansion, intensification and new irrigation and need to be considered carefully. To reduce the uncertainties related to future cropland productivity, future research should focus on differences between projected yields or cropland efficiency.

6 Conclusions: what are the consequences of global change for the Mediterranean?

In this article, we assessed how global change might influence future land systems in the Mediterranean. Similarly to global scale studies, we projected significant increases in intensively managed and irrigated cropland for the Mediterranean basin. Our study shows, that to a certain extent, it is possible to preserve traditional Mediterranean mosaic systems. The growth scenario depicts a future, where more mosaic systems will be abandoned or transformed to more intensive systems. Rural development policies focusing on improving the socio-economic conditions of rural areas, and increasing yields within traditional mosaic systems, as shown in the sustainability scenario, can be an alternative to further cropland expansion or conversion to monoculture intensive cropland systems. We have also shown, that an expansion of protected areas in the region is possible without compromising the region's abilities to produce food. The same goes for reducing the intensity of cropland and grazing activities in wetlands.

The two scenarios represent different pathways on managing Mediterranean freshwater resources and dealing with water shortages. In the growth scenario, water resources are continued to being depleted at unsustainable rates in the future with significant investments into alternative water resources. Some of them are already taking place today: water reuse, desalination, large infrastructural projects such as dams or channels (Hochstrat *et al.*, 2010; Pedrero *et al.*, 2010; El Gammal & Ali, 2011). Improving the state of freshwater resources, as projected by the sustainability scenario, is possible by increasing the efficiency of rain-fed cropland and strengthening the role of multifunctional mosaic systems.

Our results indicate, that increased food production in the Mediterranean can be accompanied by preserving landscapes with higher cultural and biodiversity values, and decreasing the pressure on freshwater resources. However, we also show that such a future is only possible under the implementation of common Mediterranean sustainable development goals and orchestrated agricultural and environmental management strategies.

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List of tables

Table 1. Demands for annual and permanent crops, livestock and built-up areas for the Mediterranean region for 2010 (EUROSTAT, 2013; EUROSTAT, 2016a, 2016b), and 2050 (modified from Fricko *et al.*, 2016; Riahi *et al.*, 2016; Popp *et al.*, 2017).

	2010		Growth 2050		Sustainability 2050	
Region	North	South	North	South	North	South
Annual crops (10^6 t)	138.23	78.62	163.53	110.61	153.19	101.89
Permanent crops (10^6 t)	68.40	21.73	80.88	30.56	78.33	30.12
Livestock (10^6 nr)	22.44	13.66	28.23	16.92	26.33	15.99
Built-up areas (10^3 km^2)	21.52	12.63	25.07	18.71	23.72	16.23

Table 2. Summary of main storyline elements of the two scenarios

	Growth	Sustainability
Population change and urban expansion		
Population in 2050	19.5% increase in the North, 47.4% increase in the South (SSP2)	
Demand for built up areas	10% higher than annual population growth rate	30% lower than annual population growth rate
Spatial pattern	Urban sprawl allowed, urban land has priority over all other uses. No expansion in protected areas	Compact and denser urban areas promoted, no expansion in protected areas
Agriculture and food production		
Food demand	Projected SSP2 marker scenario food production	10% lower annual crops demand growth. 10% higher permanent crops growth due to easier exports. Reduction in food waste resulting in total 5% lower food demand.
Yields	Irrigated systems achieve 75% of the attainable yield	Northern Mediterranean: closed yield gap for rain-fed intensive and irrigated systems Southern Mediterranean: extensive systems reach 50%, rain-fed intensive 75% and irrigated 90% of the attainable yield.
Livestock	15% efficiency improvement to landless livestock systems	5% livestock efficiency improvement to all systems
Access to irrigation	Same as baseline, 5% lower spatial preference for areas with low market accessibility	Improved accessibility
Biodiversity		
Protected areas	Only existing PAs	17% of national priority areas designated as PAs, transformations to high-intensity land systems in such areas are not possible
Wetland management	No changes	Intensity in cropland and livestock

		reduced by 30%
Grazing in arid areas	No limitations	Intensification in arid areas limited
Climate change and water		
Climate change scenario	RCP 4.5	RCP 4.5
Location specific deduction to rain-fed systems	reduced spatial preference in areas with aridity index < 0.5 by 0.1	reduced spatial preference in areas with aridity index < 0.5 by 0.05
Water resources	No limitations and changes to water withdrawal	Limited water withdrawal. Withdrawal reduced by 25%
Irrigation efficiency	N.A.	35% more efficient

Table 3. Future changes to cropland productivity (in % per year), together with considered climate change effects and future technological improvements in this study and comparable studies. EU: European Union, WBTU: Western Balkans and Turkey, MENA: Middle East and North Africa, NWA: Northwest Africa

	EU	WBTU	MENA	NWA	Climate change	Technological improvements
Observed yields change (1961-2000)	1.92	0.34	2.49			
International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD, 2009)						
High estimate	1.33	1.33	1.75		Crop responses to temperature and precipitation change, water stress (relatively small climate impacts in 2050)	Depend on investments in agricultural science and technology, and water productivity
Low estimate	0.71	0.71	0.79			
Millenium Ecosystem Assessment (MEA, 2005)						
High estimate	0.87	0.75	1.05		Crop responses to temperature and precipitation change, water stress	Increased fertilization and irrigation efficiency, major investments in agricultural research, GMOs, high mechanization level
Low estimate	0.35	0.42	0.63			Insufficient investments in irrigation and cropland productivity, difficulties to maintain fertility of land
Agrimonde (Ronzon, 2014)						
High estimate	0.81	2.22	0.67		Water stress, slower yield increase, increased variability of precipitation	Rapid technological improvements enable to overcome the impacts of climate change
Low estimate	0	1.33	0.24			Rural development and ecological intensification to increase cropland productivity, irrigation techniques, water preservation
Parry et al. (2004)						

High emissions	-0.59 to +0.04	0.08	-0.08		Crop responses to temperature and precipitation under current agricultural management	Limited: changes in planting dates, additional fertilization and irrigation on existing cropland
Low emissions	-0.17 to +0.17	0.04	-0.04			
Giannakopoulos et al. (2009)	-0.01 to +0.11	0.11 to 0.29	-0.27 to -0.13	-0.1	Crop responses to temperature and precipitation, and seasonality	No improvements. If adaptation is implemented, cropland productivity can stay the same or increase with changing sowing dates and cycles and irrigation.
This study						
Sustainability – irrigated / int. rain-fed	0.11 / 0.05	0.33 / 0.16	0.56 / 0.43	0.94 / 0.43	Productivity of rain-fed cropland is limited by current climate (Mueller et al. 2012), future climate limits the spatial extent of rain-fed cropland	Investments both in rain-fed and irrigated systems, resulting in moderate productivity increase
Growth – irrigated / int. rain-fed	0 / 0	0.16 / 0	0.45 / 0	0.78 / 0.26		Investments focus on high output systems (irrigated only), low productivity increase

Table 4. Changes to spatial extent of Mediterranean land systems in %

Land system		Growth	Sustainability
Forest systems	medium intensity forest	-6.0	-12.4
	(semi)natural forest	24.8	22.0
	high intensity forest	-79.9	-43.1
Arid grazing systems	extensive arid system	-71.9	-18.2
	intensive arid system	84.1	16.6
Agro-silvo-pastoral mosaics	closed wooded rangeland	24.4	23.7
	open woodland	-92.1	-61.6
	open wooded rangeland	57.8	78.0
	cropland/wooded rangeland	-11.5	-34.9
	cropland/rangeland	29.0	63.1
Extensive rain-fed cropland	extensive annual	-82.9	-64.1
	extensive permanent	32.3	-53.3
	extensive mosaic	-70.8	-64.3
Intensive rain-fed cropland	rain-fed intensive annual	8.2	15.4
	rain-fed intensive permanent	41.6	-14.7
	rain-fed intensive mosaic	44.5	44.1
Irrigated cropland	irrigated annual	79.1	12.6
	irrigated permanent	26.0	38.5
	irrigated mosaic	-49.3	31.2
Settlements	peri-urban	10.2	2.1
	urban	72.2	44.7

Table 5. Changes to agro-silvo-pastoral mosaic system until 2050

Change process (%)	Growth	Sustainability
Persistent multifunctional systems	42.43	67.98
Multifunctionality loss towards monoculture	21.57	10.66
Similar level of multifunctionality, different management system	23.48	15.13
Increase of functionality within mosaic systems	12.52	5.86
Extensive cropland transformed to multifunctional systems	44.87	53.40

Table 6. Irrigation water withdrawals and pressure on freshwater resources (PFR) in the Mediterranean in 2010 and 2050. Irrigation water withdrawals and freshwater resources and are based on national and subnational statistics (EUROSTAT, 2013, 2016a, 2016b; FAO, 2016).

	Sub-regions			
	W. Balkans and Turkey	**EU**	**Middle East and NE Africa**	**NW Africa**
Changes in irrigation water withdrawal compared to baseline levels (%)				
2050 – growth	+55.9	+37.0	+21.4	+59.9
2050 – sustainability	-18.0	-21.5	-27.9	-33.6
PFR (%)				
2010	11.8	10.2	94.4	30.2
2050 – growth	18.4	13.9	114.7	49.6
2050 – sustainability	9.7	8.0	68.1	20.0
Irrigation efficiency improvement to maintain current water extraction in growth scenario (%)	35.8	27.0	17.6	37.4

Figure captions

Fig. 1 The studied Mediterranean ecoregion with its 4 sub-regions

Fig. 2 CLUMondo land system change concept

Fig. 3 Mediterranean land systems map (based on: Malek & Verburg, 2017a)

Fig. 4 Future land systems in 2050 as simulated for the two scenarios: (a) growth, (b) sustainability. High resolution version of the map is available in Appendix J.

Fig. 5 Changes in land management intensity in the (a) growth and (b) sustainability scenario. High resolution version of the map is available in Appendix J.

Fig. 6 Land system change affecting mosaic land systems in the growth (a) and sustainability (b) scenario. High resolution version of the map is available in Appendix J.

Fig. 7 Future 2050 land systems scenarios in focus areas, (a) Spain and Portugal, (b) Middle East and Turkey, (c) Tunisia

Fig. 8 Future land management opportunities for the Mediterranean region, defined as spatially explicit changes between the two scenarios, with the sustainability scenario as a reference. The two maps present the consequences of implementing the policies of the sustainability scenario, described as avoided and consequent changes to a) mosaic land systems and b) irrigation, intensification, cropland expansion and abandonment. Values in brackets are in 1000 km^2.

List of appendices

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Appendix B: Mediterranean land system characteristics per 4 km^2 land system unit

Appendix C: Location factors used in calculating spatial preference maps using logistic regression

Appendix D: example of spatial preference maps

Appendix E: technical details of both scenarios

Appendix F: protected areas in the Mediterranean ecoregion

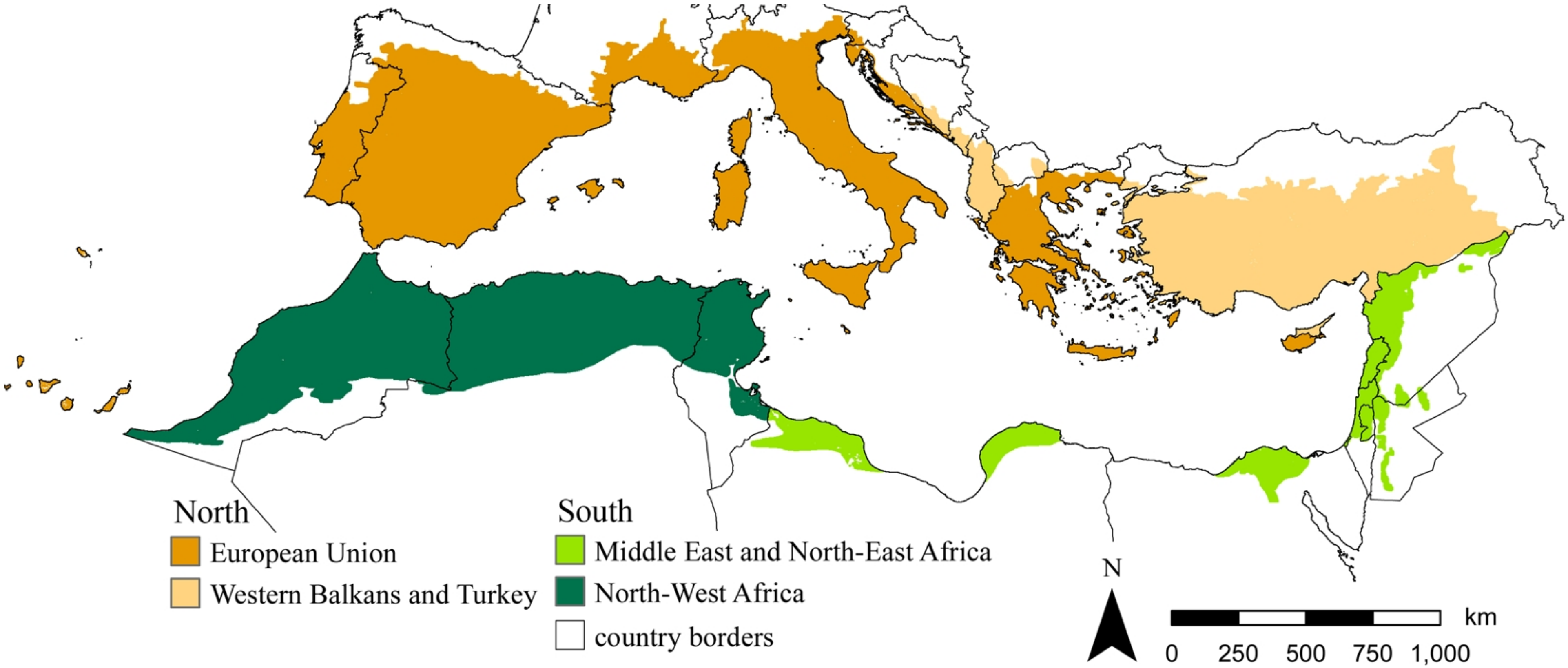
Appendix G: CMIP5 simulations of the RCP4.5 scenario used to update precipitation, temperature, PET and AI maps for the year 2050 (average of 2041-2060)

