Agroforestry from Mediterranean Partner Countries:
Report on possible technology transfer from Mediterranean Partner countries to European countries

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List of Acronyms

AGFORWARD project	Agroforestry that will Advance Rural Development project
CCCMA	Canadian Centre for Climate Modelling and Analysis
GCM	General Circulation Model
HCCPR	Hadley Centre for Climate Prediction and Research
ICRAF	World Agroforestry Centre
IPCC	Intergovernmental Panel on Climate Change
LEK	Local Ecological Knowledge
MENA region	Middle East and North African region
NMC	Northern Mediterranean Countries
PMV	Plan Maroc Vert
SEMC	Southern and Eastern Mediterranean Countries
WaNuLCAS model	Water, Nutrient and Light Capture in Agroforestry Systems model

1. Context

Agroforestry is the practice of deliberately integrating woody vegetation (trees or shrubs) with crop and/or animal systems to benefit from the resulting ecological and economic interactions. The AGFORWARD (AGroFORestry that Will Advance Rural Development) research project (January 2014-December 2017), funded by the European Commission, is promoting agroforestry practices in Europe that will advance sustainable rural development. The project has four objectives:

1. to understand the context and extent of agroforestry in Europe,
2. to identify, develop and field-test innovations (through participatory research) to improve the benefits and viability of agroforestry systems in Europe,
3. to evaluate innovative agroforestry designs and practices at a field-, farm- and landscape scale, and
4. to promote the wider adoption of appropriate agroforestry systems in Europe through policy development and dissemination.

Further details of the project can be found on the AGFORWARD website: www.agforward.eu

This report is a deliverable associated the first objective of understanding the context and extent of agroforestry in Europe. The specific objectives of work-package 1 are:

1. To inventory and explain, using existing EU27 land cover and land use databases, the extent and recent changes of agroforestry systems in Europe.
2. To identify and describe successful agroforestry practices in areas bordering Europe, that could be used to encourage agroforestry in Europe.
3. To stratify the EU27 into regions with different combinations of fruit-tree/olive, livestock, arable and rangeland agroforestry systems
4. To analyse the framework conditions under which agroforestry operates and develops in Europe.

The objective of this report is to address the second objective of work-package 1, namely to identify and describe successful agroforestry practices in areas bordering Europe that could be used to encourage agroforestry in Europe. The report comprises an introduction, a methodology, results and then a discussion section.

2. Introduction

Current predictions suggest that the Mediterranean region is likely to be significantly impacted by climate change (Tanasijevic *et al*., 2014). The projections suggest that these changes are likely to have detrimental impacts on ecosystems and agricultural production across the Mediterranean basin. North Africa, in particular is likely to face significant challenges in relation to climate change (Shilling *et al*., 2012). The agricultural sector is in all North African countries by far the largest consumer of water, often responsible for as much as 80% of water use (Shilling *et al.,* 2012). In most cases these agricultural systems are almost entirely dependent upon precipitation as the main water source. The predicted decline in precipitation is projected to lead to as much as a 40% decline in agricultural productivity in countries such as Algeria and Morocco (Cline, 2007). Morocco, in particular, is likely to experience the greatest precipitation decrease (Terink *et al*., 2013). Whilst societies in this region have historically adapted to water scarcity there is a need for alternative approaches, including the use of agroforestry systems, to deal with these environmental constraints to agricultural production.

As described in Section 1, this report is part of the AGFORWARD project which has the primary goal of promoting appropriate agroforestry practices that advance sustainable rural development in Europe. The main objective of this study is to identify and describe successful agroforestry practices in areas bordering southern Europe and comment on their potential to encourage such agroforestry practices in Europe. The analysis looks on the relative importance of field-scale and landscape-scale agroforestry in parts of North Africa that have a similar climate to the Mediterranean agroclimatic region, with a particular focus on Morocco. In common with southern Europe this region has a number of high value tree system agroforestry systems, particularly associated with olive (*Olea europaea L.*) and argan (*Argania spinosa*) cultivation both of which have high socio-economic and cultural value (Daoui and Fatemi, 2014). In Morocco, for example, agroforestry is a well-established practice commonly found both in oasis and in mountainous regions where both agricultural land area and water resources are scarce. Under the Moroccan government's Plan Maroc Vert there are now plans to expand agroforestry systems.

A key element of this work, as part of the AGFORWARD project, is to investigate the importance of agroforestry systems in potential climate adaptation strategies. As conditions in the southern Mediterranean are already significantly warmer than those in Europe there is potential to explore the viability of agroforestry systems that are currently practiced in these areas. As part of this study we used both climate analogue modelling (Luedeling *et al*., 2014) and participatory research methods (particularly local knowledge methods (Sinclair and Walker, 1998; Walker and Sinclair, 1998) to look at adaptation strategies associated with both current and potential agroforestry systems in Morocco. The World Agroforestry Centre (ICRAF) has also been involved with developing innovative modelling approaches to look at adaptation of agroforestry systems to climate change. Here we report on the use of these models in a Sahelian context. Are there lessons that can be learned from these systems that demonstrate the benefits and viability of increasing agroforestry systems in the European Mediterranean?

3. Methods

The report had three main activities which are outlined below:

1. Review of literature associated with agroforestry practices in the southern and eastern Mediterranean,
2. Climate analogues analysis to identify areas in North Africa which are currently experiencing climate similar to predicted future climates for the Spanish dehesa systems, and
3. Participatory research on agroforestry systems in one climate analogue location in Morocco.

In addition we present a summary of research by ICRAF conducted in the Sahel region. This work used the WaNuLCAS modelling approach to explore the dynamics of parkland systems in relation to climate variability (see Section 4.4)

The methodologies associated with these three main activities are described in the following sections:

3.1 Literature review

The literature review focussed on identifying examples of lessons learnt from successful agroforestry practices established in North Africa and the eastern Mediterranean region that may be relevant within a southern European context. An initial scoping review suggested that there was only limited information on agroforestry systems in North Africa with the exception of Morocco. The output from the climate analogue work (Section 3.2) suggested that there were areas in the western Mediterranean which were also potential analogue sites so the formal review was expanded to include Lebanon, Israel, Jordan, Syria and Turkey.

A set of published articles was assembled from an ISI Web of Knowledge and Science Direct search using the search string: ('agroforestry' or 'silvopasture ' or 'silvoarable' or 'alley cropping') and ('Mediterranean' or 'North Africa' or 'Morocco' or 'Algeria' or 'Tunisia' or 'Libya' or 'Egypt' or 'Lebanon' or 'Israel' or 'Jordan' or 'Syria' or 'Turkey'). In all cases the references were checked to ensure the agroforestry practices fell within Mediterranean ecoregions.

3.2 Climate analogues

Climate analogue analysis (Luedeling *et al*., 2014) is a modelling approach that allows users to search for different locations where the current climate is similar to that which is predicted for a given site in the future. Given the focus here on the potential value of agroforestry systems to moderate future climate impacts there is a need to look at how similar current conditions in North Africa are to the predicted climate of the European Mediterranean. To illustrate the methodology we focused on the high nature and cultural value dehesa systems in Spain to demonstrate the approach.

The search for analogues was based on the climatic distance method. This method finds the point on the target grid whose climate is most similar to the base grid at the sampled position. This means that for each grid cell of the target grids, and for each climate metric, the (absolute) difference between the base and target values is calculated. These values are then normalized. Distances of all included climate metrics are then weighted according to user specified weights and added up, resulting in one distance value. The grid cell with the minimum distance value is then identified as the analogue location.

Projected future climate conditions were derived for four selected dehesa systems in southern Spain (provided by AGFORWARD project partners). The co-ordinates for these are presented in Table 1 below.

Table 1. Co-ordinates for four purposively selected dehesa systems in Spain

Dehesa	Co-ordinates
1	36.86°N; 5.10°W
2	37.41°N; 7.42°W
3	37.57°N; 6.17°W
4	38.23°N; 3.85°W

Projected future climate conditions were obtained from three different global circulation models: CCCMA_CGCM2 (Canadian General Circulation Model 2, by the Canadian Centre for Climate Modelling and Analysis), CSIRO_MK2 (CSIRO Atmospheric Research Mark 2b) and HCCPR_HADCM3 (Hadley Centre Coupled Model, version 3).

These three models were selected, because projections were available to the study via the climate data portal of the Research Program on Climate Change, Agriculture and Food Security (CCAFS) of the Consultative Group on International Agricultural Research (CGIAR). All data was downscaled to 2.5 arc minute resolution (~4.6 km in the study region) using the Delta method and expressed climate change relative to the WorldClim dataset for the 1950-2000 reference period (Hijmans *et al*., 2005).

