Avian Land-Use Associations in the Eastern Mediterranean

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Contents

Abstract

Land-use change and associated habitat loss and species invasions are two of the greatest threats to global biodiversity. In Europe, changes in farmland management practices driven in part by the European Union (EU) Common Agricultural Policy (CAP) have caused dramatic declines in associated biodiversity. This thesis studied avian land-use associations to understand the relative importance of different habitat and landscape elements to the farmland bird community, with particular emphasis on priority species for conservation, in Cyprus, a recently acceded EU Member State, as a case study for the eastern Mediterranean. Results provide the first evidence base to inform CAP agri-environment measures in the region. A wide range of habitats and land-uses were important for bird species and assemblages and local habitat diversity was of key value. Farmland habitats, particularly viticulture and groves, and remnant scrub were the most important, demonstrating the high value of heterogeneous farmland mosaics to breeding and wintering avian biodiversity in Cyprus. The area of land under agriculture in Cyprus has substantially decreased, with much of this attributable to declines in marginal low-intensity crops on which much avian biodiversity depends. Building development appears to be one important driver behind these trends. Changes observed in the distributions of Sardinian Warbler *Sylvia melanocephala*, a recently established breeder in Cyprus, and the endemic Cyprus Warbler *Sylvia melanothorax* are more likely mediated by changing land-use patterns relating to grazing intensity of scrub, as there was no evidence of competitive displacement. The complex Mediterranean farmland mosaic was created by traditional farming practices that are usually economically marginal. Agri-environment mechanisms to support this heterogeneity are necessary for effective conservation of priority species and bird biodiversity in the eastern Mediterranean.

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Chapter 1

Introduction


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1.1 Environmental change and the value of studying avian land-use associations

Human-induced environmental change drives changes in species distributions and abundances (Parmesan & Yohe 2003), while land-use change is considered the greatest cause of global biodiversity loss (Sala *et al.* 2000, Millennium Ecosystem Assessment 2005). Changing land-use not only results in loss of habitat, but can facilitate species invasion, which in itself constitutes another major threat to biodiversity (Didham *et al.* 2007). These major anthropogenic developments represent some of the most serious challenges to which conservation in the twenty-first century has to rise. One way of doing so is through the study of species–habitat and species–land-use associations, which can provide valuable evidence to inform conservation action and influence land management to benefit biodiversity in the face of environmental change.

The use of birds as surrogates for biodiversity is contentious, with evidence suggesting that birds perform poorly when compared to other taxa (e.g. Lund & Rahbek 2002, Moore *et al.* 2003, Williams *et al.* 2006, Wolters *et al.* 2006). This is partly due to the scale at which different biodiversity elements respond, with the highly mobile habits of wide-ranging bird species making them weak predictors of small-range or sedentary taxa such as plants and invertebrates (Wolters *et al.* 2006, Eglington *et al.* 2012). However, birds show population responses to environmental change, which can reflect changes in other animals and plants (e.g. Benton *et al.* 2002, Robinson & Sutherland 2002, Thomas *et al.* 2004), particularly at larger spatial scales and in heterogeneous landscapes (Eglington *et al.* 2012). Despite reservations in their value as surrogates, a greater degree of understanding is available for bird populations, distributions and habitat and land-use associations than for other elements of biodiversity, as they are easily surveyed and have broad public appeal (Gregory *et al.* 2008, Larsen *et al.* 2012). Avian biodiversity forms one of the most important parts of the European Union (EU) biodiversity policy framework and the EU biodiversity strategy to 2020 (European Commission 2011a), in the form of the Birds Directive (European Commission 2009a), an instrument with real statutory power. Furthermore, trends in farmland birds have been adopted by the EU as a proxy for the conservation status of farmland and as an indicator of sustainable development, in the form of the European Farmland Bird Index (Gregory *et al.* 2008). Consequently, birds have the potential to drive biodiversity policy and conservation effort, particularly in a European context.