Appendix H: PET and AI calculation and map example

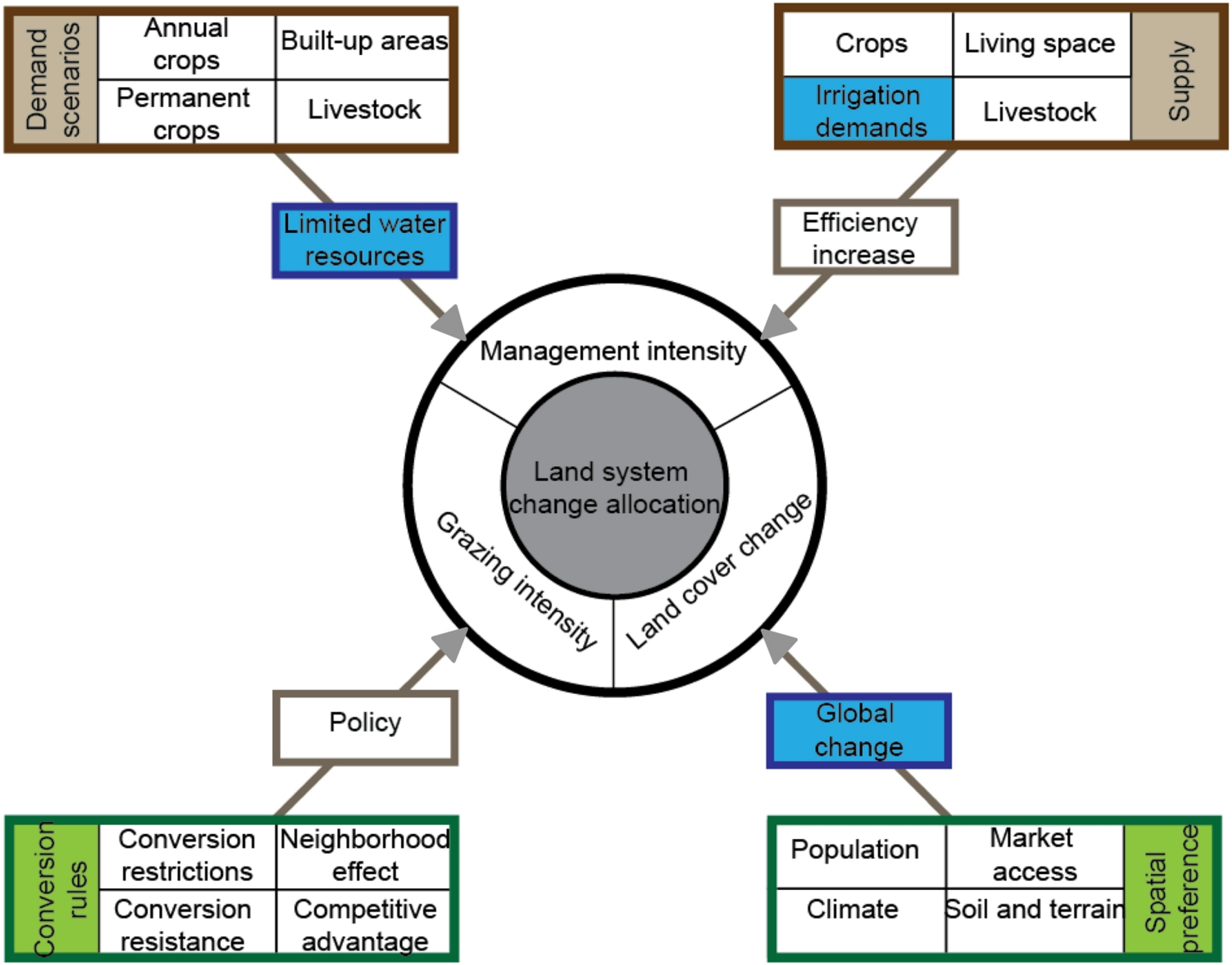
Appendix I: Changes to urban population

Appendix J: Scenarios: high resolution figures

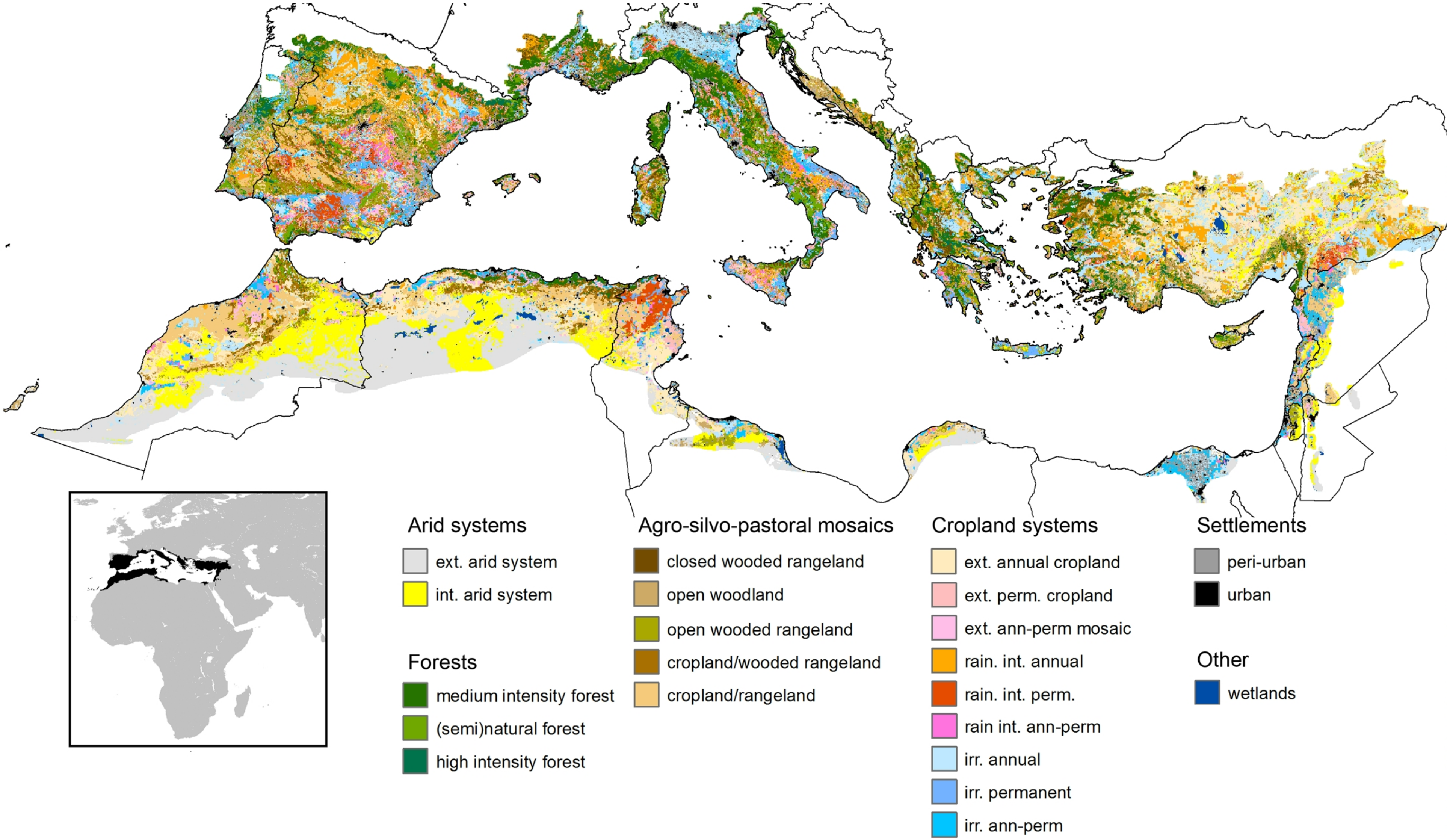
Appendix K: Freshwater resources and irrigation water withdrawal



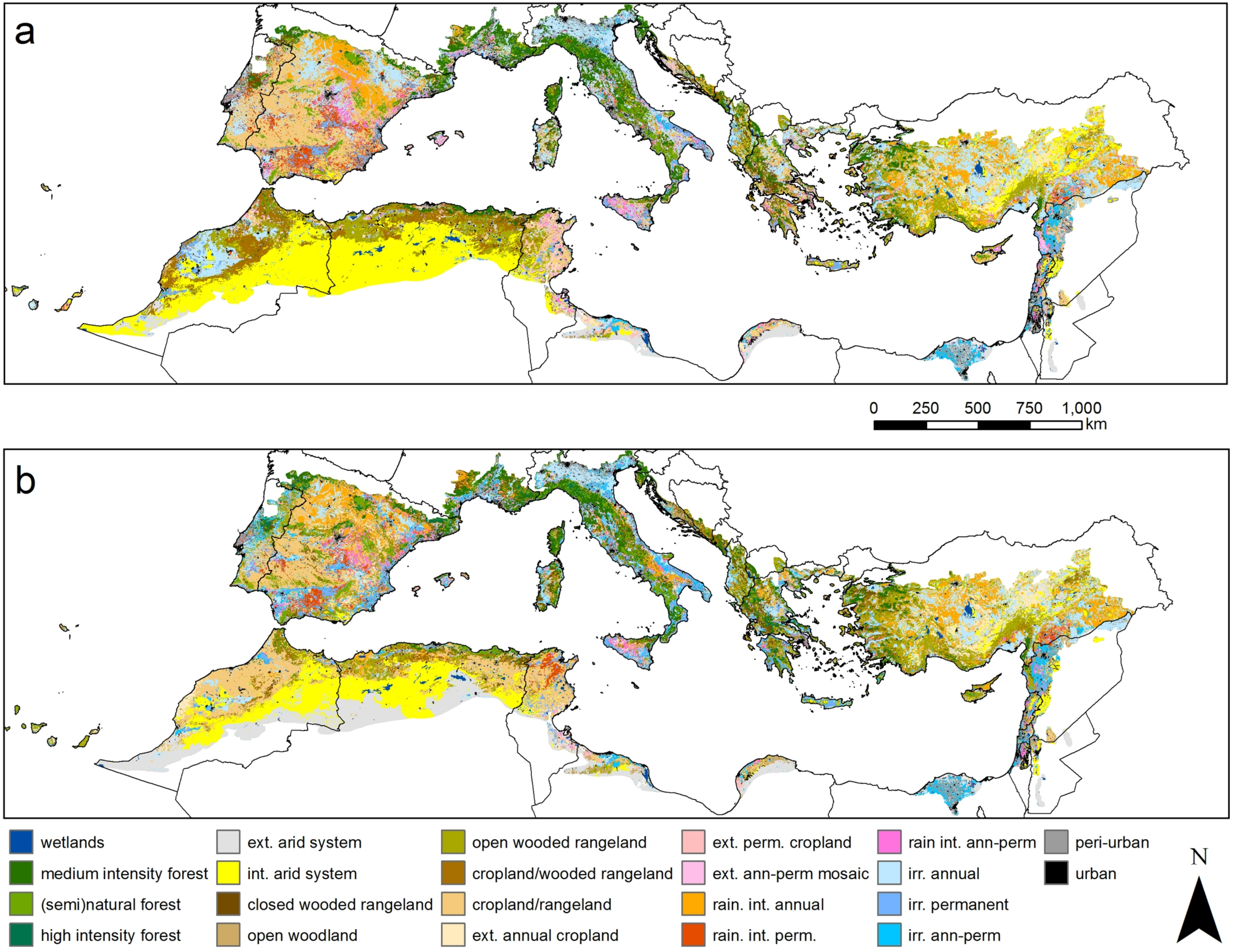
North
European Union
Western Balkans and Turkey
South
Middle East and North-East Africa
North-West Africa
country borders
N
km
0
250
500
750
1,000