The climate analogue search was based on three local climate metrics: mean monthly precipitation, mean monthly minimum temperature and mean monthly maximum temperature. These metrics were used to compare all the grid cells within the search domain with future climates projected for the baseline location. This was done by computing 'climatic distances' between places using a Euclidean distance calculation (Luedeling and Neufeldt, 2012):

$$\text{Climatic distance} = \sqrt{\left(\sum_{par}\sum_{m} w_{par,m} \times \left(\frac{P_{par,m} - F_{par,m}}{norm_{par}}\right)^2\right)}$$

In which *par* stands for the array of weather parameters, *m* is the list of all months in the year. $w_{par,m}$ is a weighting factor to determine which of the weather parameters is given priority over the others. In this study, precipitation was assigned a weight of 2, while minimum and maximum temperatures received weights of 1. $P_{par,m}$ and $F_{par,m}$ are the values for the respective parameter for the present and future scenarios and $norm_{par}$ is a normalization parameter, which was set to the interquartile range of the distribution of the respective monthly values across all grid cells of the analogue search domain.

Separate climatic distance measures were calculated for each climate scenario. The grid cell with the lowest distance value is the best 'matching' analogue location. By using this method, a total of 18 climate analogue locations (3 models × 2 scenarios × 3 time horizons) were determined for each handpicked reference point.

Climate analogue analysis is particularly useful if climate is a dominant driver of differences between baseline and analogue site pairs. The main advantage of the approach in the case of this project is that it can be used for identifying potential adaptation strategies. If adaptation options have already proven their viability in a situation that represents the climatic future of the site of interest, then there is potential to apply these technologies in the base line location (Ramirez-Villegas *et al*., 2011).

Whilst not particularly relevant for the dehesa systems used in this example (which are not commonly found in North Africa) the method could also be used to see if agroforestry systems currently present in Europe can thrive under future climate conditions. If a particular practice is successfully applied at both baseline and analogue sites, it can be argued that the practice is likely to remain viable, and plant or animal species that thrive at both locations are unlikely to be vulnerable to climate change. Climate analogue analysis is less likely to be useful as an approach in predicting the impacts of climate change on agroforestry systems where there is limited socio-ecological characterisation in place as it is critical to also account for differences in land use, land cover or socio-economic conditions between locations (Luedeling *et al*., 2014).

3.3 Case study in northern Morocco

In 2008, the Kingdom of Morocco launched the Plan Maroc Vert (PMV) to address the threat of increasing water scarcity (Ministère de l'Agriculture et de la Pèche Maritime, 2011). Agroforestry is likely to be an important component of the plan as the government wants to start large-scale conversion of water-intensive cereal cropping systems into high value tree orchards, emphasizing olive tree cultivation for improved water use efficiency (Agence pour le Développement Agricole, 2013). In common with the aims of the AGFORWARD project, research towards an improved understanding of existing agroforestry practices and agroforestry options within farming systems of northern Moroccan smallholders, is a vital first step towards ensuring political and institutional support for smallholder farmers, seeking to increase farming system resilience.

In this context a field study was conducted using participatory approaches in the Zerhoun massif which is part of the Meknès–Tafilalet region of northern Morocco (Figure 1) in the summer of 2014. The principal aim of this research was to both characterise existing agroforestry systems and to identifying options for tree based diversification and tree cover increase. This is an area identified in the climate analogue modelling as a potential future analogue to the dehesa systems in southern Spain – with a climate system similar to what will be experienced in Spain potentially as soon as 2020 (see Figure 5 - Section 4.2).

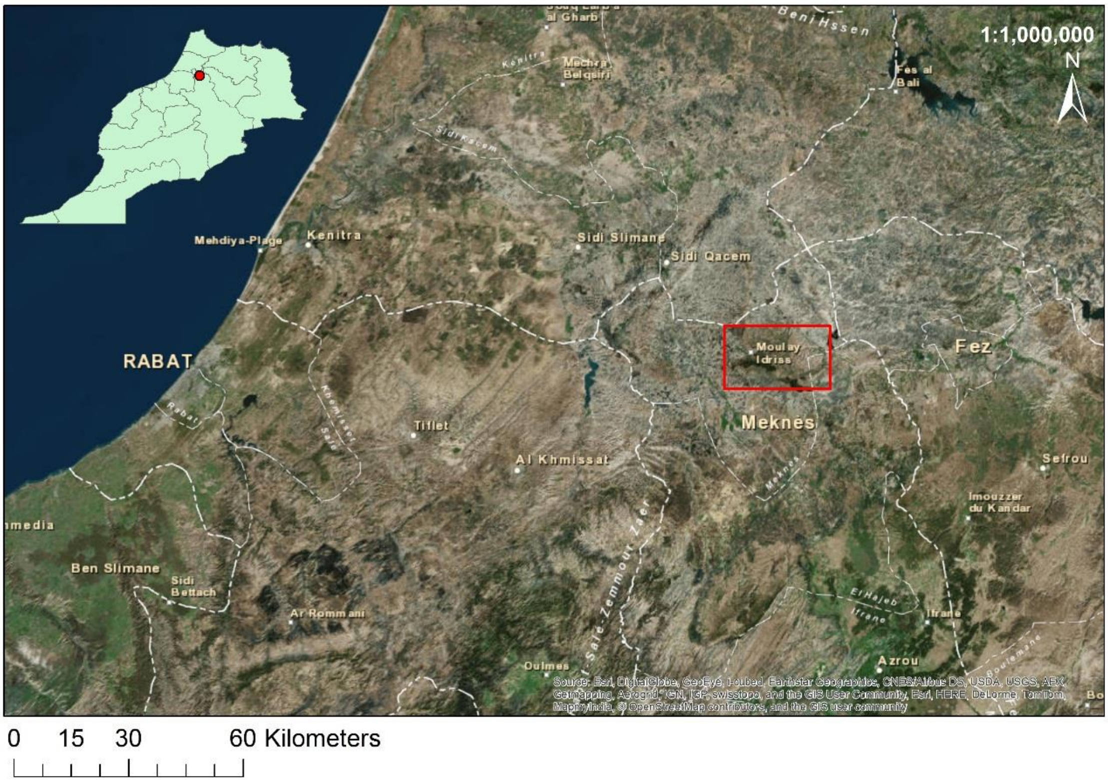

Figure 1. Map and satellite image of part of northern Morocco, with the red dot and rectangle indicate the location of the study site in the Meknès–Tafilalet region. Field work was conducted near the city of Meknes in northern Morocco.

Importantly there are a number of key differences between the sites – not least the topography and the cultural context for the agroforestry systems which will account for some significances between the sites (there is no direct analogue for dehesa in Zerhoun massif – although there are significant areas of silvopastoral cork oak (*Quercus suber*) dominated open woodlands in north-western Africa (Vallejo *et al*. 2006). Instead the site offers an insight into issues surrounding agroforestry generally under conditions that, climatically, are likely to be similar to southern Europe.

3.3.1 Local knowledge methods

Local knowledge about agroforestry systems in the Zerhoun massif was collected using knowledge-based systems methods (Walker and Sinclair 1998; Sinclair and Walker 1998). First a short scoping study with key informants was completed. This involved discussions with local farmers and extension workers.

The local knowledge was recorded using the AKT5 software system (Dixon *et al*. 2001) that involved disaggregation of knowledge into sets of unitary statements represented using a formal grammar (Walker and Sinclair 1998), with associated contextual information about the definition and taxonomy of terms (Sinclair and Walker 1998). The knowledge was evaluated for coherence and consistency as it was collected, using a suite of automated reasoning tools (Kendon *et al*. 1995) and a diagrammatic interface to explore connections among statements (Walker *et al*. 1995).

Detailed knowledge was acquired by repeated interviews with a purposive sample of 32 willing and knowledgeable farmers. The sample was stratified across an altitudinal gradient. Five strata were selected for interviews based on the scoping activities in the study area. These included:

- **Lowland farmers** owning land situated in the lowland plain west of Moulay Idriss Zerhoun (lowland farmers).
- **Irrigation farmers**; the majority being located in close proximity to Lkhammane River which runs through the Zerhoun massif.
- **Lower slope farmers** cultivating land in the foothills of the mountain range.
- **Mountain farmers** farming land within the mountain range, north and north-east of Moulay Idriss Zerhoun.
- **Livestock farmers** primarily involved in livestock husbandry, moving across the study area to feed their animals.

Repeated interviews with the same people were important in obtaining deeper explanatory knowledge and resolving inconsistencies, while stratification ensured broad coverage of the types of knowledge locally held about agroforestry systems. The process of knowledge acquisition during the compilation stage was iterative. Information gaps identified during the development of unitary statements were addressed in subsequent interviews (Table 2).

Table 2. Number of farmers interviewed during local knowledge research.