1.2 Agricultural land-use change in Europe and effects on avian biodiversity

Of the global land area, 38% is under agriculture (including cropland and permanent pasture: The World Bank 2012) and, in those regions with a long history of agriculture, a non-trivial proportion of the biodiversity that remains is found in farmed landscapes. This may be because farmland supports the highest densities of species or the greatest absolute numbers of individuals compared to other habitat types, or because species may depend on farmland, as low-intensity land-use often substitutes for lost natural ecological processes (Wright *et al.* 2012). In Europe, where agriculture has transformed the natural landscape over millennia (Donald *et al.* 2002), more than 45% of land area is under agriculture (European Environment Agency 2006) and it is estimated that more than half of European species use farmland habitats (European Environment Agency 2005). For example, the most important habitats for butterfly species are anthropogenic (van Swaay *et al.* 2006) and high natural value (HNV) agricultural habitats host numerous bird species (Bignal & McCracken 1996, Donald *et al.* 2002). This biodiversity is threatened by changes in land-use (Stoate *et al.* 2001, Sirami *et al.* 2008, Stoate *et al.* 2009, Flohre *et al.* 2011, Warren & Bourn 2011), with 62% of bird species of European conservation concern (SPEC) associated with agricultural habitats, more than any other habitat type (Tucker & Evans 1997).

Agricultural land-use change is driven by a variety of interacting factors, including world supply and demand, technology, input prices, national and international policy and trade agreements, social, cultural and demographic change, and the effects of climate change on production (Rounsevell *et al.* 2005, Poláková *et al.* 2011). In Europe, one of the major drivers of agricultural change is the EU Common Agricultural Policy (CAP), which, alongside other economic and technological drivers, has led to profound changes in farm management practices. The CAP has resulted in contrasting intensification and abandonment of traditional low-intensity agriculture, both having negative effects on farmland biodiversity (Donald *et al.* 2002). Agricultural expansion and intensification are now widely seen as the main causes of the widespread declines in farmland bird species' distribution and abundance observed since the 1970s (Fuller *et al.* 1995, Donald *et al.* 2001, Benton *et al.* 2003, Verhulst *et al.* 2004, Green *et al.* 2005, Donald *et al.* 2006, Reif *et al.* 2008, Flohre *et al.* 2011). Farmland abandonment is also considered an important threat to farmland birds in Europe, mainly affecting marginal or mountain areas (Díaz *et al.* 1997, Suárez *et al.* 1997, MacDonald *et al.* 2000, Suárez-Seoane *et al.* 2002, Laiolo *et al.* 2004, Coreau & Martin 2007, Sirami *et al.* 2008).

1.2.1 Regional variation in the effects of land-use change

The land-use features that are important and the mechanisms of the threat differ markedly among regions. Research conducted to date has shown the great importance of habitat heterogeneity to farmland birds and other biodiversity (Weibull *et al.* 2000, Tscharntke *et al.* 2005, Hendrickx *et al.* 2007), with homogenisation contributing to species declines (Benton *et al.* 2003). In northern and western Europe, increased use of fertilisers and biocides, changes in crops and crop rotations, homogenisation of crop structure and loss of non-farmed habitat and boundary features have all contributed to species declines (Robinson & Sutherland 2002, Benton *et al.* 2003, Fuller *et al.* 2004, Newton 2004, Vickery *et al.* 2009).

In Central and Eastern Europe, declines in farmland birds have been linked to the negative effects of management intensity (Verhulst *et al.* 2004, Reif *et al.* 2008). In Poland and the Baltic countries, retention of woody edge vegetation is important for species richness and the abundance of farmland species (Herzon *et al.* 2008, Sanderson *et al.* 2009). In contrast, the creation of boundary features and increased landscape heterogeneity has caused declines in farmland birds in Hungary (mostly comprising grassland species), a country with a long history of large-scale extensive grassland management (Batáry *et al.* 2007, Báldi & Batáry 2011).