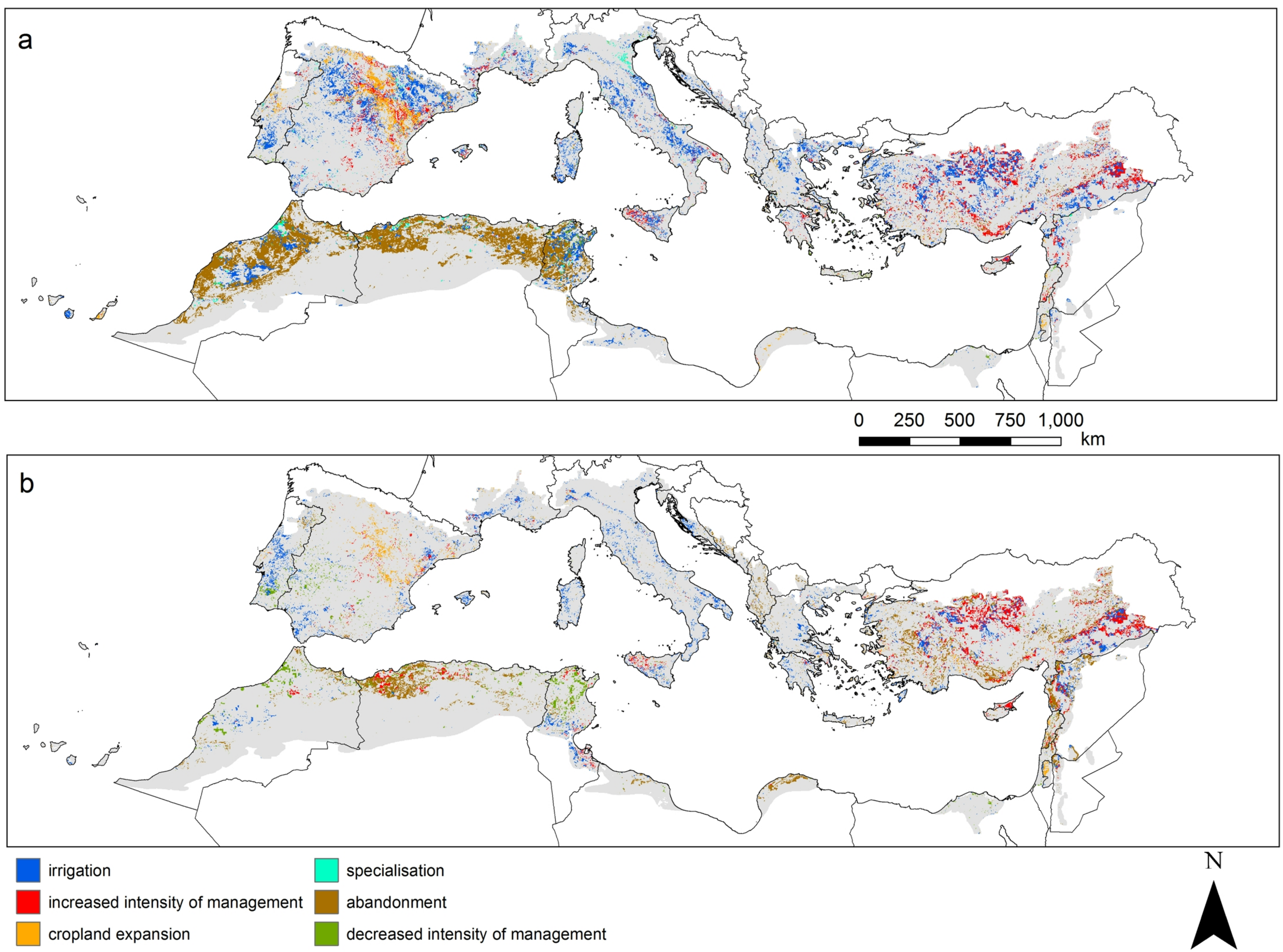


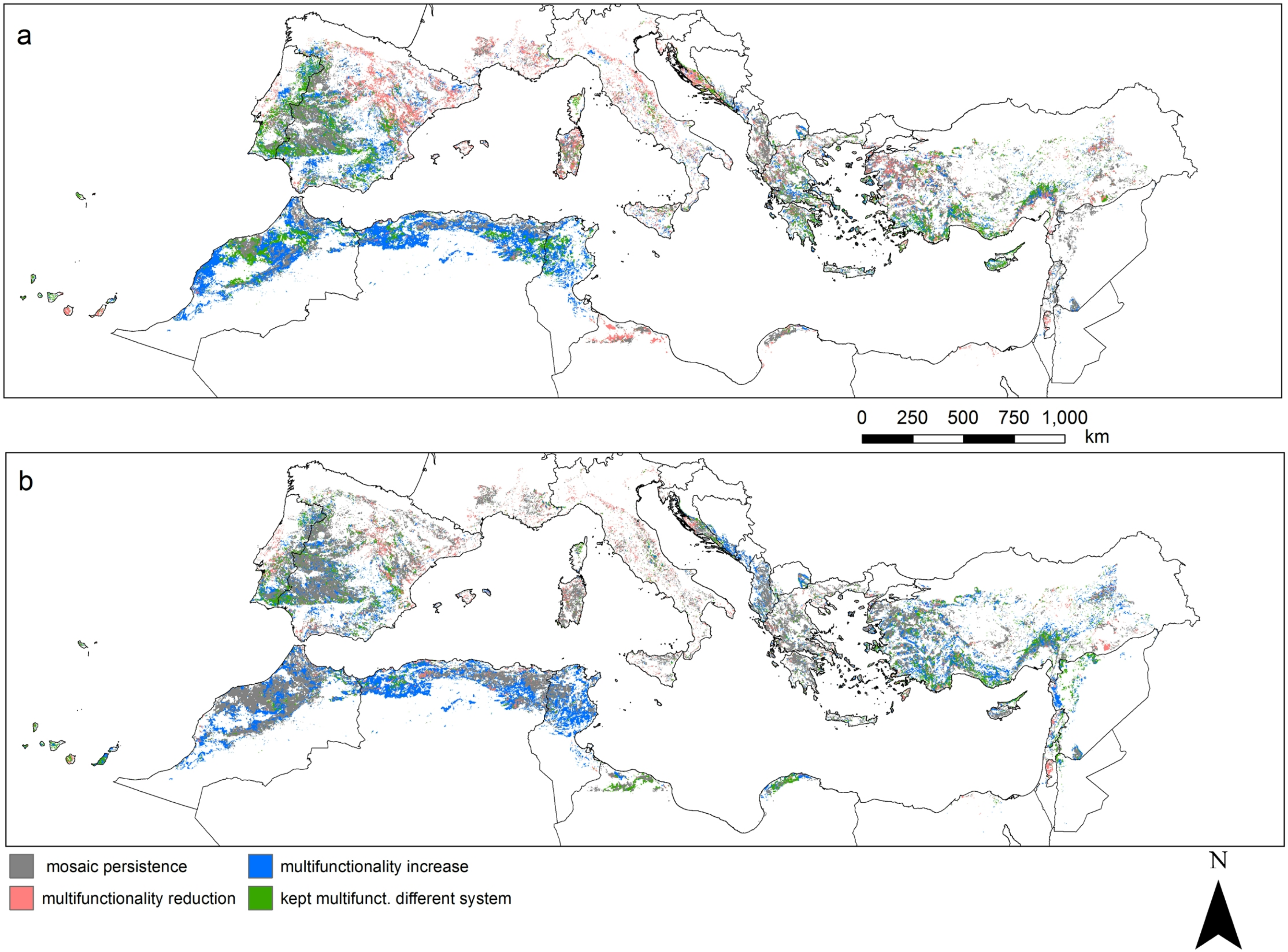
Demand scenarios
Annual crops
Built-up areas
Permanent crops
Livestock
Crops
Living space
Irrigation demands
Livestock
Supply
Limited water resources
Efficiency increase
Management intensity
Land system change allocation
Grazing intensity
Land cover change
Policy
Global change
Conversion rules
Conversion restrictions
Neighborhood effect
Conversion resistance
Competitive advantage
Population
Market access
Climate
Soil and terrain
Spatial preference



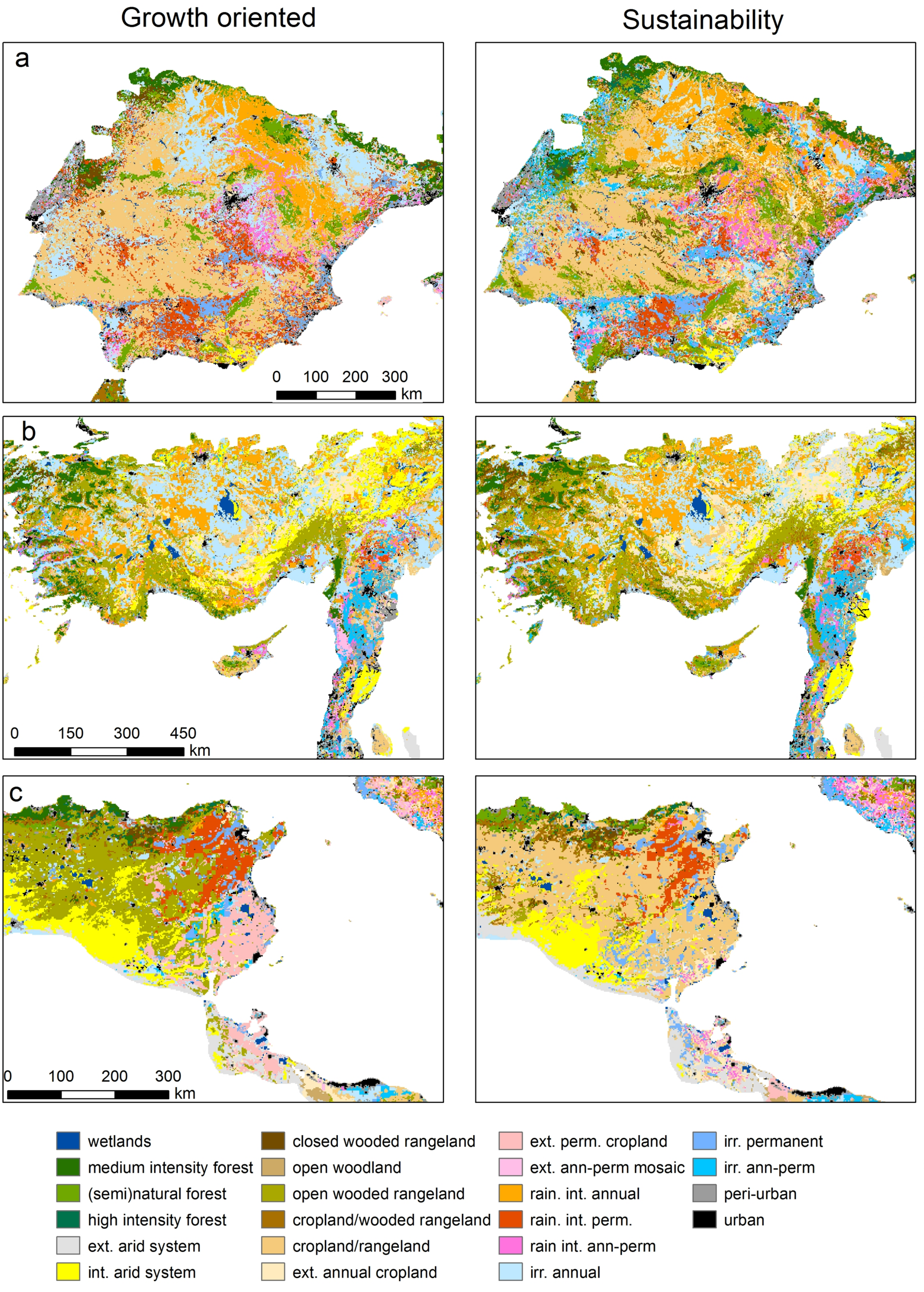
Arid systems
ext. arid system
int. arid system
Forests
medium intensity forest
(semi)natural forest
high intensity forest
Agro-silvo-pastoral mosaics
closed wooded rangeland
open woodland
open wooded rangeland
cropland/wooded rangeland
cropland/rangeland
Cropland systems
ext. annual cropland
ext. perm. cropland
ext. ann-perm mosaic
rain. int. annual
rain. int. perm.
rain int. ann-perm
irr. annual
irr. permanent
irr. ann-perm
Settlements
peri-urban
urban
Other
wetlands


a
0
250
500
750
1,000
km
b
wetlands
medium intensity forest
(semi)natural forest
high intensity forest
ext. arid system
int. arid system
closed wooded rangeland
open woodland
open wooded rangeland
cropland/wooded rangeland
cropland/rangeland
ext. annual cropland
ext. perm. cropland
ext. ann-perm mosaic
rain. int. annual
rain. int. perm.
rain int. ann-perm
irr. annual
irr. permanent
irr. ann-perm
peri-urban
urban
N