Stratum	**Number of participants**		
	1st interview	2nd interview	3rd interview
Lowland farmers	6	2	-
Irrigation farmers	6	4	-
Lower slope farmers	6	3	1
Mountain farmers	7	3	-
Shepherds	7	-	-
Total = 45	**32**	**12**	**1**

Three focus group discussions were also conducted during the final stages of the knowledge acquisition phase: one with lower slope farmers, the second with shepherds and a third with mountain farmers. These were used to triangulate information obtained from the detailed semi-structured interviews with a broader audience. The discussion with shepherds provided an opportunity to learn more about their seasonal migration across rangelands and gain further insight on constraints to animal husbandry across the study site.

4. Results

4.1 Review of agroforestry practices

The Mediterranean is one of the world's 18 biological 'hot spots' (Myers *et al*., 2000). There were significant disparities in information associated with agroforestry systems in northern Mediterranean countries (NMCs) and southern and eastern Mediterranean countries (SEMCs). The literature review revealed a limited amount of formal study of agroforestry systems in northern Africa and in the Eastern Mediterranean. The Web of Science searches returned 123 potential studies against the search criteria (see Section 3.2). Of these only 18 were potentially relevant to AGFORWARD (these are listed in Appendix A). A number of countries had very little research associated with their agroforestry systems – especially in areas of these countries analogous to a Mediterranean climate (e.g. Algeria, Egypt, and Syria). While countries such as Tunisia had slightly more agroforestry studies, many of these were from the more southerly areas of the country and did not fall within the Mediterranean bioclimatic limit (i.e. they were more closely associated with Saharan conditions) and were excluded on this basis.

4.1.1 Drivers of decline in forest cover

In the south of the Mediterranean basin, the region is generally under semi-arid to desert conditions, and is characterized by low forest cover – 10 percent or less of the land area is covered by forests. The forest vegetation is generally composed of open woodlands with scattered trees and xerophytic shrubs (FAO Forestry Department, 2013). Mediterranean forests and other wooded lands are expected to be increasingly exposed to environmental and anthropogenic threats. Climate change is a significant driver of deforestation – through extending the dry period and decreased precipitation (FAO Forestry Department, 2013). In common with the NMCs, forest fires, soil degradation and increasing desertification pose significant risks. The primary cause of desertification is the removal of vegetation. This causes removal of nutrients from the soil, making land infertile and unusable for arable farming.

Whilst abandonment is an increasingly significant issue in many parts of the NMCs (Mazzoleni *et al*. 2004), in north Africa and the eastern Mediterranean the opposite is observed with significant increases in land-use intensification (Vallejo *et al*., 2006) associated with population increase; between 1955 and 2010 the population in SEMCs increased by 238%. There is evidence that climate change is leading to increased variability in precipitation in marginal areas often leading to floods and water erosion. During dry seasons, the overall decline in rainfall and cloud cover leads to increased evaporation and reduced underground water resources. This lack of water has led to the abandonment of upland farms in Morocco (CBA Morocco Programme, 2011).

Demand for fuel wood is a significant driver of deforestation in the SMECs. For example, fuel wood constitutes 30 percent of energy consumption in Morocco. Current estimates are that the consumption of wood energy in Morocco easily surpassed the productive capacity of vegetation, making it a major contribution to deforestation. The rate of deforestation in Morocco is estimated at approximately 30,000 ha per year (FAO Forestry Department, 2013)

4.1.2 Examples of North African and the eastern Mediterranean agroforestry

The paucity of information means that it is not possible to characterise all the agroforestry systems in North Africa and the eastern Mediterranean. Instead we have detailed some of the better studied agroforestry systems, particularly in Morocco. Even in Morocco, where agroforestry practices have a long tradition, these systems have received little research attention (Daoui and Fatemi, 2014).

Olive agroforestry systems (Morocco, Tunisia and Algeria)

Olives (*Olea europaea* L.) are among the oldest examples of agroforestry systems in the Mediterranean (Figure 2). Olives are a cash crop of great economic importance not least because of its resilience to drought. Recent modelling work has shown that rain-fed olive groves are expected to become unviable across the Mediterranean area as a result of climate change, particularly in the arid and semi-arid zones where olives are traditionally cultivated (Tanasijevic *et al.,* 2014).

Figure 2. Olive orchards on the lower slopes of the Zerhoun massif, Morocco. The image depicts the scattered growth of carob trees (bottom left corner and upper centre of the image) within olive stands. The image further depicts scrubland and state managed forests on the ridges above Moulay Idriss (see Section 4.3.3).

Argania spinosa (Morocco)

In Morocco, natural forests of argan trees (*Argania spinosa*) cover an area of about 800,000 hectares in densely populated arid and semiarid zones (about seven percent of the total forest cover). The tree has a high biodiversity value and is part of a multi-use silvopastoral system which produces about 4,000 tons of argan oil each year (Chaussod et al., 2005). Argan woodlands are suffering degradation due to the abandonment of traditional management practices and the intensification of their use (Fund and Hogan, 2014). This traditional agro-ecosystem is now in crisis, with consequences at ecological and socio-economical levels as the tree is important for the subsistence of two million rural Moroccans (Chaussod et al., 2005)

Cork oak (Tunisia, Algeria and Morocco)

Cork oak (*Quercus suber* L.) is endemic in Tunisia, Algeria and Morocco. The woodlands are associated with a range of traditional agro-silvopastoral practices including grazing and the gathering of a number of non-timber forest products (Campos *et al.*, 2009). Across the region there has been a significant decline in the area of cork oak forests. A total of 632,000 ha have been lost; equivalent to approximately a third of the total area of cork oak woodland (Harfouche *et al.* 2005). Long dry seasons, forest fires and overgrazing are considered to be the main factors contributing to the decline in forest area (Campos *et al*. 2007).

In the eastern Mediterranean there are a couple of examples of experiments using grazing to rehabilitate degraded *Quercus calliprinos* (Kermes oak) woodlands (Gutman *et al*., 2000; Dufour-Dror, 2007).

Alley cropping with Saltbush (Morocco)

In Eastern Morocco, alley cropping systems which combine saltbush (*Atriplex nummularia*) with barley have been introduced. This area suffers from permanent water shortage and recurrent drought. This agroforestry system is valued by farmers as the saltbush allows farmers to meet livestock nutritional requirements during feed gap periods (*Atriplex* has a high content of crude protein and minerals throughout the year). In addition studies have shown that the association improved the soil water status and enabled a 39% increase in barley grain yield (Shideed *et al*., 2007; Chebli *et al*., 2012).

4.2 Climate analogues

The climate analogue approach has high value for planning associated with climate change impact projection and adaptation planning. This is particularly true for complex agroforestry systems such as the dehesa systems. The initial results from the climate analogue works show analogue sites for dehesa systems in southern Spain (Figures 3 to 7). The maps use climate change predictions from three models over three time periods to model the projected climate for the selected dehesa examples. These were used to identify locations where the current climate is similar to these projected conditions.

Climate modelling (Figures 3 to 6) suggests that most analogue sites for dehesa are found in Spain for the earliest predictions i.e. 2020. As the timescale increases then the location of potential climate analogue sites changes, often including locations in both the southern and eastern Mediterranean. For example, the results from the analogue mapping show the areas of Western Turkey become analogues for dehesa systems in 2080 (see Figure 3). This means that this area is currently experiencing mean monthly precipitation, mean monthly minimum temperatures and mean monthly maximum temperatures that are likely to be equivalent to what will be experienced in the dehesas in 2080.

Morocco has the most climate analogue sites (providing part of the rationale for the participatory described in Section 4.3). They start to appear in both the 2020 and the 2050 predictions (Figures 3 to 6). By comparing baseline-analogue pairs, information on climate impacts and opportunities for adaptation can be obtained.