As in other parts of Europe, farmland birds in western Mediterranean landscapes have declined as a result of agricultural intensification (Suárez *et al.* 1997, Stoate *et al.* 2001, Suárez *et al.* 2003, Brotons *et al.* 2004). Moreover, homogenisation resulting from land-use abandonment and development of closed-canopy sclerophyllous forest is likewise a major threat to numerous open-habitat species associated with complex traditional human landscapes (Preiss *et al.* 1997, Suárez-Seoane *et al.* 2002, Laiolo *et al.* 2004, Coreau & Martin 2007). It has even been suggested that abandonment of farmland in Mediterranean Europe is the major cause of declines in avian diversity in this region (Farina 1995, 1997).

1.2.2 Mechanisms to mitigate biodiversity loss in farmland

Successive reforms of the CAP, which accounts for about 40% of the EU budget (European Commission 2007), sought to mitigate its impacts on biodiversity. Restructuring of CAP mechanisms since the 1980s and 1990s has meant that direct subsidies, Pillar I of the CAP (72% of CAP budget: Atkin 2011), have been decoupled from agricultural production, and linked to compliance with rules for meeting environmental, public health and animal welfare standards (cross-compliance). In addition, agri-environmental measures, which support environmentally friendly farming practices, are a major component of Pillar II, the Rural Development Programme (RDP: European Commission 2007). The RDP is co-financed by the EU and the Member States and the relative expenditure allocated to agri-environment measures and other RDP components varies among Member States (Gay *et al.* 2005). Although subsidy decoupling, cross-compliance and agri-environment measures are aimed at environmental and biodiversity conservation, their effectiveness has been heavily criticised, mainly owing to poor implementation and lack of funding (European Court of Auditors 2005, BirdLife International 2008, European Court of Auditors 2008, Boccaccio *et al.* 2009).

Despite a recent resolution adopted by the European Parliament, which states that the CAP should be a key mechanism for biodiversity conservation in addition to food production and rural development (European Parliament 2012), proposals for the upcoming CAP reform (European Commission 2011b) have caused disappointment among biodiversity conservation advocates (see BirdLife International 2011, IEEP 2011). Although reform proposals include a compulsory 'Greening Payment' under Pillar I that requires 'enhanced' cross-compliance, which has the potential to benefit biodiversity, there are no provisions for minimum expenditure on agri-environment measures (BirdLife International 2011) and it has been argued that 'greening' may result in farmers opting out of agri-environment measures in response to increased environmental and biodiversity obligations under Pillar I (EFRA 2012). Criticism has also been directed towards the lack of obligatory support for farmland within or neighbouring Natura 2000 areas (a EU-wide network of nature protection areas encompassing valuable and threatened habitats and species: European Commission 2009b) and continued inadequate support for HNV farmland through 'less favoured area' funding, which reflects geographical location rather than agricultural management practices (BirdLife International 2012).

Agricultural intensification and abandonment meanwhile continue to pose major threats to European biodiversity (Stoate *et al.* 2009, Poláková *et al.* 2011). Agri-environment measures form the main policy mechanism for mitigating farmland biodiversity decline. Their implementation is obligatory, although each Member State develops its own set of voluntary schemes (Poláková *et al.* 2011). The effectiveness of agri-environment measures is controversial (Kleijn *et al.* 2001, Kleijn & Sutherland 2003, Kleijn *et al.* 2011) and varies with landscape context (Batáry *et al.* 2011, Concepción *et al.* 2012). However, it is argued that well-planned and well-implemented measures can be effective in halting or even reversing biodiversity declines (Poláková *et al.* 2011) and such measures have been successful (e.g. Peach *et al.* 2001, Perkins *et al.* 2011, Whittingham 2011). EU enlargement has increased the rate of agricultural land-use change in new Member States brought under the CAP (Stoate *et al.* 2009), but has also extended agri-environment measures to these countries. Region-specific evidence is necessary to optimise these measures and ensure their effectiveness (Báldi & Batáry 2011, Tryjanowski *et al.* 2011).