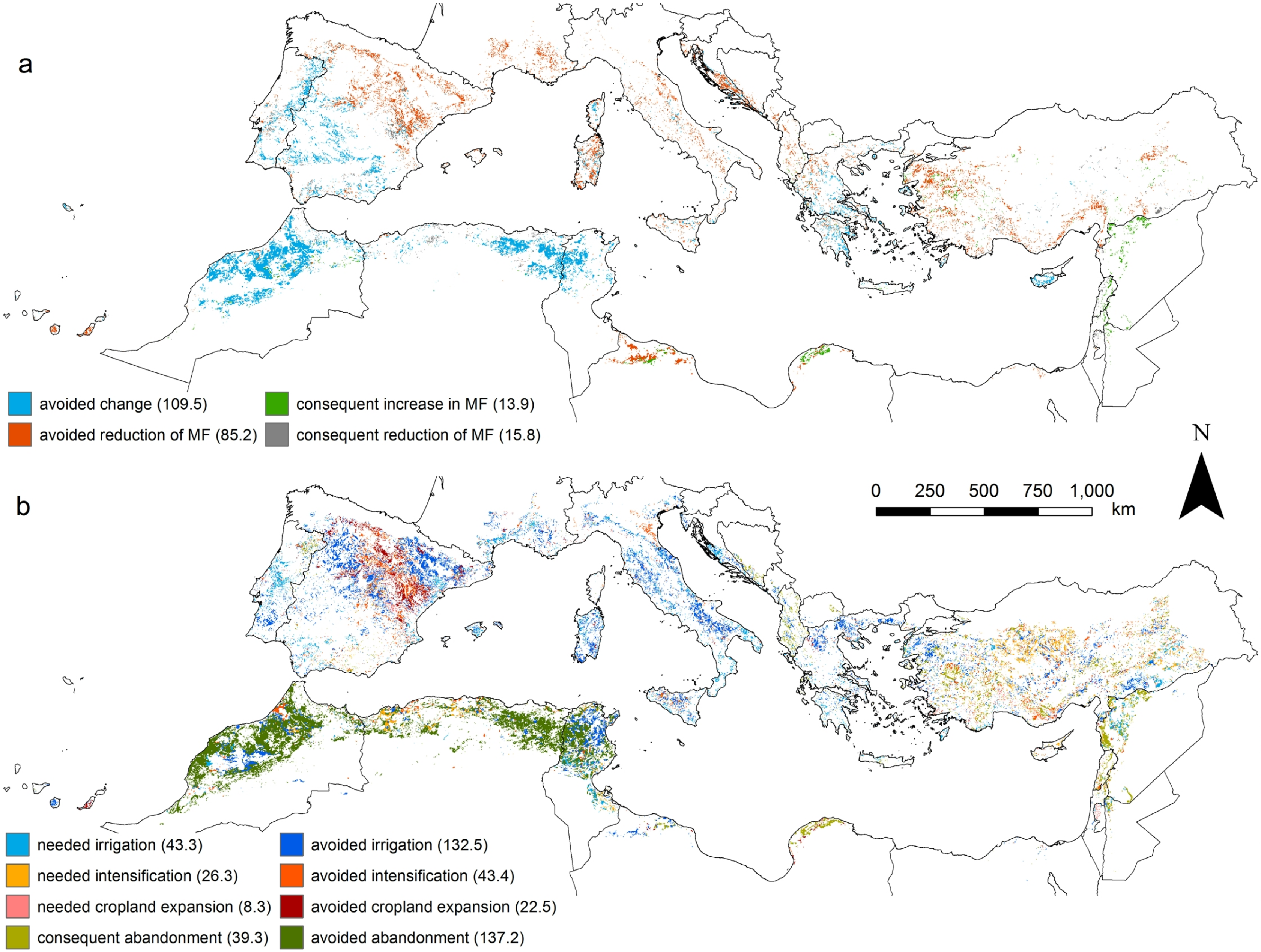

a
0 250 500 750 1,000
km
b
irrigation
increased intensity of management
cropland expansion
specialisation
abandonment
decreased intensity of management
N



a
b
0
250
500
750
1,000
km
mosaic persistence
multifunctionality reduction
multifunctionality increase
kept multifunct. different system
N



Growth oriented
Sustainability
a
0 100 200 300 km
b
0 150 300 450 km
c
0 100 200 300 km
wetlands
medium intensity forest
(semi)natural forest
high intensity forest
ext. arid system
int. arid system
closed wooded rangeland
open woodland
open wooded rangeland
cropland/wooded rangeland
cropland/rangeland
ext. annual cropland
ext. perm. cropland
ext. ann-perm mosaic
rain. int. annual
rain. int. perm.
rain int. ann-perm
irr. annual
irr. permanent
irr. ann-perm
peri-urban
urban


a
avoided change (109.5)
avoided reduction of MF (85.2)
consequent increase in MF (13.9)
consequent reduction of MF (15.8)
N
0 250 500 750 1,000
km
b
needed irrigation (43.3)
needed intensification (26.3)
needed cropland expansion (8.3)
consequent abandonment (39.3)
avoided irrigation (132.5)
avoided intensification (43.4)
avoided cropland expansion (22.5)
avoided abandonment (137.2)

Appendix A – List of consulted documents on Mediterranean future

Benoit G, Comeau A (2012) A Sustainable Future for the Mediterranean: The Blue Plan's Environment and Development Outlook. Routledge, 465 pp.

European Commission (ed.) (2011) EuroMed-2030: Long term challenges for the Mediterranean area. Report of an expert group. Publications Office of the European Union, Luxembourg, 139 pp.

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Sanna S, Le Tellier J (2013) Building on the Mediterranean scenario experiences. Cross-cutting approaches between regional foresight analysis and participatory prospective. Plan Bleu, Paris.

Appendix B – Mediterranean land system output calculation and characteristics

Land systems present an approach, where different data on land cover, management intensity, irrigation and livestock are combined. The initial land systems map of 2010 (Malek and Verburg, 2017) provides values for each land system as a combination of annual and permanent crops, livestock density and urban areas (see tables on next pages). Usually, land cover based simulations focus only on crop productions on cropland (as defined in a land cover product) and neglect agricultural activities in other areas, for example in peri-urban systems, and traditional mosaics. These areas contribute significantly to crop production in the Mediterranean ecoregion.

In this study, each land system in the region provides four services: annual and permanent crops, livestock, and urban areas. Their provision is based on the average values of each land system for cropland extent (%), permanent cropland extent (%), livestock density (livestock units in nr.) and urban extent (%). All four services are described as the average output of a land system unit (4 km^2). The numbers deviate from reported statistics on yields, due to the fact, that every land system is a combination of different land use and land cover. In the Mediterranean, an average irrigated cropland system has between 42 (Turkey) to 68% (North-west Africa) of cropland. Irrigated land systems, present landscapes dominated (but not completely covered) with irrigated cropland. The rest of the landscape can either be covered with woodland, arid areas, or infrastructure (roads, ditches, etc.). All these values are based on global data on land cover, cropland extent, irrigation and land management, and are described in more detail in Malek and Verburg (2017).

To associate crop production to land systems in a sub-region, we first aggregated subnational and national crop production statistics for a specific sub-region. Then, we divided the crop production based on the share of crops produced in irrigated, intensive and extensive rainfed cropland, where we used data from SPAM (You et al. 2014). For example, total values of crops produced on irrigated cropland were assigned to irrigated land systems, based on their average cropland extent (mean % of land system unit) and their regional coverage. Values on the regional coverage and mean cropland extent are described in the next pages per sub-region.

The same is valid for irrigation values – reported irrigation water withdrawals were assigned to irrigated systems. Crop production in irrigated system is therefore also associated with a cost in terms of water use. Irrigation values present mean values for each unit of land system and not the actual demand of crops per ha.

Some values of land system output deviate from common crop production statistics. These seemingly surprising values can be explained threefold. First, we work with reported statistics on crop production. If statistics on a specific crop had errors, were inconsistent or unavailable, this was reflected in the lower land system output. Secondly, in several parts of the Mediterranean, the climate or irrigation enables multicropping. This could lead to higher average values of crop output per land system unit. Finally, the initial map of 2010 was generated using global data, where some of intensive cropland was possibly not captured. This could also result in higher output values per land system unit, particularly in the Southern Mediterranean.

Table B.1a Mediterranean North – European Union (% or land system unit or output per km²)

Land System	Regional coverage (% of region)	Mean cropland extent (% of land systems unit)	Mean permanent cropland extent (% of land systems unit)	Annual crops (t)	Permanent crops (t)	Livestock (nr)	Built up (ha)	Demand for water (m^3)
wetlands	0.2	16.5	3.7	56.39	30.52	6.80	1.17	
medium inten. forest	10.6	14.37	3.1	6.91	7.50	7.30	0.57	
(semi)natural forest	5.9	10.9	2.3	5.28	5.55	7.78	0.25	
high inten. forest	2.4	9.8	1.6	4.99	3.93	8.04	0.29	
ext. arid system	0.5	12.0	3.3	5.27	8.14	7.19	1.34	
int. arid system	0.7	17.9	6.9	6.75	16.76	14.48	0.76	
closed wooded rangel.	2.8	17.3	2.7	8.97	6.46	20.82	0.24	
open woodland	5.7	14.7	4.7	6.11	11.41	6.18	0.97	
open wooded rangel.	7.3	19.3	4.3	9.15	10.60	16.56	0.43	
cropl./wooded rangel.	8.8	36.6	5.1	19.28	12.45	16.78	0.66	
cropland/rangel.	5.5	44.7	5.5	24.01	13.44	30.12	0.56	
exten. annual	3.3	46.5	5.6	25.07	13.52	11.81	0.84	
exten. permanent	2.3	37.5	31.1	3.90	75.82	9.03	1.26	
exten. mosaic	3.7	43.3	14.4	17.69	35.07	12.18	0.90	
rainfed inten. annual	8.0	49.7	3.3	331.35	27.19	17.29	0.70	
rainfed inten. perm.	3.3	46.1	34.0	86.32	281.03	12.11	1.07	
rainfed inten. mosaic	2.3	50.2	12.5	269.09	103.37	13.62	0.86	
irrigated annual	10.0	44.4	4.4	194.17	36.24	22.08	1.33	232.03
irrigated permanent	4.1	44.3	36.1	18.68	295.11	9.75	1.56	213.32
irrigated mosaic	4.5	43.9	14.8	128.42	121.25	14.95	1.50	199.43
peri-urban	6.3	38.3	13.7	108.59	112.17	13.93	9.34	120.47
urban	1.7	29.0	10.1	83.51	82.63	7.48	28.03	89.56

Table B.1b Mediterranean North – European Union – total crop production per land system group

Total crop production in 2010 (EUROSTAT, 2013, 2016a, 2016b). Crop production category ”Irrigated” relates to irrigated and urban land systems, “Rainfed high” to rainfed intensive land systems, and “Rainfed low” to all remaining land systems, and is based on the shares provided by You et al. (2014).