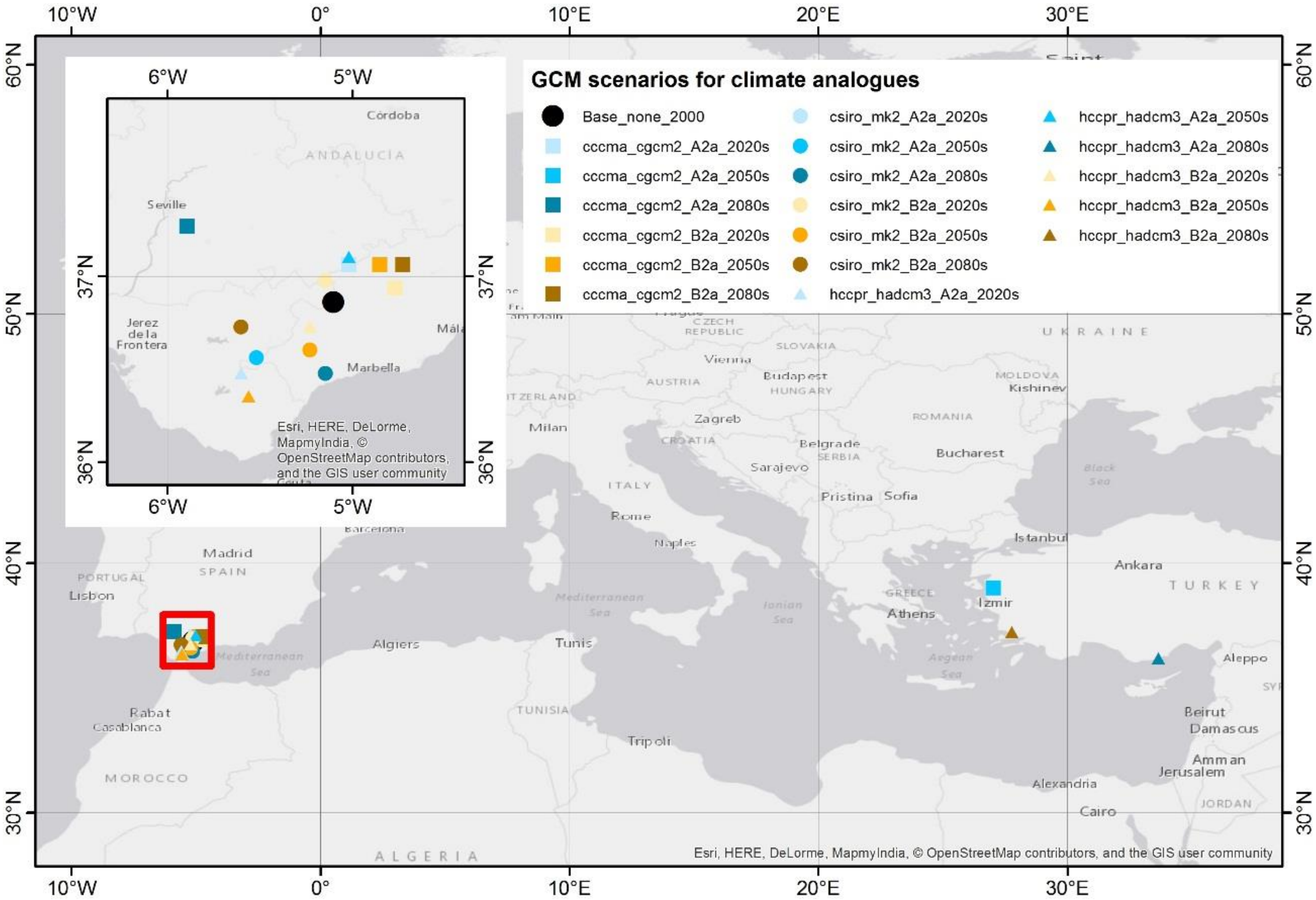

Figure 3. Climate analogues for dehesa 1 as calculated by three different general circulation models (GCMs) from the Canadian Centre for Climate Modelling and Analysis (CCCMA), CSIRO Atmospheric, and the Hadley Centre for Climate Prediction and Research (HCCPR) in two future scenarios (IPCC A2a and B2a) for the year 2020, 2050 and 2080.

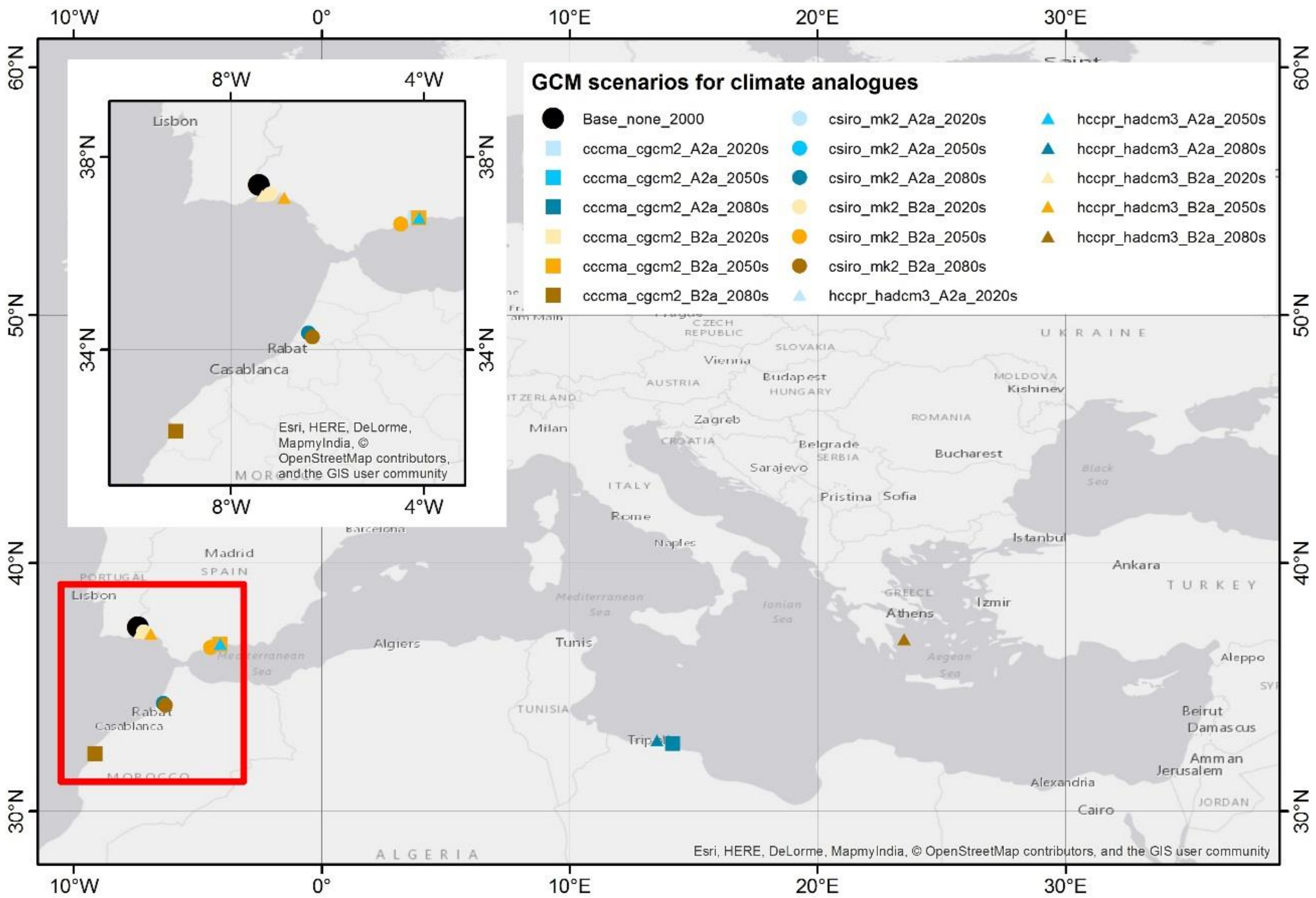

Figure 4. Climate analogues for dehesa 2 as calculated by three different general circulation models (GCMs) from the Canadian Centre for Climate Modelling and Analysis (CCCMA), CSIRO Atmospheric, and the Hadley Centre for Climate Prediction and Research (HCCPR) in two future scenarios (IPCC A2a and B2a) for the year 2020, 2050 and 2080.