Agri-environment measures follow a 'land-sharing' approach, whereby environmentally friendly practices seek to meet food production and biodiversity conservation goals on the same land. However, agri-environment measures and the low-intensity agricultural practices that the EU RDP seeks to maintain usually result in lower yields of production that necessitate the use of larger areas of farmland (Phalan *et al.* 2011a). 'Land-sparing' is an alternative approach to tackling biodiversity loss in the agricultural landscape, through increasing intensification and

Figure 1.1. *The location of Cyprus in the eastern part of the 'Mediterranean Forests, Woodlands and Scrub' ecoregion of the Palearctic (shaded; source: The Nature Conservancy 2012).*

yield in parts of the land while releasing other parts from production as conservation land (Green *et al.* 2005). These contrasting strategies are subject to extensive debate (e.g. Fischer *et al.* 2011, Phalan *et al.* 2011b), with proponents of land-sparing arguing that integration of food production and biodiversity conservation compromises both goals (Phalan *et al.* 2011a), and critics contesting that separation of the two is too simplistic and ignores the complexity of land systems (Tscharntke *et al.* 2012). In practice, land-sparing in Europe would amount to 'rewilding' of marginal or abandoned agricultural land, that is restoration of natural, non-farmland habitat (Navarro & Pereira 2012), while intermediate strategies or combining elements of both land-sparing and -sharing have also been suggested (Fischer *et al.* 2008, Adams 2012, Benayas & Bullock 2012).

1.4 The eastern Mediterranean and Cyprus as a case study

Cyprus joined the EU in 2004, but there is little understanding of agricultural land-use change in this, the easternmost New Member State. Although bird–habitat associations have been extensively researched in north-western Europe and the western Mediterranean (see above), there is scant understanding in the eastern Mediterranean (Tryjanowski *et al.* 2011, but see Kati & Sekercioglu 2006). Although the entire Mediterranean Basin is part of a single ecological region (in one study called 'Mediterranean Forests, Woodlands and Scrub': Olson *et al.* 2001; Fig. 1.1), the eastern parts differ in climate from the western and central areas in that they experience longer summer droughts (Vogiatzakis & Griffiths 2008). They also host distinct flora and fauna (Covas & Blondel 1998, Blondel & Aronson 1999, Moreira & Russo 2007). Mediterranean biodiversity in the Palearctic derives from many biogeographic regions as a result of the geographic location of the Mediterranean Basin, which also places it along major bird migration routes, resulting in high avian biodiversity (Covas & Blondel 1998). The Mediterranean Basin has been identified as a biodiversity 'hot-spot' (an area which combines exceptional biodiversity and endemism with high levels of threat: Myers *et al.* 2000), but biodiversity across the region is not uniform. There are two major areas of richness in the Mediterranean: one in the western and one in the eastern part, the latter including Cyprus, the third largest Mediterranean island (Médail & Quézel 1999). The eastern Mediterranean hosts distinct avifauna, with Middle Eastern and Asian influences on bird biodiversity (Blondel 1991, Covas & Blondel 1998, Moreira & Russo 2007).

1.4.1 Pre-human fauna and flora

During the Pleistocene period, Mediterranean island fauna and flora were determined by the fluctuating climate, with forests dominating during interglacials and steppe grassland or semi-desert during the last glacial maximum c. 18,000 years ago (Mannion 2008). The ancient and profound anthropogenic impacts on Mediterranean landscapes make it difficult to determine the structure of vegetation during the current interglacial, prior to human colonisation, while limited paleobotanical data exist from the islands (Tzedakis 2007). Pollen records show that the northern and western parts of the region were forested, but it is unlikely that closed forests ever established in the southern and eastern Mediterranean, potentially due to human activities (Tzedakis 2007). Though Neolithic man caused large-scale deforestation in the Mediterranean Basin for settlement and agriculture (Blondel 2006, Navarro & Pereira 2012), there is confounding evidence that at the time increasing summer aridity was also having a negative effect on woodlands (Tzedakis 2007). Data from Cyprus are rare, but it is presumed that much of the island was covered by Mediterranean evergreen sclerophyllous forest, with maquis dominating the more arid lowlands (Simmons 1999).