	Share (%)	Production (t)
Annual crops		
Irrigated	41.6	33104235
Rainfed high	48.7	35277415
Rainfed low	9.7	7036980
Total annual		75418630
Permanent crops		
Irrigated	56.7	28885123
Rainfed high	27.2	13826362
Rainfed low	16.1	8197011
Total permanent		50908496

Table B.2a Mediterranean North – Western Balkans and Turkey (% or land system unit or output per km²)

Land System	Regional coverage (% of region)	Mean cropland extent (% of land systems unit)	Mean permanent cropland extent (% of land systems unit)	Annual crops (t)	Permanent crops (t)	Livestock (nr)	Built up (ha)	Demand for water (m³)
wetlands	1.1	12.9	0.3	51.21	7.91	4.52	0.22	
medium inten. forest	6.4	13.4	0.6	36.28	8.62	11.03	0.18	
(semi)natural forest	0.1	15.3	0.0	43.41	0.27	7.58	0.32	
high inten. forest	1.3	18.1	1.5	47.05	20.47	14.60	0.34	
ext. arid system	4.2	21.4	0.4	59.51	5.96	5.26	0.08	
int. arid system	5.9	24.6	0.6	68.22	8.07	12.97	0.17	
closed wooded rangel.	1.4	18.3	0.9	49.46	12.18	33.53	0.11	
open woodland	6.5	17.0	0.8	45.90	11.26	7.90	0.29	
open wooded rangel.	6.8	21.4	1.6	56.16	22.01	19.97	0.30	
cropl./wooded rangel.	6.0	32.8	1.2	89.92	15.74	17.40	0.29	
cropland/rangel.	5.8	41.2	2.8	109.10	38.29	24.80	0.48	
exten. annual	20.1	40.6	0.7	113.36	9.58	11.28	0.31	
exten. permanent	0.6	32.8	23.9	25.32	326.86	19.58	0.75	
exten. mosaic	0.8	40.3	8.0	91.94	108.77	13.80	0.48	
rainfed inten. annual	11.0	44.7	1.2	240.28	21.38	16.36	0.44	
rainfed inten. perm.	1.1	40.0	34.7	29.29	608.17	16.54	0.75	
rainfed inten. mosaic	0.8	43.7	11.1	180.43	193.67	17.08	0.50	
irrigated annual	16.4	45.1	1.0	179.85	23.02	20.31	0.63	306.17
irrigated permanent	0.4	42.2	16.3	64.83	611.44	25.76	1.45	279.89
irrigated mosaic	0.8	43.4	8.7	141.65	201.33	23.46	0.84	283.18
peri-urban	1.5	40.3	4.8	196.24	83.95	21.27	10.87	121.12
urban	0.8	29.7	4.1	141.31	72.39	18.14	33.70	77.05

Table B.2b Mediterranean North – Western Balkans and Turkey – total crop production per land system group

Total crop production in 2010 (EUROSTAT, 2013, 2016a, 2016b). Crop production category ”Irrigated” relates to irrigated and urban land systems, “Rainfed high” to rainfed intensive land systems, and “Rainfed low” to all remaining land systems, and is based on the shares provided by You et al. (2014).

	Share (%)	Production (t)
Annual crops		
Irrigated	26.1	16645751
Rainfed high	27.9	17473003
Rainfed low	46.0	28688356
Total annual		62807110
Permanent crops		
Irrigated	24.2	4232387
Rainfed high	38.9	6800665
Rainfed low	36.9	6456238
Total permanent		17489290

Table B.3a Mediterranean South – Middle East and North-East Africa (% or land system unit or output per km^2)

Land System	Regional coverage (% of region)	Mean cropland extent (% of land systems unit)	Mean permanent cropland extent (% of land systems unit)	Annual crops (t)	Permanent crops (t)	Livestock (nr)	Built up (ha)	Demand for water (m^3)
wetlands	1.6	5.4	1.3	39.25	15.60	89.34	0.67	
medium inten. forest	0.4	33.0	12.2	46.02	98.27	17.36	0.36	
(semi)natural forest	0.0	5.8	3.9	4.22	31.44	17.34	0.00	
high inten. forest	0.1	38.8	10.7	40.03	86.23	192.62	1.72	
ext. arid system	16.2	2.4	0.6	3.97	4.73	1.41	0.23	
int. arid system	13.6	7.4	1.8	12.41	14.39	15.40	0.53	
closed wooded rangel.	0.1	28.5	11.5	37.58	92.77	53.82	1.00	
open woodland	2.4	7.8	1.9	13.01	15.37	38.50	0.60	
open wooded rangel.	4.1	9.0	2.3	14.72	18.63	23.77	0.67	
cropl./wooded rangel.	0.7	43.2	7.9	77.85	64.17	29.03	1.10	
cropland/rangel.	11.9	59.6	9.3	111.06	75.39	21.22	1.38	
exten. annual	4.2	54.7	3.1	113.96	24.97	10.21	0.93	
exten. permanent	0.6	66.6	25.8	68.07	208.25	19.14	0.42	
exten. mosaic	2.9	57.4	12.9	98.37	103.84	16.90	1.16	
rainfed inten. annual	0.7	56.3	4.6	501.43	113.87	35.42	1.05	
rainfed inten. perm.	0.0	43.0	19.1	231.42	721.35	18.74	0.25	
rainfed inten. mosaic	1.3	52.0	10.5	402.31	260.42	81.33	1.15	
irrigated annual	10.6	63.2	2.4	587.39	28.41	33.90	1.96	877.67
irrigated permanent	1.1	62.8	28.7	232.89	334.23	20.96	1.43	738.03
irrigated mosaic	10.5	66.4	10.7	538.19	124.91	49.04	1.99	902.86
peri-urban	12.9	60.1	7.3	510.05	85.45	47.83	9.59	734.42
urban	4.0	35.0	5.7	283.35	66.24	25.04	45.79	292.28

Table B.3b Mediterranean South – Middle East and North-East Africa – total crop production per land system group

Total crop production in 2010 (EUROSTAT, 2013, 2016a, 2016b). Crop production category ”Irrigated” relates to irrigated and urban land systems, “Rainfed high” to rainfed intensive land systems, and “Rainfed low” to all remaining land systems, and is based on the shares provided by You et al. (2014).

	Share (%)	Production (t)
Annual crops		
Irrigated	82.9	38857839
Rainfed high	4.4	1759748
Rainfed low	12.7	5027599
Total annual		45645186
Permanent crops		
Irrigated	58.2	6560864
Rainfed high	8.0	900796
Rainfed low	33.8	3809004
Total permanent		11270664

Table B.4a Mediterranean South – North-West Africa (% or land system unit or output per km²)

Land System	Regional coverage (% of region)	Mean cropland extent (% of land systems unit)	Mean permanent cropland extent (% of land systems unit)	Annual crops (t)	Permanent crops (t)	Livestock (nr)	Built up (ha)	Demand for water (m³)
wetlands	0.9	6.6	1.5	29.89	12.15	288.60	0.12	
medium inten. forest	1.2	30.8	5.3	14.11	14.23	16.08	0.33	
(semi)natural forest	0.3	25.2	0.5	13.66	1.39	14.14	0.07	
high inten. forest	0.3	44.5	5.4	21.67	14.46	18.83	0.48	
ext. arid system	29.8	2.2	0.2	1.12	0.52	1.57	0.09	
int. arid system	20.1	6.2	1.0	2.90	2.57	8.49	0.10	
closed wooded rangel.	0.6	33.6	4.7	16.00	12.59	27.38	0.40	
open woodland	0.4	30.5	3.1	9.60	8.42	9.30	0.57	
open wooded rangel.	1.8	24.8	2.5	12.34	6.70	15.07	0.14	
cropl./wooded rangel.	4.4	52.9	2.2	28.08	5.84	15.73	0.28	
cropland/rangel.	13.2	64.9	6.0	32.63	16.05	18.47	0.31	
exten. annual	13.0	58.2	1.6	31.33	4.29	7.38	0.33	
exten. permanent	0.8	69.4	32.9	14.66	88.20	13.80	0.48	
exten. mosaic	2.4	57.6	11.1	25.73	29.82	13.22	0.37	
rainfed inten. annual	0.4	69.3	3.6	586.14	12.31	12.93	0.72	
rainfed inten. perm.	1.9	65.8	32.5	296.55	112.55	22.45	0.23	
rainfed inten. mosaic	0.4	61.8	11.7	447.05	40.33	18.46	0.42	
irrigated annual	3.0	48.7	2.3	388.31	18.91	12.43	0.76	338.74
irrigated permanent	1.2	68.8	33.7	205.62	274.28	17.11	0.93	439.42
irrigated mosaic	1.6	61.4	14.1	276.70	114.93	14.83	0.94	357.07
peri-urban	1.6	55.1	8.2	274.41	66.76	22.56	11.54	106.19
urban	0.8	37.2	6.5	179.82	52.66	10.05	39.80	54.17

Table B.4b Mediterranean South – North-West Africa – total crop production per land system group

Total crop production in 2010 (EUROSTAT, 2013, 2016a, 2016b). Crop production category ”Irrigated” relates to irrigated and urban land systems, “Rainfed high” to rainfed intensive land systems, and “Rainfed low” to all remaining land systems, and is based on the shares provided by You et al. (2014).

	Share (%)	Production (t)
Annual crops		
Irrigated	52.8	17419629
Rainfed high	22.0	7242574
Rainfed low	25.2	8310512
Total annual		32972716
Permanent crops		
Irrigated	49.0	5117591
Rainfed high	16.6	1733763
Rainfed low	34.4	3604275
Total permanent		10455630

Appendix C – Location factors used in calculating spatial preference maps using logistic regression

Location Factor	Unit/description	Resolution	Date	Source
Socio-economic				
Population density*	People/km^2	1 km	2010	CIESIN (2015)
Rural population*	Rural population/km^2	1 km	2000	CIESIN et al. (2011)
Market accessibility	Index (0-1)	1 km	2000-2010	Verburg et al. (2011b)
Market influence	USD/person (ppp)	1 km	2000-2010	Verburg et al. (2011b)
Accessibility**	Distance to roads (m)	vector	1999	NGIA (2015)
Soil				
Drainage	Drainage class	1 km	2010	Hengl et al. (2014)
Sand content	Sand mass in %	1 km	2010	Stoorvogel et al. (2016)
Clay content	Clay mass in %	1 km	2013	Stoorvogel et al. (2016)
Cation Exchange Capacity (CEC)	cmol/kg	1 km	2010	Hengl et al. (2014)
pH	log(h+)	1 km	2010	Hengl et al. (2014)
Organic carbon content	g/kg in the top 50 cm	1 km	2013	Stoorvogel et al. (2016)
Soil depth	cm	1 km	2013	Stoorvogel et al. (2016)
Terrain				
Altitude	m above sea level	1 km	2005	Hijmans et al. (2005)
Slope	Slope degrees	1 km	2005	derived from Hijmans et al. (2005)
Climate				
Precipitation*	annual precipitation (sum of monthly means) in mm	1 km	1960-1990	Hijmans et al. (2005)
Temperature*	Temperature (mean of monthly means) Celsius degree	1 km	1960-1990	Hijmans et al. (2005)
Solar radiation	Horizontal surface irradiation (kWh/m^2), 1998-2011 mean	1.5 arc minute	2012	Huld et al. (2012)
Other				
Potential Evapotranspiration (PET)*	annual PET in mm	1 km	1960-1990	Zomer et al. (2008)
Potential vegetation	Pot. vegetation classes	10 km	2000	Ellis & Ramankutty (2008)