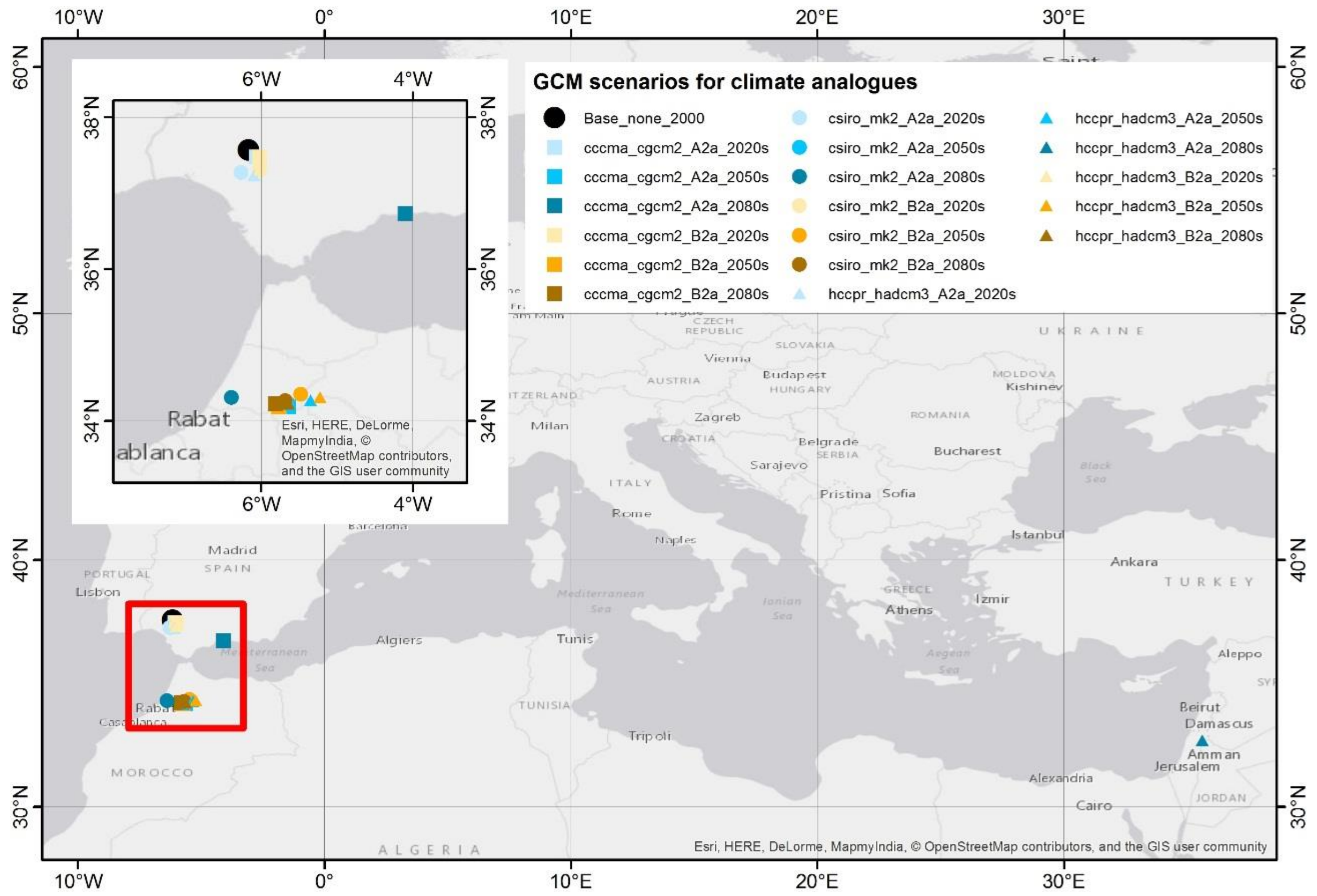

Figure 5. Climate analogues for dehesa 3 as calculated by three different general circulation models (GCMs) from the Canadian Centre for Climate Modelling and Analysis (CCCMA), CSIRO Atmospheric, and the Hadley Centre for Climate Prediction and Research (HCCPR) in two future scenarios (IPCC A2a and B2a) for the year 2020, 2050 and 2080.

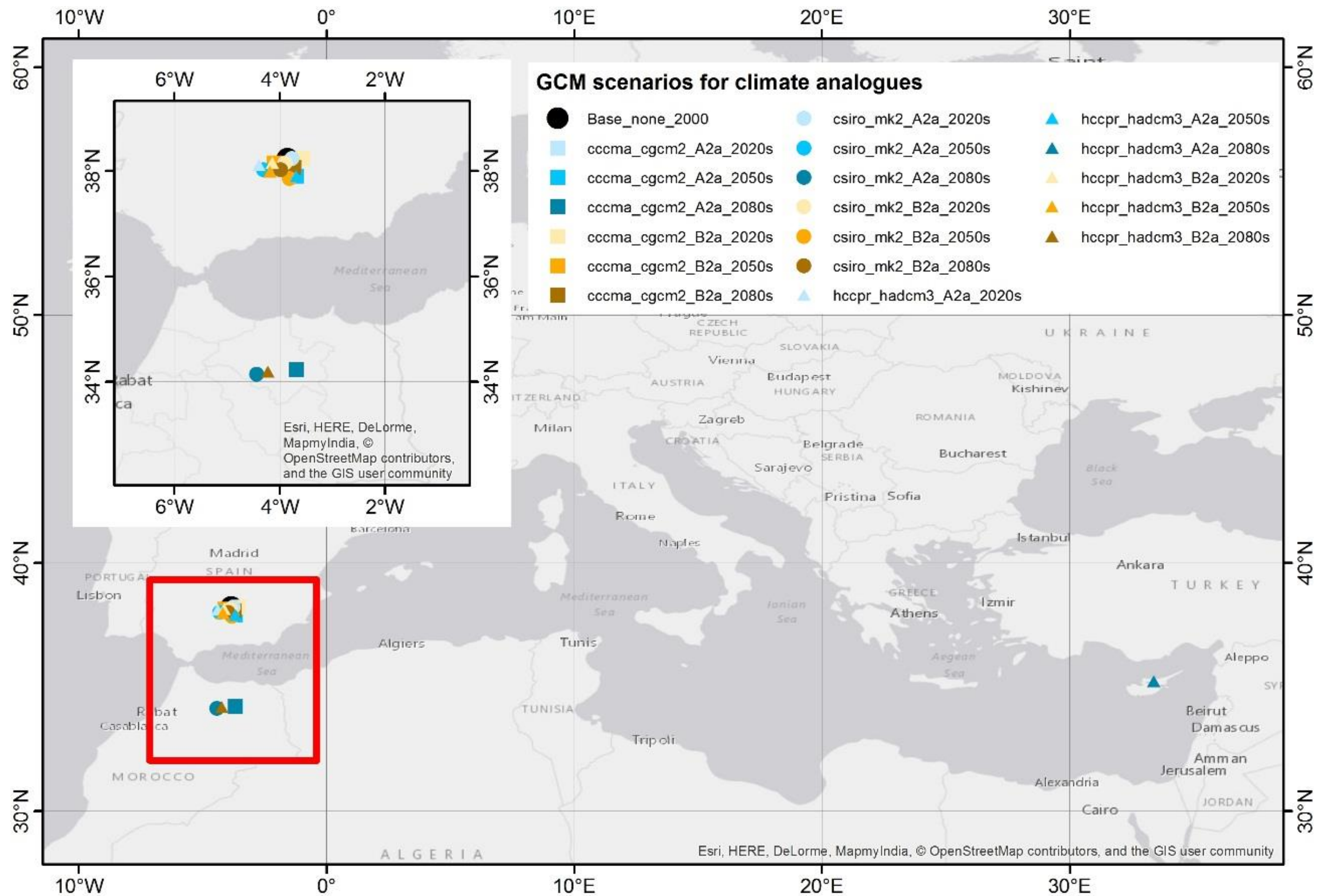

Figure 6. Climate analogues for dehesa 4 as calculated by three different general circulation models (GCMs) from the Canadian Centre for Climate Modelling and Analysis (CCCMA), CSIRO Atmospheric, and the Hadley Centre for Climate Prediction and Research (HCCPR) in two future scenarios (IPCC A2a and B2a) for the year 2020, 2050 and 2080.

4.3 Case study: tree cover increase and diversification options in northern Morocco

In this section we summarise findings from a study conducted in the Zerhoun region of Morocco (Kmoch, 2014). The Zerhoun massif (Figure 7) is located in one of Morocco's most favourable cropping regions, near the city of Meknès (CGIAR, 2013).

Figure 7. Landscape of the Zerhoun region in Morocco.

4.3.1 Country overview

Morocco is a dryland country of the Middle East and North African (MENA) region, comprising arid, semi-arid and sub humid arable land (Berkat and Tazi, 2004). Almost half of the country's population live in rural areas and the agricultural sector employs close to a quarter of the total economically active population (FAO STAT, 2013). In 2012, agriculture contributed 15% to the countries total gross domestic product (The World Bank, 2014). Morocco's agricultural sector is characterised by intensive agricultural production on irrigated lowland areas and more traditional, subsistence-oriented practises on rainfed farmland (Kadi and Benoit, 2012). Poverty prevails in rural areas, where alternative employment opportunities, independent of the agricultural sector, remain scarce. Approximately 5.5 million rural Moroccans are either landless or they own micro-farms (Kadi and Benoit, 2012). Morocco's population is highly vulnerable to food insecurity. Net primary production on Moroccan agricultural land in 2007 was just sufficient to meet food consumption demands (Rochdane *et al*., 2014). Morocco's strong import dependence and exposure to international markets render the country extremely vulnerable to food price inflation (Huppé *et al*., 2013). Although cereals occupy 65% of the country's total cultivated land area, Morocco currently imports 50% of its wheat (FAO STAT, 2013; Huppé *et al*., 2013). In 2008, Moroccan government launched the Plan Maroc

Vert (PMV) aimed at modernising the countries agriculture sector and to foster rural development and institutional innovations, to address the threat of increasing water scarcity.