During the glacial–interglacial cycles of the Pleistocene, there would also have been major changes in the faunal assemblages of the Mediterranean Basin, although most evidence is from the mainland (Blondel & Aronson 1999). The distance from the mainland and the existence of land bridges had an important effect on the animal species that were able to colonise the islands. Cyprus, for example, was never connected to the mainland, as it was of oceanic origin, and had an impoverished fauna as a result (Marra 2005). The most notable Pleistocene mammals were the endemic pygmy hippopotamus *Phanourios minutus* and pygmy elephant *Elephas cypriotes* (Simmons 1999), the ancestors of which swam to Cyprus from the mainland (Reyment 1983). Dwarfism of island mammals was an evolutionary response to the absence of predators and the limited resources available (Burness *et al.* 2001). The pygmy hippopotamus, which dominates the fossil record of Cyprus, most probably foraged in scrubland habitats, as it showed morphological adaptations for walking on mountainous terrain, browsing, and reduced dependency on water (Simmons 1999).

The arrival of humans on the island c. 10,500 years ago coincided with the extinction of the pygmy hippopotamus and pygmy elephant. The extinction of Mediterranean island endemic mammals has been variously attributed to anthropogenic or climatic factors, as well as a combination of the two, but uniquely in Cyprus there is direct evidence that hunting by early settlers was the cause (Simmons 1999). In Cyprus, as in the other islands of the Mediterranean Basin, humans introduced livestock (cattle, sheep and goats) and game species, including moufflon *Ovis orientalis*, Persian fallow deer *Dama mesopotamica*, and wild boar *Sus scrofa* (Simmons 1999), which would have replaced the endemic mammals in their role of maintaining patchy vegetation structure (Blondel 2006).

1.4.2 Agricultural landscapes

Much variation exists in the cultural as well as the natural landscapes of the Mediterranean Basin, with the history of human impact, and agriculture in particular, having shaped and continuing to shape the landscape structure (Grove & Rackham 2001, Vogiatzakis *et al.* 2008). Climatic and topographic constraints alongside the high degree of fragmentation of farmland in the Mediterranean have resulted in the later onset and slower rates of agricultural development in the region compared to north-western Europe (Potter 1997, Lains & Pinilla 2009), as well as the prevalence of agricultural abandonment described in the previous section (Grove & Rackham 2001, Vogiatzakis *et al.* 2008). These constraints are presumably greater in the eastern Mediterranean, which suffers the most limiting climate and where agriculture is dominated by very small (< 5 ha) agricultural holdings (FAO 2010).

There is a gap in knowledge regarding environmental change and ecosystem response in the eastern Mediterranean (Vogiatzakis *et al.* 2006). Cyprus is a valuable case study for the region, as it is representative in terms of climate, physical landscape and of the agricultural holding patterns that characterise the eastern Mediterranean in general, as well as the main crop types cultivated in surrounding countries (Fig. 1.2; FAOSTAT 2012). However, a much larger proportion of farmland in other eastern Mediterranean and Middle-eastern countries is dedicated to pastoral activities (Fig. 1.2), probably owing to their more arid climates or greater extent of mountainous topography. The low proportion of pasture in Cyprus is also a result of legislation in 1935 that greatly limited free-range grazing on the island (Christodoulou 1959). The proportion of free-range livestock (sheep and goats) in Cyprus remains low today and the shift