* dynamic factor, updated annually

** stays the same in growth scenario, improved accessibility in the sustainable scenario

Appendix D – example of spatial preference maps

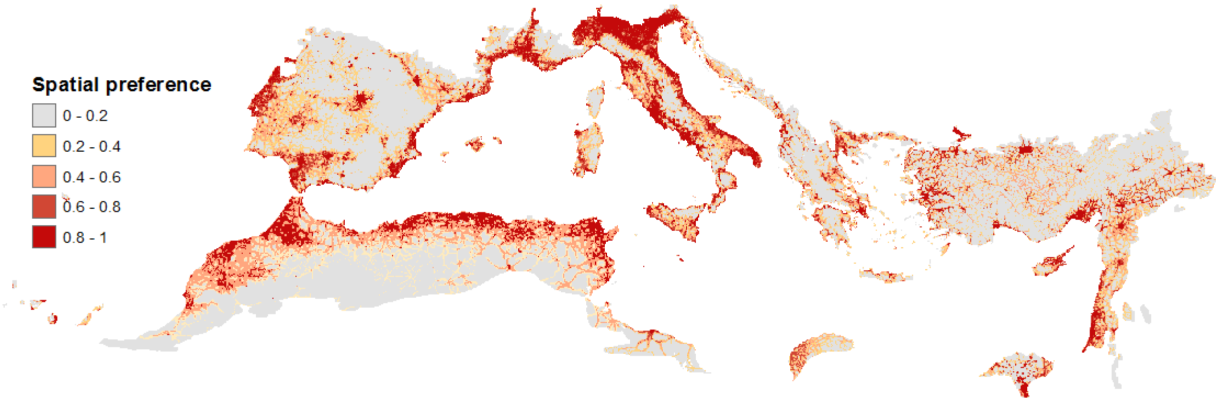

Fig. D.1 Spatial preference map for the urban system

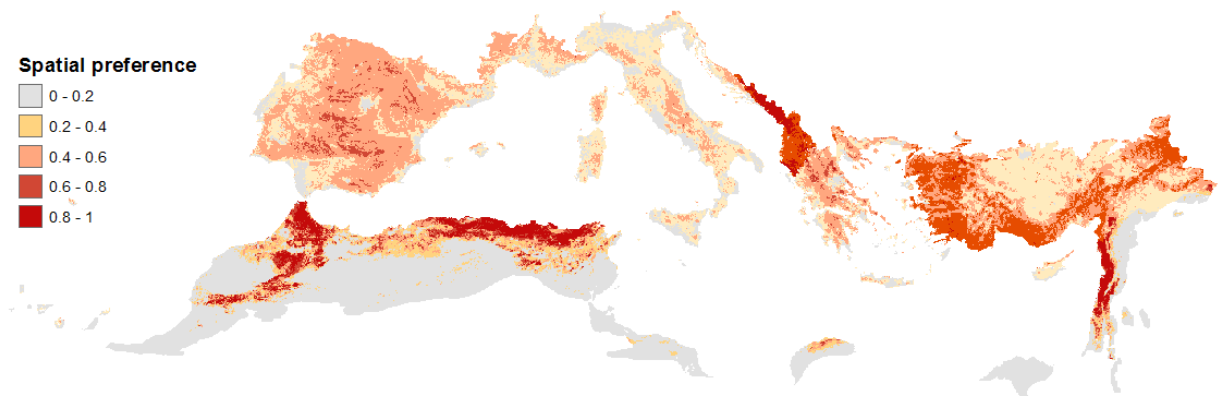

Fig. D.2 Spatial preference map for the cropland/wooded rangeland mosaic system

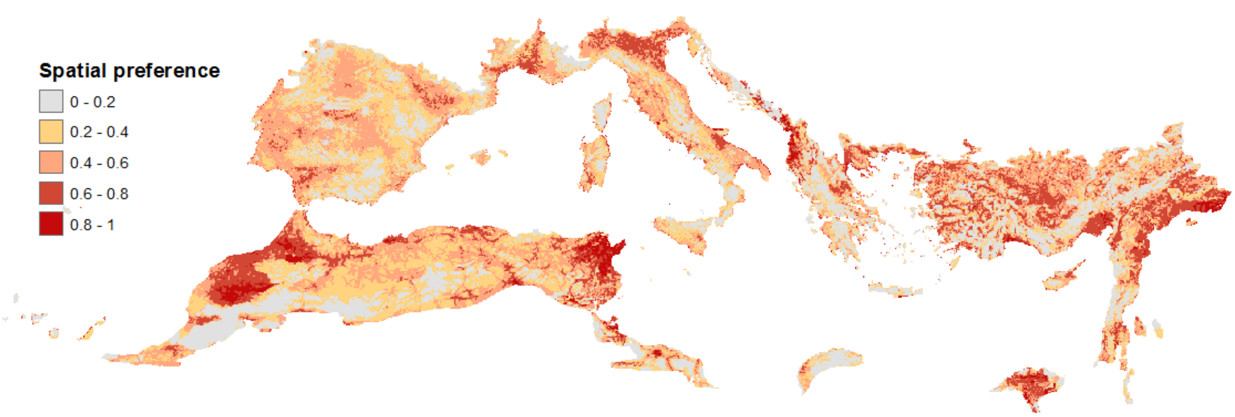

Fig. D.3 Spatial preference map for the irrigated annual cropland system

Appendix E – technical details of both scenarios

Table continues on several pages

Model setting	Sustainable scenario	Growth oriented
Dynamic driving factors		
Population density	Growth rates based on SSP2 projections of Jiang and O'Neill (2015) applied to high population areas only (> 250 per km^2, S9)	Growth rates based on SSP2 projections of Jiang and O'Neill (2015) applied to high population areas only (> 250 per km^2, S9)
Rural population density	Rural population stabile	Change rates (growth/decrease) based on SSP2 projections of Jiang and O'Neill (2015) applied to rural population density map
Temperature, climate, potential evapotranspiration	Based on RCP4.5 climate change maps (mean of all model runs for RCP4.5). PET calculated using PET equations.	Based on RCP4.5 climate change maps (mean of all model runs for RCP4.5). PET calculated using PET equations.
Aridity index	Calculated using the AI equation, dynamic for every year (RCP4.5)	Calculated using the AI equation, dynamic for every year (RCP4.5)
Static driving factors		
Market index and accessibility	All inaccessibility above average reduced by 40 %.	Stays as it is (differences)
Demands		
Annual crops	1. Due to the common Mediterranean market, MENA can easier satisfy its food demand by imports, the demands for MENA are so lower (10 % lower growth rate compared to growth scenario). 2. 5 % decrease in total demand due to a reduction of food waste.	Annual crops follow the SSP2 marker scenario for food production.
Permanent crops	1. Due to the common Mediterranean market, exports of permanent crops are easier and thus higher (10 % higher growth rate compared to the growth scenario). 2. 5 % decrease in total demand due to a reduction of food waste.	Permanent crops follow the SSP2 marker scenario for food production.
Livestock	1. Due to the common Mediterranean market, MENA can easier satisfy its livestock by imports, and thus the demands for MENA are lower (10 % lower growth rate compared to growth scenario). 2. 5 % decrease in total livestock demand due to a reduction of food waste.	Livestock numbers follow the SSP2 scenario for livestock numbers.

Built up areas	Demand linked to population change (SSP2), with 30 % lower growth rate due to increased density and compactness of new urban areas.	Demand linked to population change (SSP2), with a 10 % higher growth rate than population growth.
Land system specific settings		
Wetlands		
Supply	Wetlands still contribute fulfilling the demand, but the output is reduced: 30 % decrease in crops and livestock output of wetlands.	Same supply as baseline (overgrazing of wetland areas still possible).
Spatial pattern/change process	Protected – no change possible	Protected – no change possible
Other wetland conservation	Sustainable water management implementation on the regional scale. Irrigated land systems are defined with a water demand value (demand table, S2). Each region has limited water resources, cannot allocate more irrigated areas.	No other wetland conservation measures.
Settlement systems		
Supply	1. Remains the same as in the baseline for built up areas 2. Efficiency improvement for livestock (5 % increase) 3. Efficiency improvement for crop production (closing yield gaps in EU, 90 % attainable yield achieved in other regions)	1. Remains the same as in the baseline for built up areas 2. Efficiency improvement for livestock (15 % increase due to hosting indoor livestock breeding facilities) 3. Efficiency improvement for crop production (75 % attainable yield achieved)
Spatial pattern/change process	1. Lower conversion order for peri-urban systems (2), higher density urban systems preferred. 2. Neighborhood of land system allocation more compact (only 2 neighboring cells). 3. Conversion to urban only possible in non-protected areas. 4. More difficult urban expansion on the account of best cropland (higher conversion resistance for intensive cropland systems).	1. Higher conversion order for peri-urban systems (3), higher conversion order for livestock provision 2. Larger neighborhood of urban and peri-urban land system allocation (3 cell neighborhood). 3. Urban land has absolute priority. Any system (except natural forests and wetlands) can be converted to a settlement.
Forest systems		
Supply	N.A.	N.A.
Spatial pattern/change process	1. All forest systems (including closed wooded rangeland) can change to open woodland in areas with an aridity index < 0.65. 2. Forest expansion (open	1. All forest systems (including closed wooded rangeland) can change to open woodland in areas with an aridity index < 0.65. 2. Forest expansion (open

	woodlands to forests) only possible in areas with an AI > 0.65	woodlands to forests) only possible in areas with an AI > 0.65
Rainfed intensive		
Supply	1. Yields reach 75 % of attainable yield - higher yields in the region often not possible without irrigation (Mueller *et al.*, 2012) 2. 5 % decrease in total cropland output due to ecological focus areas (EFA) – set aside policy.	1. Rainfed intensive systems have to be at 50% of attainable yield (all regions already achieve that, except the Maghreb region). 2. Increased livestock efficiency by 15 %.
Spatial pattern/change process	1. Possible only in areas with AI > 0.2. In areas with 0.2<AI<0.65, there is a decrease in probability of rainfed intensive areas (-0.05) to account for extreme climate events. This value is lower than in the growth scenario, as it considers crop change or cultivar improvements. 2. Not possible in new protected areas (unless existing). 3. Can be transformed to less intensive systems after 10 years (annual crops) or 15 years (permanent crops)	1. Possible only in areas with AI > 0.2. In areas with 0.2<AI<0.65, there is a decrease in probability of rainfed intensive areas (-0.1) to account for extreme climate events. This value is higher than in the sustainable scenario, as there are no changes in crops. 2. Can be transformed to less intensive systems after 10 years (annual crops) or 15 years (permanent crops)
Extensive cropland		
Supply	1. 50 % of attainable yield achieved due to crop change or labor intensification (due to rural development policies and small farm promotion). 2. 5 % decrease in annual cropland output due to ecological focus areas (EFA) – set aside policy. 3. Increase in livestock output by 5 % due to improvements in breeds and herd fattening.	No efficiency increase, considered as economically unattractive areas.
Spatial pattern/change process	1. No spatial limitations. 2. Conversions to woodlands after being inactive for 10 years (abandonment).	1. No spatial limitations. 2. Conversions to woodlands after being inactive for 10 years (abandonment).
Irrigated cropland		
Supply	1. Yield gaps closed in EU, in other regions yields reach 90 % of attainable yield. 2. Improved irrigation efficiency by 35 % 3. Increase in livestock output by 5 % due to improvements in breed and herd fattening	1. Yields achieve 75 % of attainable yield. 2. Increased livestock efficiency by 15 %
Spatial	Irrigated areas limited by amount of	Irrigated areas have a reduced spatial

pattern/change process	available water resources (by region)	probability (locspec -0.1) in areas with a market index below 0.3 (areas with extremely low investment potential).
Mosaic systems		
Supply	1. Increase in livestock output by 5 % due to improvements in breeds and herd fattening	1. No increase in output of traditional systems 2. Lower conversion resistance of traditional systems as they experience further marginalisation
Spatial pattern/change process	1. Higher conversion resistance of mosaic systems (less likely to be changed to more intensive, or abandoned). 2. Higher conversion order of mosaic systems to satisfy the demand for livestock and crops (we tell the model it needs to promote those systems)	More intensive rangeland mosaics preferred (so a 2 function open woodland preferred to a 3 function medium tree cover woodland)
Arid systems		
	1. Arid systems have reduced potential to fulfill demand for livestock. 2. Grazing intensification in arid systems not allowed.	1. Arid systems' potential to fulfill demand for livestock remains the same. 2. Grazing intensification in arid systems allowed.
Other		
Biodiversity/nature protection	Aichi targets reached – 17 % of terrestrial areas defined as protected areas (Pouzols *et al.*, 2014), S6. Conversions to less intensive systems, and systems with low intensity is possible in the protected areas.	Aichi targets not reached. National parks and similar areas are protected and excluded from changes, no expansion of PAs in MENA.
Ecological Focus Areas (EFA)	A Mediterranean Common Mediterranean Agricultural Policy (CAP) results in a set aside policy – farmers have to ensure that 5 % of their land is set aside to receive payments from the CAP. EFAs are either buffer strips, set aside land or similar. Land systems in question will experience a 5 % decrease in the annual cropland output of their systems. This decrease in output will occur gradually from year 0 to year 5.	No such measure applied.