The mountain areas also face significant erosion challenges – with gulley erosion potentially accounting for annual soil losses of up to 100-300 tonnes per hectare (Sabir *et al.*, 2014). In these environments, agroforestry can improve the sustainability of agriculture by improving the organic matter and hydrology of the soil, particularly on steep land.

4.3.2 Climate change Impacts

The local climate is typically Mediterranean, with a mean annual precipitation of 580 mm (Centre de Conseil Agricole Béni Amar, 2006); 90% of rainfall occurs between November and April (CGIAR, 2013). The mean annual minimum and maximum temperatures are 11°C and 28°C, respectively. The altitudinal gradient across the massif ranges from 300 m in the plain, to above 1100 m on mountain peaks; a great proportion of farmland is located on slopes greater than 15%. Soil types are varied, but calcareous clay soils dominate (Centre de Conseil Agricole Béni Amar, 2006)

Models derived through downscaling of IPCC scenario data, with observations from in country meteorological stations, predict that climate change in the Zerhoun region will result in higher mean temperatures in all seasons, alongside decreased precipitation particularly in spring (Babqiqi and Messouli, 2013). In addition a forecasted increase in vegetation reference evapotranspiration is likely to lead to decreased runoff and groundwater recharge (Terink *et al*., 2013).

4.3.3 Agroforestry in Zerhoun

Forest cover in the study area is extremely sparse, as most land is used for agriculture (CGIAR, 2013). There are several common agroforestry practices in Zerhoun, including: boundary plantings with olives on annual cropland and prickly pear, agave or cape gum around gardens, homesteads and fields; clumps of irrigated fruit trees near homesteads or in corners of annual croplands. There are also agrosilvicultural practices such as intercropping of vegetables, legumes and forages in fruit and olive orchards and silvopastoralism, i.e., livestock grazing under mature olive and carob trees. Farmers also retain hedgerows of wild trees and grow ornamentals in villages, but seldom use trees to stabilise stream banks.

Olive is by far the most prominent tree species on all farms, with the exception of irrigated properties. Carob, fig and almond are also commonly cultivated and particularly numerous on slopes. In contrast, fruit trees outside irrigated orchards are restricted to a few trees per farm and are mainly cultivated for subsistence needs (Figure 8). The number and diversity of wild trees on farms tend to increase with altitude.

Figure 8. Transition from irrigated fruit orchards, to annual cropland, with dispersed olive trees, situated on the lower slopes of the Zerhoun massif in Morocco. The image illustrates the stark contrast in cultivation opportunities, arising for owners of frequently irrigated (centre) and rainfed farmland (bottom and top third of the image). The image further depicts silvopastoral practices (top right corner and centre) and the onset of erosion, where annual crops are cultivated on sloped land.

4.3.4 Key findings

Local Ecological Knowledge research revealed that Zerhoun's farmers were affected by numerous drivers of tree cover change and that a number of barriers such as water scarcity, low profitability of production systems, restrictive tenure and grazing pressure need to be overcome to facilitate tree planting and diversification in the study area. These findings are in accordance with observed and predicted impacts of global change and established constraints to smallholder production in North African countries (Dixon *et al*., 2001) and northern Morocco (compare 1.3.1) (CBA Morocco Programme, 2011; Direction Provinciale de l'agriculture de Meknes, 2007).

This study showed that resilience varied between the strata (Table 2) and would require a broad range of agroforestry options to increase resilience.

Lowland farmers managed intensified, cereal and legume dominated farming systems. Farmers were exposed to recurrent droughts, which they cannot mitigate through irrigation. The productivity of wheat, lowland farmers' main cash crop, was closely linked to annual rainfall patterns; severe crop shortfalls occur during drought periods (Balaghi *et al*., 2007, Jarlan *et al*., 2013). Farmers are thus highly vulnerable to a predicted increase in the frequency of droughts.

These farmers were most interested in fruit tree establishment. However, Local Ecological Knowledge indicates that subsidies for planting material would be insufficient to improve farmers' resilience, as long as farmers remain unable to sell their tree products. This implies a need for capacity development. A policy shift, emphasizing diversification, rather than conversion of farming systems with a single tree species, (i.e. olive in Zerhoun), appears desirable to shift livelihoods onto a more resilient trajectory. Cultivating a range of tree species with low irrigation requirements (e.g. fig, carob, almond, pomegranate, apricot, suitable introduced species and annual crops) would allow farmers to be less vulnerable to both market fluctuations and drought.

Farmers' perceived recurring droughts and increasing dryness as particularly challenging; this local knowledge corresponded with scientific knowledge, although respondents did not accurately recall the exact timing of drought events. Climate change was associated with a loss of high value tree species; many fruit trees and grape vines used to grow on farmland above and surrounding the study area; but recurrent drought and decreasing winter rains resulted in gradual dieback of all tree species, except olive, in areas without access to irrigation. Farmers were particularly concerned about the severe decline of fig trees, a species perceived as drought adapted. Triangulation with other interviewees revealed, that vine, apple pomegranate and fig tree decline were triggered by the interplay of a number of factors (Figure 9), but declining rainfall and recurrent drought were central causes.

Irrigation farmers cultivate water intensive, highly profitable fruit tree species, mitigating water scarcity and drought through irrigation. However, dependency on irrigation water resources make these farmers vulnerable to social conflict over the allocation of scarce water resources, to deteriorating irrigation infrastructure, or water resource decline. Conversion from traditional flood irrigation to drip irrigation technology could greatly improve the water use efficiency of irrigation farmers and could thus be supported to reduce farmers vulnerability and to avoid water scarcity induced tree cover decline. Irrigation farmers with properties adjacent to rivers were also vulnerable to flooding events and erosion.

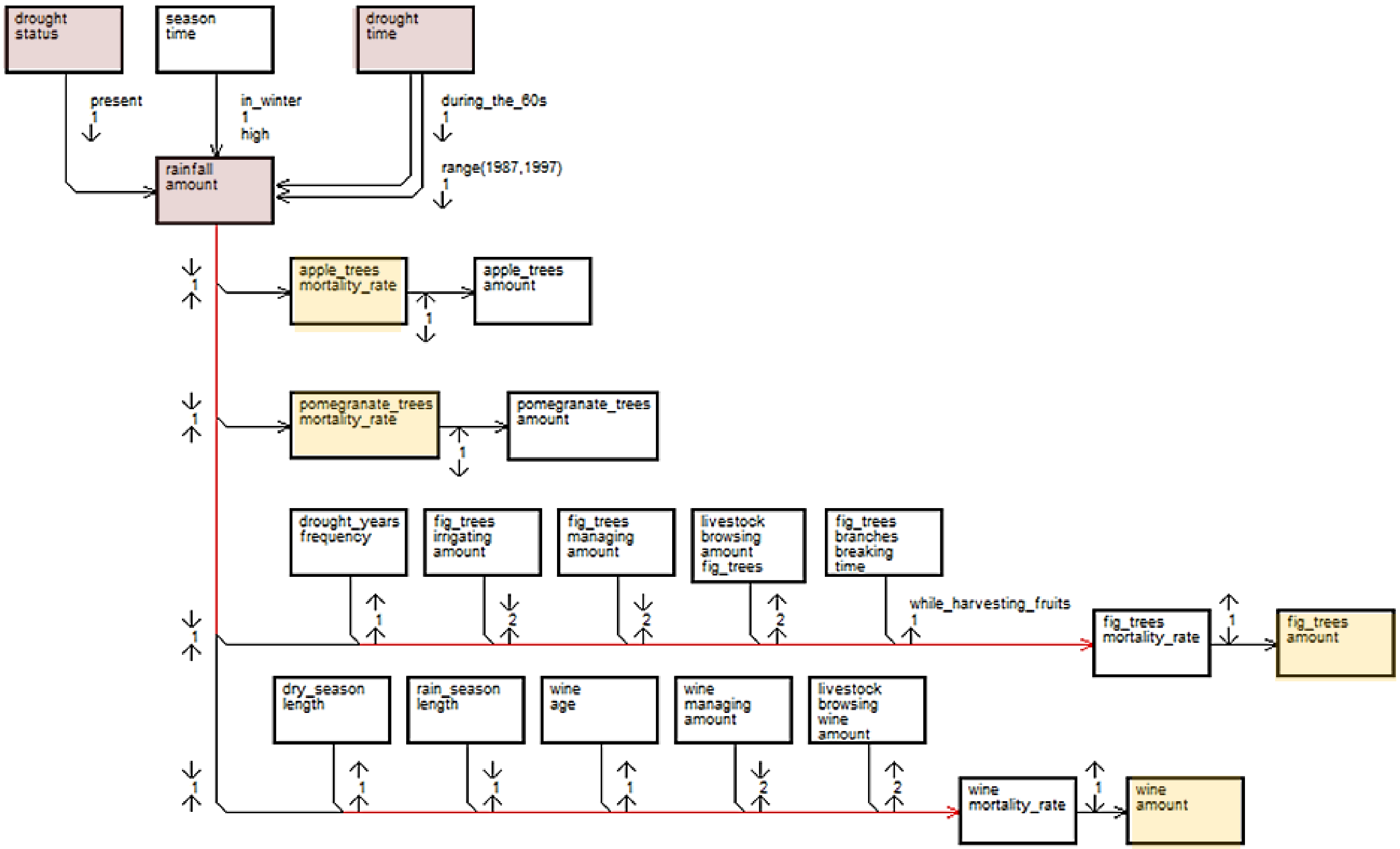

Figure 9. Factors contributing to high value tree cover decline around Bouassel village. This causal diagram illustrates the local ecological knowledge (LEK) of lower slope farmers, about drivers of tree loss on farmland surrounding their village. Key drivers and effects are shaded red and yellow, respectively.