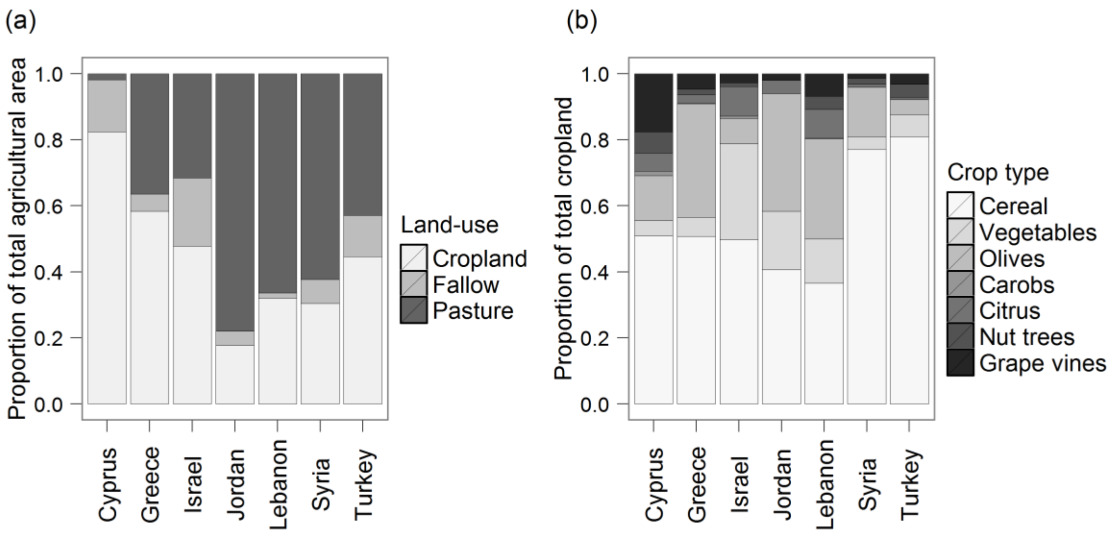

Figure 1.2. *Composition of agricultural land area (a) and of area of crops harvested (b) in Cyprus and its neighbouring eastern Mediterranean countries according to FAOSTAT data for 2007.*

in husbandry practices to tethering (Economides 1997) has probably had a profound effect on scrubland structure. The Greek islands of the Aegean Sea and the south-western coastal regions of Turkey are likely to be more similar in agricultural landscape and structure to Cyprus than suggested by the aggregate country-wide data reported by FAOSTAT. However, accession of Cyprus to the EU in 2004 places it in a different political and economic context to its neighbours apart from Greece (with the partial exception of Turkey, for which EU accession negotiations began in 2005).

1.5 Thesis background

1.5.1 Research approach

The use of empirical models to understand associations with habitats and land-uses is a key tool in ecological research and biodiversity conservation, as they allow inferences to be made about the effects of environmental change. Such models involve relating information about the species or community under study to predictor variables relating to the habitat or land-use, often in a Generalised Linear Model framework (Guisan & Thuiller 2005). Models with large numbers of predictors are simplified in order to achieve the most parsimonious model. Selection of the minimum adequate model can be carried out using a stepwise multiple regression approach, whereby the significance of predictor variables in the model is evaluated by their successive removal or addition, or by employing an information theoretic approach, which identifies multiple models that perform equally well. Stepwise modelling has been criticised in the literature, as it results in a perceived "best" model when in fact different sets of predictors can explain the observed data with a similar goodness-of-fit, and the algorithm used to carry out the model simplification as well as the order of variable removal or addition can affect the selected minimum adequate model (Whittingham *et al.* 2006). As a result, the information theoretic approach is advocated and increasingly adopted in ecology and evolution research (Johnson & Omland 2004, Grueber *et al.* 2011).