Appendix F – protected areas in the Mediterranean ecoregion

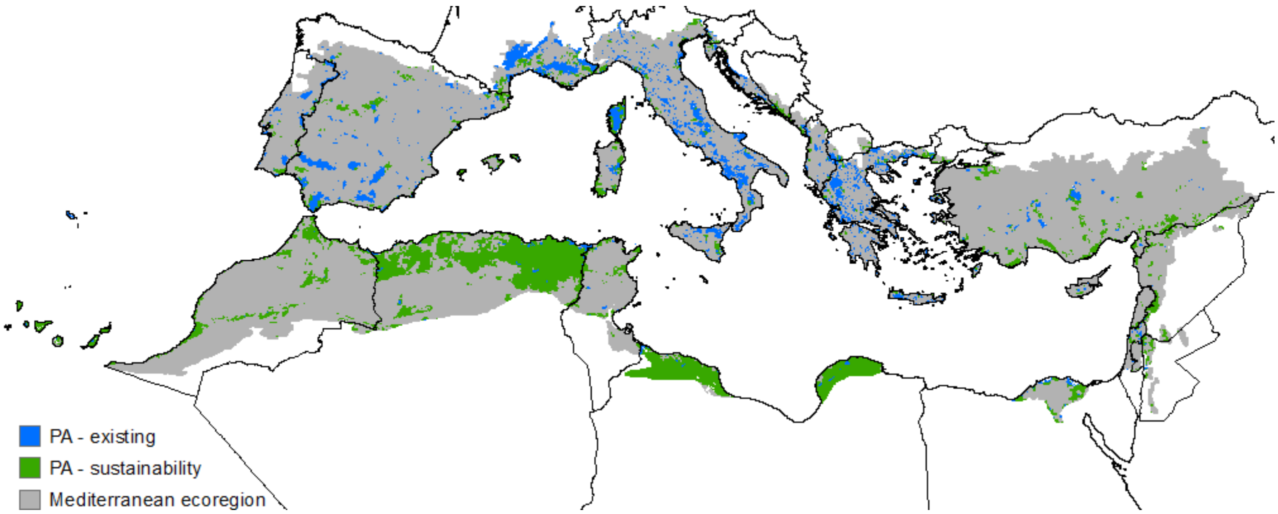

Fig. F Existing and recommended protected area (PA) extent. Recommended areas used in the sustainability scenario are based on the national priorities for protected areas (Pouzols *et al.*, 2014) and are defined as 17 % of national terrestrial areas

Appendix G – CMIP5 simulations of the RCP4.5 scenario used to update precipitation, temperature, PET and AI maps for the years 2041-2060 (representing 2050)

Model	Institution
ACCESS1-0	Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Bureau of Meteorology, Australia
bcc-csm1-1	Beijing Climate Center, China Meteorological Administration
CCSM4	National Center for Atmospheric Research, USA
CESM1(CAM5.1, FV2)	National Science Foundation, Department of Energy, National Center for Atmospheric Research, USA
CNRM-CM5	Centre National de Recherches Meteorologiques / Centre Europeen de Recherche et Formation Avancees en Calcul Scientifique, France
GFDL-CM3	NOAA, Geophysical Fluid Dynamics Laboratory, USA
GFDL-ESM2G	NOAA, Geophysical Fluid Dynamics Laboratory, USA
GISS-E2-R	NASA Goddard Institute for Space Studies, USA
HadGEM2-AO	National Institute of Meteorological Research / Korea Meteorological Administration
HadGEM2-CC	Met Office Hadley Centre, UK
HadGEM2-ES	Met Office Hadley Centre / Instituto Nacional de Pesquisas Espaciais)
INM-CM4	Institute for Numerical Mathematics, Russia
IPSL-CM5A-LR	Institut Pierre-Simon Laplace, France
MIROC-ESM-CHEM	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies
MIROC-ESM	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies
MIROC5	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology
MPI-ESM-LR	Max Planck Institute for Meteorology (MPI-M), Germany
MRI-CGCM3	Meteorological Research Institute, Japan
NorESM1-M	Norwegian Climate Centre

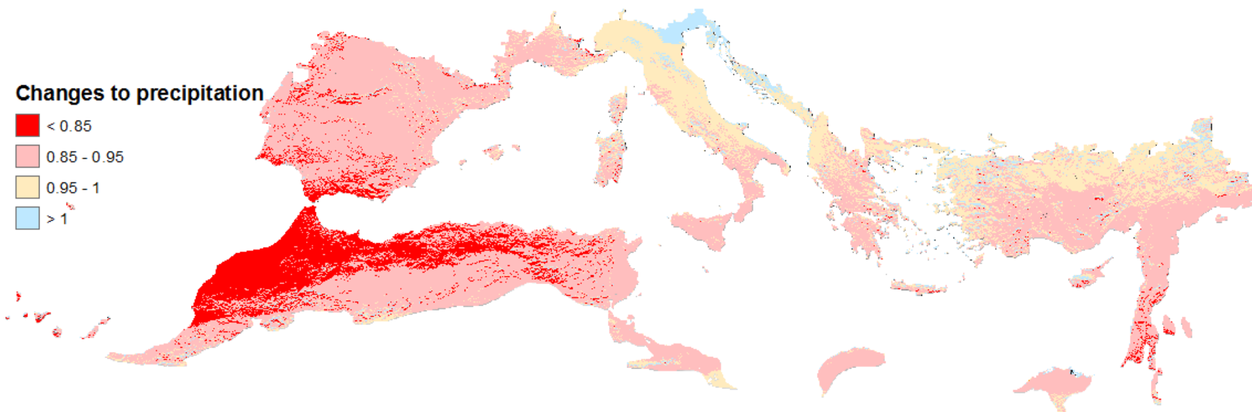

Fig. G.1 Changes in precipitation until 2050 (compared to current climate, represented by the 1960-1990 average) based on the mean of 19 CMIP5 simulations of the RCP4.5 for the Mediterranean ecoregion

Fig. G.2 Changes in temperature in °C until 2050 (compared to current climate, represented by the 1960-1990 average) based on the mean of 19 CMIP5 simulations of the RCP4.5 for the Mediterranean ecoregion

Appendix H – PET and AI calculation and map example

Potential evapotranspiration (PET) represents the ability of the atmosphere to remove water through evapotranspiration processes, and was introduced by the FAO (Allen & FAO, 1998; Trabucco *et al.*, 2008). We used the Hargreaves model (Hargreaves & Allen, 2003) to calculate future PET in this study, as it was also used to calculate the current PET in Zomer et al. (2008):

$$PET = 0.0023 \times RA \times (Tmean + 17.8) \times TD^{0.5}$$

PET – monthly average PET (mm/year)

RA – annual extra-terrestrial radiation, radiation on top of atmosphere expressed (mm/year)

Tmean – annual mean temperature (°C)

TD – annual mean daily temperature range (°C)

We used spatial distributions on RA, Tmean and TD from the Worldclim dataset (Hijmans *et al.*, 2005). Future temperature spatial distributions were acquired by calculating the mean from 19 CMIP5 simulations of the RCP4.5 scenario (S7).

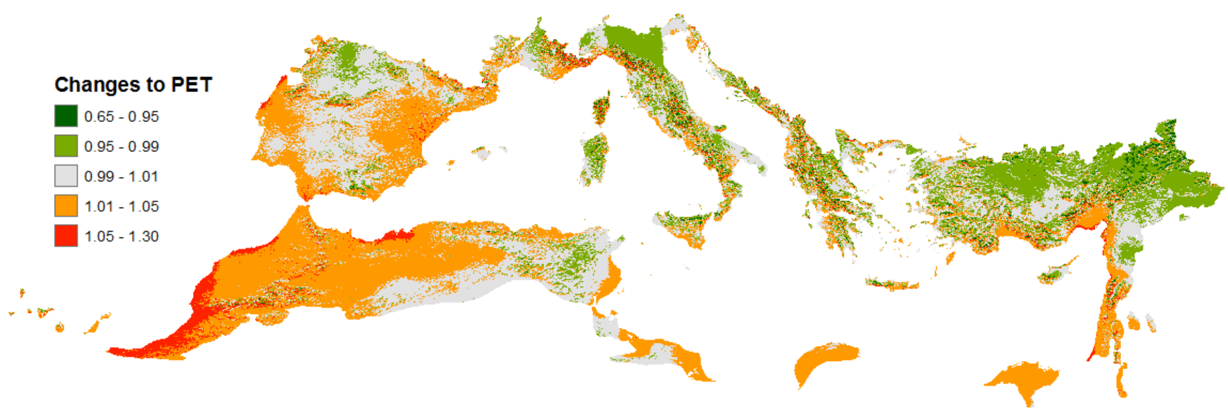

Fig. H.1 Changes in annual PET until 2050 based on the 19 CMIP5 simulations of the RCP4.5 for the Mediterranean ecoregion. The future decrease in the temperature range is balancing the increase in the mean temperature, leading to a decrease in PET in some areas (marked as green on the figure).

The Aridity index serves as an indicator to quantify precipitation deficits over atmospheric water demand (UNEP, 1997; Zomer *et al.*, 2008). It is defined as a function of precipitation and potential evapotranspiration (PET):

$$AI = \frac{MAP}{MAE}$$

AI – aridity index

MAP – mean annual precipitation (mm/year)

MAE – mean annual potential evapotranspiration (PET, mm/year)

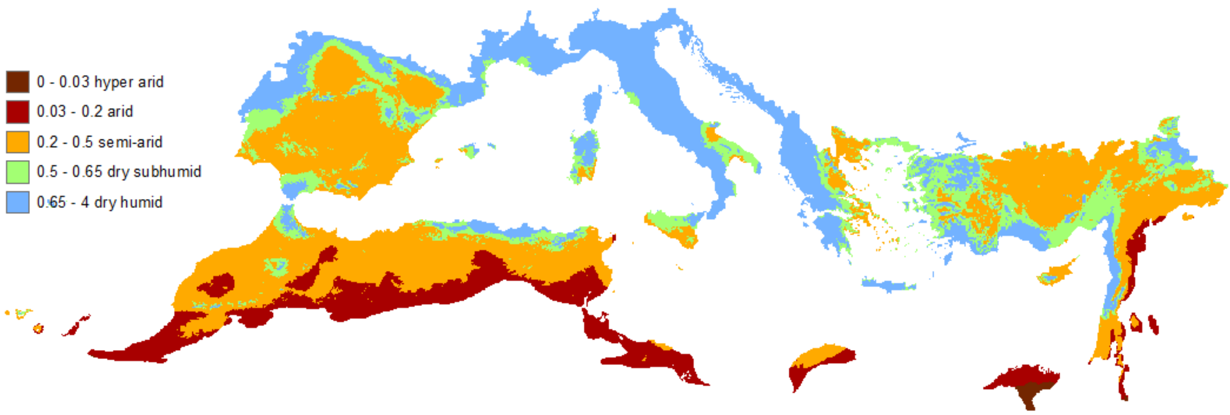

Fig. H.2 Current aridity index (Zomer et al. 2008)

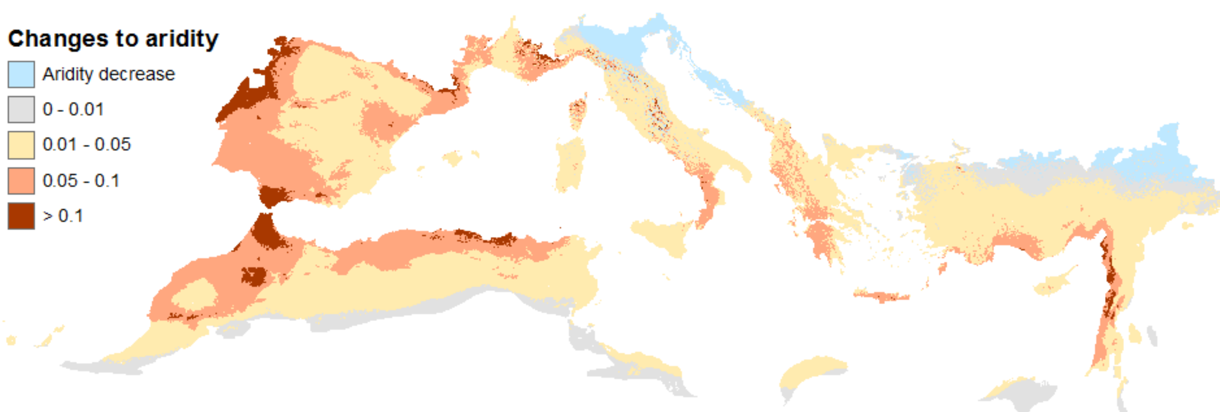

Fig. H.3 Changes to aridity until 2050 based on the 19 CMIP5 simulations of the RCP4.5 for the Mediterranean ecoregion

Appendix I – Changes to urban population

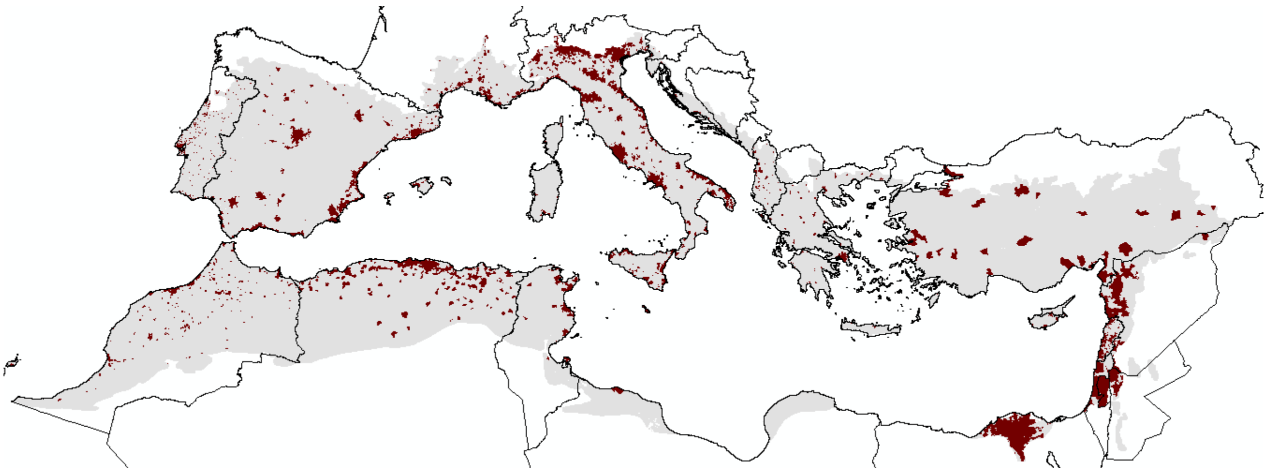

Fig. I Areas with high population density where urban population change trends based on the SSP2 scenario were applied (Kc & Lutz, 2014; Jiang & O’Neill, 2015)