Diversified production systems and the persistence of farming livelihoods irrespective of adverse farming conditions, i.e. low profitability, recurrent drought and grazing pressure imply an inherently high resilience of lower slope and mountain farmers. However, local knowledge suggested increasing vulnerability due to higher drought frequency, declining rainfall, population increase, and reduced profitability of smallholder production systems. These experiences resemble those experienced regionally and throughout northern Africa (CBA Morocco Programme, 2011; Dixon *et al*., 2001). Many smallholder livelihoods were under transformation (either diversification of livelihood activities beyond agriculture or regional and temporary international migration), although farmers continued to engage in agricultural production due to a lack of alternatives and to produce subsistence.

Agroforestry options were not obvious as farmers' human, financial and natural resources are limited and tree cover on non-marginal farmland was relatively high. Nonetheless, potential pathways to improve farming system resilience emerged from respondents' local ecological knowledge: improved tree husbandry, e.g. pest and disease management could help to raise farm incomes. However, knowledge development alone is unlikely to be sufficient, as farmers had limited ability to invest in agro-industrial inputs. Extension activities may have to be accompanied by public subsidies for pesticides. Alternatively, farmers could be trained in low-price phyto-sanitary measures, such as pruning (Ouguas and Chemseddine, 2011) or the application of bio-pesticides e.g. spices, essential oils, soap or alcohol (Sekkat *et al*., 2013). Knowledge development about grafting techniques could allow farmers to realise the full production potential of currently non-grafted carob trees and the feasibility to graft wild trees, desired by respondents. Lower slope and mountain farmers would further benefit from agroforestry options that reduce grazing pressure, facilitate farmer collaboration, and improve access to profitable markets for tree products. Diversification could be promoted through the provision of subsidies for other tree species than olive. Public investment in irrigation and road infrastructure and employment of additional extension staff appear desirable, but would be costly.

Pastoralism constitutes an employment opportunity for a growing number of Zerhoun residents, in need of additional off-farm income in the face of the low profitability of smallholder production systems, a lack of farmland ownership, and population growth. Shepherds depend on access to public and private lands to meet their herds' forage demands and they shift rangelands according to seasonal forage availability. However, due to a lack of social and financial capital, respondents are highly vulnerable to land use decision making of other social groups.

Traditional, non-formalised, socio-cultural norms provide shepherds with de facto seasonal access and withdrawal rights to private farmland, *habus* land[1] and forests. Little conflict arises, where shepherds' activities do not conflict with interests of stakeholders exercising their tenure rights. But conflicts do occur where lower slope and mountain farmers

[1] Land under management of the ministry of Islamic affairs

exercised alteration rights, transforming farmland through tree establishment and excluding shepherds from traditional rangelands.

Lack of management and mutual exclusion rights prevent shepherds from improving *habus* and abandoned farmland rangelands, e.g. through forage cultivation. In addition, shepherds were unable to lease *habus* land due to their limited financial assets. During the post-harvest summer season, shepherds relied on cereal stubble from lowland farms. This is a case of cereal-livestock farming, where benefits are derived through complementariness between livestock husbandry and cereal cultivation (Magnan *et al*., 2012). The case of cereal-livestock farming in Zerhoun is distinct in so far, as two actor groups exercise rights to the resource base. The informal, socio-cultural norms allow shepherds to exert access and withdrawal rights to crop-stubble, while lowland farmers exert higher level rights. Results from the study suggest that this fragile arrangement may shift if lowland farmers expand tree cover on their farms. Shepherds are highly dependent on lowland forage resources, but are dependent on access and withdrawal rights. Lowland farmers, in contrast, may execute their full bundle of rights, and would do so, in a scenario of increased tree establishment in the future. This could induce severe hardship on shepherds.

Shepherds resilience may be increased through re-negotiation and formalisation of bundles of rights, currently governing access to rangelands and the establishment of boundary plantings with forage trees, according to farmers' preference. The conflict between tree owners and shepherds may be mitigated through enforcement of a zero grazing regime or preferential lease of *habus* land to shepherds.

4.3.5 Conclusions

The study demonstrated that participatory tools, such as the formal acquisition of local ecological knowledge, allow researchers to identify and qualitatively assess fine-scale variation of farming systems at local landscape scale. Along an altitudinal transect from the western lowland plain, to mountain farmland situated north east of Moulay Idriss, the intensity of the production system declined and the tree cover increased with altitude. Analysis of the farmers' local knowledge confirmed increasing climate stress in the study area including recurring drought, flooding and associated erosion events. There were also increased problems associated with uncontrolled browsing of small ruminants and changing market incentives as the major drivers of loss of tree cover.

Farmers of all strata expressed an interest to increase and diversify tree cover. Agroforestry options identified by respondents included the use of trees for better management of water and soil resources, targeted extension services and improved animal husbandry. The fine scale variation of farming systems documented in the study implied that provincial level assessments (Direction Provinciale de l'agriculture de Meknes, 2007) did not capture farming conditions at a sufficiently detailed scale to enable the design of stakeholder specific extension activities. This is an increasingly common problem that has been identified in many farming systems (Coe *et al*., 2014). Research towards an improved understanding of existing agroforestry practices and agroforestry options, such as within farming systems of northern Moroccan smallholders, is a vital first step towards ensuring political and institutional support to increase farming system resilience.

The characterisation of farming systems, such as provided by this study, can help guide the conception and operation of extension activities. Combined with farmers' local knowledge about local tree cover dynamics, it improve our understanding of farmers' exposure, sensitivity and adaptive capacity to social, economic and environmental hazards, trends and disturbance.

Promotions of agroforestry or other interventions are unlikely to succeed if they remain unaccompanied by the development of an enabling environment. Results from the study indicate that improved resilience of agricultural production in the case study site in Morocco is unlikely without substantial institutional support and public investment. Farmers were constrained by their limited livelihood assets; particularly a lack of financial and social capital, as it prevents investment into farm and community infrastructure and prevents collaboration, required to enhance farmers' market capacity, address landscape scale land use impacts and facilitate local governance of scarce water resources.

4.4 Crop production under different conditions in agroforestry parkland systems

The aim of this ICRAF study was to gain more understanding about plant-soil-atmosphere interaction and how the trees and annual crops adapt to current climate variability and future climate change. The study is also reported in the following publication:

> Coulibaly, Y.N., Mulia, R., Sanou, J., Zombré, G., Bayala, J., Kalinganire, A., van Noordwijk, M. (2014). Crop production under different rainfall and management conditions in agroforestry parkland systems in Burkina Faso: observations and simulation with WaNuLCAS model. *Agroforestry Systems* 88:13–28. DOI 10.1007/s10457-013-9651-8

4.4.1 Observations and simulation with WaNuLCAS model

This study was conducted in three different climatic sites (Tougouri, Nobéré, and Soukouraba) in the Burkina Faso in the Sahel. Soukouraba has an average precipitation of 1061 mm whilst Nobéré has 859 mm. Tougouri has the lowest precipitation (557 mm). All measures of precipitation were based on the mean rainfall between 1980 and 2011. Similar to many parts of the NMCs and SMECs this system has been under increasing risk of desertification driven by loss of vegetation cover. The reason for the initial removal of vegetation varies, but the two dominant reasons are a) human activity – cutting down trees to allow more grazing, or over-grazing of land by farmed animals (similar to areas of North Africa) and b) climate change – warming of air temperatures and decreases in precipitation can cause drought conditions and prevent the sustained growth of vegetation (common to the whole Mediterranean basin).