Bird–habitat models require good quality data on bird incidence or abundance. The survey methods adopted in this study account for differences in detectability (the probability of detection) among habitats by employing a Distance Sampling approach (Buckland *et al.* 2001). This approach allows comparisons of relative abundance to be made across habitats and land-uses, while addressing potential confounding effects of detectability. Sampling was carried out along line transects for efficiency and for robustness to violations of Distance Sampling assumptions (Buckland *et al.* 2008) and line transect length (500 m) was selected to capture the fine-scale heterogeneity of the Cyprus landscape. Although the selected length optimised detection of small to medium-sized bird species, it was not effective for the survey of wide-ranging species, such as raptors, which are usually surveyed by covering larger distances (Andersen *et al.* 1985, Boano & Toffoli 2002).

The relative importance of different habitat and landscape elements to bird species is predicted to differ between the breeding and non-breeding season (Block & Brennan 1993), owing to contrasting resource requirements between chick provisioning and non-breeding subsistence, seasonal changes in resource availability, changing trade-offs between foraging opportunity and predator risk, or requirements for thermal shelter in winter (Wilson *et al.* 2005). However, most work examining habitat associations of farmland birds in Europe has focused on the breeding season, with studies in winter largely restricted to western Europe (e.g. Robinson & Sutherland 2002, Suárez *et al.* 2004, Siriwardena *et al.* 2007, Suárez-Seoane *et al.* 2008, but see Geiger *et al.* 2010). In this study, therefore, we consider both breeding and wintering assemblages in one year (2009–2010).

Short-term studies such as this cannot confidently be trusted to provide the same level of insight and understanding that can be achieved through analysis of long-term datasets (e.g. Perkins *et al.* 2012). Species populations show inter-annual variation in addition to long-term trends, such that low sample sizes may be achieved for some species in some years. Nevertheless, studies in a single breeding or wintering season can provide powerful data on a large sample of species. Although habitat associations may change in a density-dependent manner in response to changing population size driven, for example, by weather or other demographic variation (Kluyver & Tinbergen 1953, Brown 1969, Gill *et al.* 2001), at the scale of habitat and landscape elements considered in this study any such changes are likely to be subtle and to not undermine conclusions regarding the relative value of land-uses. Detailed work on the effects of within-field management practices, such as fertiliser and biocide application, timing of cultivation and tillage and boundary feature management, on the productivity of individual species leads to understanding the mechanisms behind species declines (e.g. Green & Stowe 1993, Wilson *et al.* 1997, Hart *et al.* 2006, Moorcroft *et al.* 2006) and enables targeting, assessment and evaluation of agri-environment measures (e.g. Vickery *et al.* 2004, Vickery *et al.* 2009, Whittingham 2011, Baker *et al.* 2012). However, fine-scale assessment of the effects of within-field management practices was beyond the scope of this study. They will be required to develop further the evidence in support of prescriptions, and ultimately to test their efficacy, but the starting point in the eastern Mediterranean required some more basic and fundamental assessment before this can take place. This study represents the first assessment of how bird assemblages, species composition and abundance differ among land-uses and landscapes in the region. A relatively coarse-grain, overview approach was necessary in order to achieve a baseline dataset for Cyprus, which will inform further studies and monitoring on the island and also provide a blueprint for future work in the wider region.

1.5.2 Objectives

The overarching aim of this thesis was to provide the first elements of an evidence base to inform the development of appropriate instruments for avian conservation in the rapidly changing farmed landscapes of Cyprus. As Cyprus is the largest island in the eastern Mediterranean, this can provide an evidence base for appropriate agri-environment measures in the wider region. Given the diversity of crop types and land-uses, and the lack of any previous quantitative or even qualitative study evaluating their relative importance, a fundamental aim was to determine what land-uses and what landscapes are important for which bird species. Differences in bird assemblages and species composition will be compared among habitats (defined as local-scale habitat and land-use type) and among landscapes (considered in terms of relative land-cover composition). Effects of land-use and landscape structure on Species of European Conservation Concern (SPEC: BirdLife International 2004) and characteristic Mediterranean species were a particular focus of study. We hypothesised that the local landscape complexity and structural heterogeneity would be valuable to the avian assemblage, due to the juxtaposition of habitats offering contrasting complementary resources.