Appendix J – Scenarios: high resolution figures

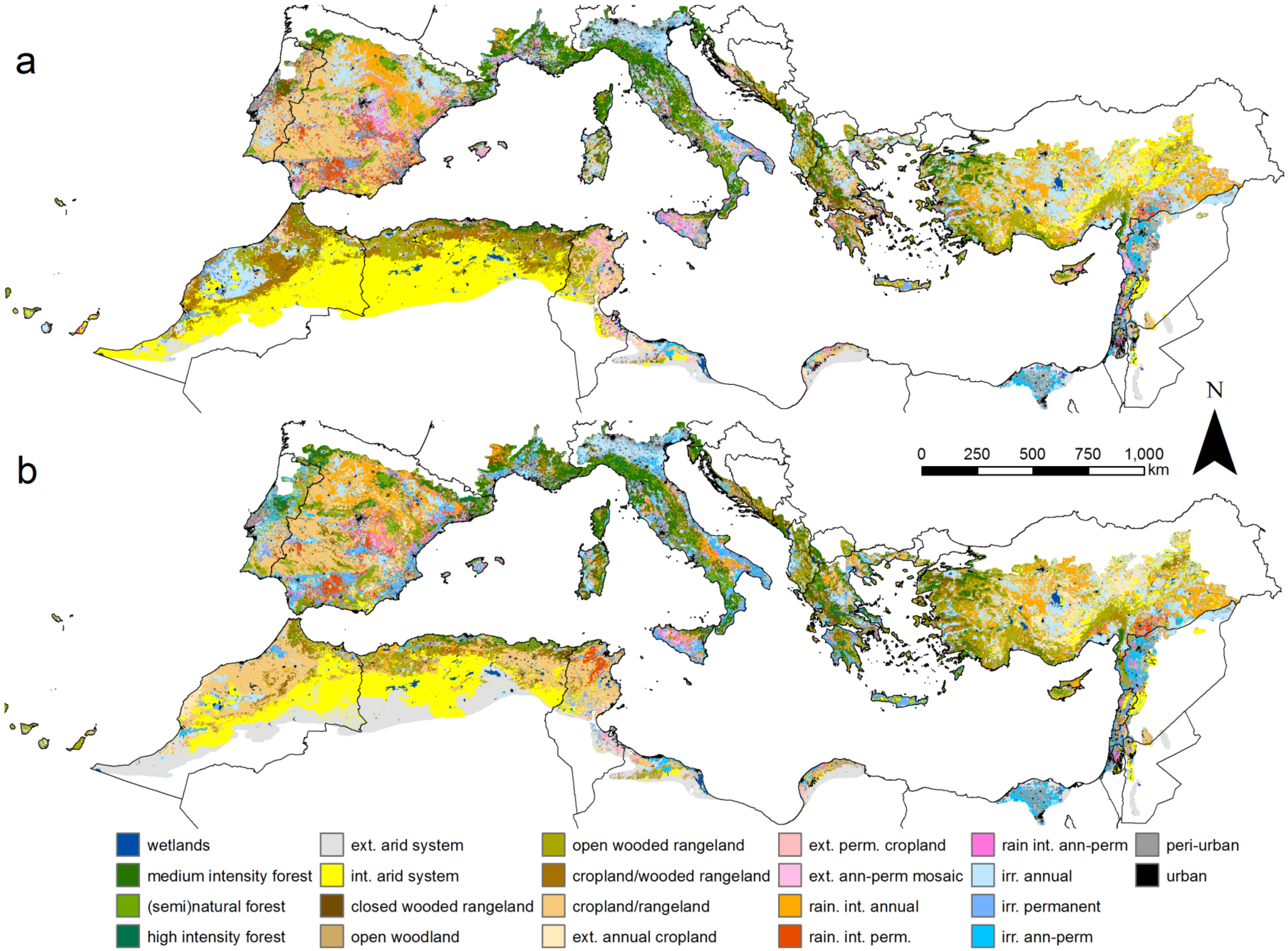

Fig. J.1 Future land systems in 2050 as simulated for the two scenarios : (a) growth, (b) sustainability

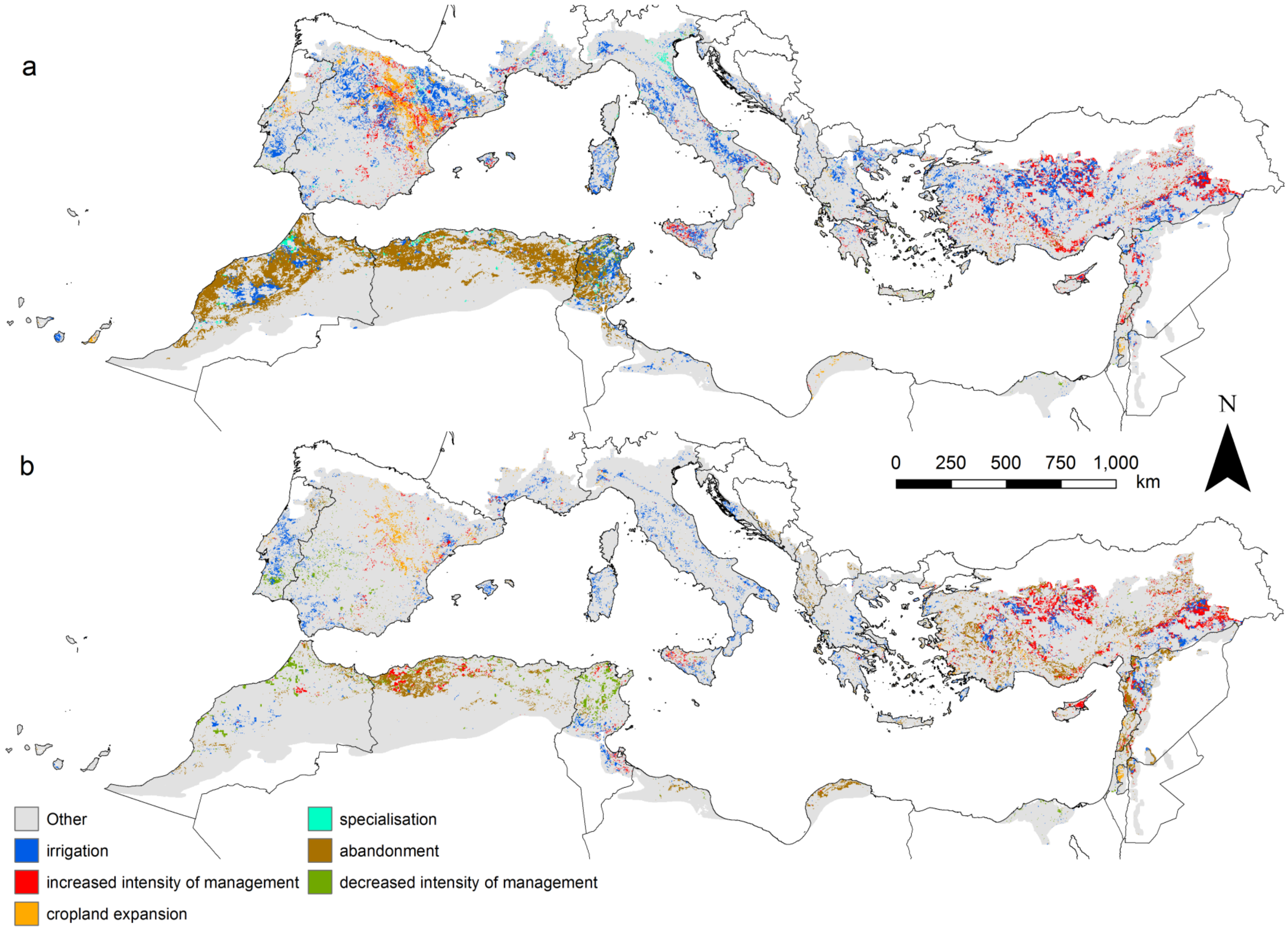

Fig. J.2 Changes in land management intensity in the (a) growth and (b) sustainability scenario

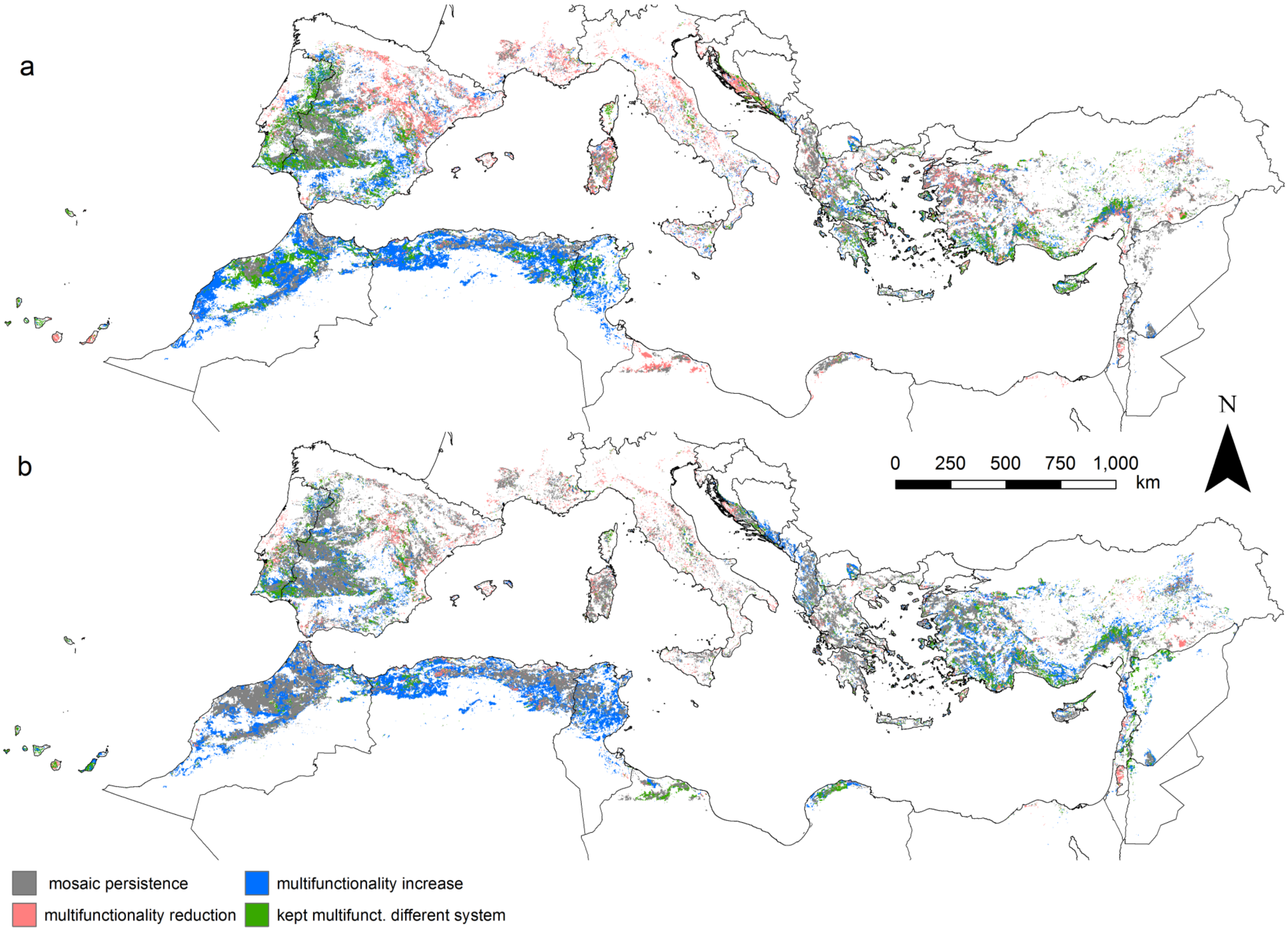

Fig. J.3 Land system change affecting mosaic land systems in the growth (a) and sustainability (b) scenario

Appendix K – Freshwater resources and irrigation water withdrawal (EUROSTAT, 2013, 2016; FAO, 2016)

	North		**South**	
	W Balkans and Turkey	European Union	Middle East and NE Africa	NW Africa
Renewable freshwater resources (km^3)	255.3	478.5	62.8	55.3
% of irrigation water withdrawal in total water withdrawal	78.9	39.3	93.8	78.2
Irrigation water withdrawal (km^3/yr)				
2010	30.1	48.6	59.3	16.7
Growth scenario	46.9	66.6	72.0	27.4
Sustainability scenario	24.7	38.2	42.8	11.1

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