As part of the study, the WaNuLCAS (Water, Nutrient and Light Capture in Agroforestry Systems) model was used to assess the impact of different crop management and climate scenarios to the growth of trees and annual crops in the systems (van Noordwijk *et al*., 2011). The simulation results were compared to experimental data. The observed parklands of each site involved three different tree species (baobab (*Adansonia digitata* L.), néré (*Parkia biglobosa* (Jacq.) Benth), and karité (*Vitellaria paradoxa* C. F Gaertn)) associated with sorghum annual crops (*Sorghum bicolor* (L.) Moench). The data of crop growth (represented by final biomass, yield, and harvest index) in year 2011 was used for model validation. The simulated scenarios were to assess the effect of mulching, tree pruning, density, and types of tree rooting system as well as the effect of rainfall amount and pattern to crop and tree growth.

4.4.2 Field data analysis

Site (water or rainfall amount) effect: crop biomass and yield were higher in Soukouraba and Nobere than in Tougouri. However the highest harvest index (i.e. ratio between yield and biomass) was found in the driest site (i.e. Tougouri). This indicates that in the dry condition where water became the most limiting factor for growth, the sorghum allocated a higher proportion of reserves to grain than to leaves. Similar results have been reported by Wenzel *et al*. (2000) in sorghum and by Bunce (1990) in soybean.

Tree species (shading) effect: Sorghum growth was inferior when associated *Parkia biglobosa* that has denser canopy than the two other species. Similar results have also been reported by Bayala *et al*. (2002), Bazié *et al*. (2012), Jonsson *et al*. (1999), Kater *et al*. (1992), Kessler (1992) and Sanou *et al*. (2012). The *Parkia biglobosa* canopy can reduce light by 62–80% (Bayala *et al*., 2002; Jonsson *et al*., 1999; Kessler, 1992). This is a greater proportion than the 40-65% by baobab (Belsky *et al*., 1989, Sanou *et al*., 2012) and 53% reported for *Vitellaria paradoxa* (Bayala *et al*. 2002).

Distance (shading and microclimate) effect: in Nobere and Soukouraba, the crop growth was generally higher with distance from the tree trunk. One reason for this could be that shading by the tree reduces higher crop performance. The same evidence was found by Bayala *et al*. (2002), Boffa *et al*. (2000), Kessler (1992), and Sanou *et al*. (2012). In Tougouri however, crop growth tends to be higher in the areas under tree shade. Bayala *et al*. (2012) also reported that cereal yield was higher in the parkland than in monoculture when precipitation was less than 800 mm, as in the case of Tougouri. This indicates that the shading effect by the adjacent tree can to some extent be compensated by a better microclimate condition under tree shade.

4.4.3 Simulation results

Effect of long-term cropping and mulching: model simulation with slow growing (i.e. late maturing) sorghum shows that crop growth is stable during the long-term simulation even without mulching application. This indicates that, due to the slow nutrient extraction by the annual crops, trees have enough time to replenish soil organic matter through litterfall and fine root decay. Simulations with medium and fast growth sorghum varieties show the decrease in crop performance across simulation years despite the regular mulching application. Long-term cropping with these kinds of sorghum variety needs more external nutrient inputs.

Effect of tree density and pruning: the annual crops exhibited better performance when associated with pruned trees in any of the simulated tree densities. This indicates that tree density in the parkland systems could be increased as long as accompanied by regular pruning application.

Effect of rainfall amount: when the crop was grown with mature trees that have large, wide and dense canopy, and the leaf area index of tree canopy was set to be fixed across simulation time, there is no significant effect of change in rainfall amount to crop growth. In contrast, when the leaf area index of tree canopy is set to be dynamic, crop growth was predicted to be better in drier than wetter condition. This is because in drier condition, trees adapt to the lack of soil water by reducing canopy density and as consequence there is less shading to adjacent crops, and vice versa. Therefore, although the data from the field experiment in 2011 showed that crop growth was higher in Soukouraba and Nobere (which had more rainfall than Tougouri), under certain conditions, for example when tree canopy is sensitive to water condition, reduced rainfall does not necessarily result in lower crop growth.

Effect of rainfall pattern: changes in rainfall pattern during the growing season do not greatly affect crop growth as long as it can be buffered by soil moisture. Trees play an important role in the water balance through rainfall interception and evapotranspiration (Breman and Kessler, 1995; Ong *et al*., 1996; Ong and Swallow, 2004) as well as soil infiltration and ground water recharge (Ilstedt *et al*., 2007), that enhance soil water buffering.

Effect of the depth of tree root system and hydraulic lift: the models showed that trees with root systems that are able to transport water from low levels in the soil towards to soil surface (hydraulic lift) are able to develop denser canopies. As a consequence, although adjacent crops can to some extent use the soil water transferred by the tree root system into superficial layer, the denser tree canopy can reduce crop growth, so that crop growth is lower with trees that perform hydraulic lift than those without. Indeed, under dry soil conditions, trees that performed hydraulic lift developed the highest leaf area index. But when the root system is located in deeper horizons, the trees cannot exploit the high fertility in the upper soil layers and therefore grow slowly and display less severe shade (van Noordwijk et al. 2012). It can be recommended to pay specific attention to species root architecture when they are being promoted to reclaim degraded lands. Tree species which perform this hydraulic function and have deep rooting system are mostly recommended for high aridity environments.

5. Discussion and conclusions

The primary aim of this report was to compile information about different examples of agroforestry innovations in areas bordering Europe, such as the wider Mediterranean, that could inspire future agroforestry solutions for Europe in the context of climate warming for the AGFORWARD project.

Agroforestry systems in the Southern and Eastern Mediterranean Countries have similarities but also key differences with agroforestry systems in Europe. Unfortunately one of the key attributes is that these systems are generally understudied. In many cases there is not currently enough information present about the agroforestry systems in the Southern and Eastern Mediterranean to make recommendations.

Many of the agricultural systems associated with the Southern and Eastern Mediterranean are under threat. In both the NMCs and the SEMCs, climate change will have significant effects in the near future. This has implications for existing agroforestry systems, particularly for high value agroforestry systems such as rain-fed olive systems. The climate analogue methodology makes a strong case for looking more closely at the adaptation potential of these systems and also, when used in combination with the climate models, offers some spatially explicit information on potentially both when and where climatic thresholds may be reached. The potential threat to traditional rain-fed olive production systems, for example, is likely to have significant ecological and socio-economic consequences across the region suggesting that we should focus on the role of high nature agroforestry systems in these environments to increase resilience.

5.1 Resilience

Findings from the participatory research in Morocco suggested that all the farmers expressed an interest to increase and diversify tree cover. Agroforestry options identified by respondents included the use of trees for better management of water and soil resources, targeted extension services and improved animal husbandry. There was recognition that the climate was changing (resulting in the loss of fruit trees). As reported by Shilling *et al.*, (2012) “to increase resilience against climate change, agricultural policies should shift from maximizing agricultural output to stabilizing it”.

The WaNuLCAS Modelling in Burkina Faso described the important role of perennial plants such as trees in parkland systems to help agricultural systems adapt to climate change. They can enhance the buffering of soil water content, maintain conducive microclimate conditions around adjacent crops, and supply organic matter through litterfall and root decay.

The work suggested that once certain climate thresholds are reached then agroforestry is likely to be able to provide significant benefits to crops grown in association with the trees through provision of a favourable microclimate and by increasing soil health. Agroforestry systems thus represent effective tools to increase the resilience of systems at risk of desertification.

5.2 Fine scale variation

At the Zerhoun study site in Morocco, the farmers had to make decisions in a complex constantly evolving environment where there are a multitude of interacting factors and trade-offs between various opportunities and constraints. Understanding the context is critical for developing appropriate resilience strategies (van Ginkel *et al*., 2013). The analysis suggest that if national schemes seeking to implement agroforestry, such as the Plan Maroc Vert in Morocco is to be successful, then there is a need to capture the fine scale variation of farming systems. The study demonstrated that participatory tools, such as the formal acquisition of local knowledge, allow researchers to identify and qualitatively assess fine scale variation of farming systems at local landscape scale.

This need for fine-scale assessment suggests that there is also a need for better institutional support for decision making about agroforestry at small scales. For example, are the organisations wishing to promote agroforestry in Europe able to capture variation in farming conditions at a sufficiently detailed scale to enable the participatory design of stakeholder specific extension activities?

5.3 Institutional capacity

This study of agricultural systems in Southern and the Eastern Mediterranean suggest that the promotion of agroforestry is unlikely to succeed unless accompanied by the development of an enabling environment. Agroforestry land use systems are resource efficient and functionally diverse, but benefits from agroforestry will often only be realised in an enabling context, where these practises are compatible with the local biophysical constraints, and other land use or livelihood objectives. Results from the Zerhoun study indicate that improved resilience is unlikely without substantial institutional support and public investment. Agroforestry interventions need to be embedded in a conducive policy, market and institutional environment (Coe *et al*., 2014; Mbow *et al*., 2014).

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