Anthropogenic change, including land-use and climatic change, can facilitate invasive species with potential knock on effects on specialist and endemic fauna (Parmesan & Yohe 2003, Jetz *et al.* 2007). Within the wider study of avian land-use associations, the opportunity was taken to examine whether there was evidence in support of a negative impact of a recently arrived congener (Sardinian Warbler *Sylvia melanocephala*) on one of the endemic species of the island (Cyprus Warbler *S. melanothorax*). The habitat associations of the two species were identified and compared, and a comparison between habitat associations of Cyprus Warbler in the area of sympatry and beyond the range of Sardinian Warbler was used to assess whether there was any evidence for displacement.

As well as understanding the value of different land-use elements it is important to also understand the trajectory and direction of agricultural change in order to inform the development of appropriate policies of mitigation. An important additional aim, therefore, was to use agricultural census and survey data, collected by the government of the Republic of Cyprus, to examine changes in the areal extent of major crop types, fallow and abandoned land, crop diversity and field size.

1.5.3 Thesis structure

The thesis begins (Chapter 2) with a study of the breeding-season habitat associations of the endemic Cyprus Warbler and the closely related and recently established Sardinian Warbler as a model for mechanisms of species invasion.

Chapters 3 and 4 investigate the multi-scale land-use associations of the Cyprus farmland bird community in both breeding and winter seasons. Chapter 3 examines the whole bird assemblage, grouping species into categories defined by habitat requirements, while Chapter 4 concentrates on the community structure and on individual species identified as priorities for conservation.

Chapter 5 examines the nature of agricultural change in Cyprus in the last four decades. Finally, Chapter 6 summarises the thesis findings and their implications for farmland birds and agricultural policy in Cyprus and the eastern Mediterranean, and suggests directions for future work.

The four results Chapters (Chapters 2–5) are written in the form of scientific papers. At the time of submission, Chapter 2 was published (Ieronymidou *et al.* 2012), Chapter 3 is awaiting revision prior to resubmission and Chapter 4 is presented as a manuscript in preparation.

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Chapter 2

Endemic Cyprus Warbler *Sylvia melanothorax* and colonizing Sardinian Warbler *Sylvia melanocephala* show different habitat associations

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Sardinian Warbler © A. Trepte

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2.1 Abstract

Anthropogenic habitat change and assisted colonization are promoting range expansions of some widespread species with potential consequences for endemic fauna. The recent colonization of Cyprus by breeding Sardinian Warblers *Sylvia melanocephala* has raised concerns that it might be displacing the closely related and endemic Cyprus Warbler *Sylvia melanothorax*. Habitat associations of both species were examined using models of abundance within the 95% density kernel of the Sardinian Warbler's range and also outside this range for Cyprus Warbler. Within the Sardinian Warbler's range, the two species were associated with subtly different scrub habitats. Outside the Sardinian Warbler's range, the Cyprus Warbler differed again in its habitat association, but this probably resulted from marked differences in habitat extent and availability in different parts of the island rather than from competitive displacement, as none of the habitat or land-use elements differentially associated with Cyprus Warblers was positively associated with Sardinian Warbler occurrence. This suggests that Sardinian Warbler has exploited a different niche, rather than displacing the endemic species, and has perhaps benefitted from changing land-use patterns, particularly recent fallows and abandoned agriculture, in contrast to the stronger association of Cyprus Warblers with semi-natural scrub.

2.2 Introduction

Many species are undergoing range changes in response to changing climate and land-use (Parmesan & Yohe 2003), including many bird species (e.g. Thomas & Lennon 1999, Carrillo *et al.* 2007, Jetz *et al.* 2007). Colonization of new regions is often facilitated by human activity through deliberate or accidental introduction and through anthropogenic habitat change. For example, Australian species such as White-faced Heron *Egretta novaehollandiae* and Pacific Swallow *Hirundo tahitica* have colonized New Zealand naturally over the past century as a result of changes in land-use that created suitable conditions for their establishment (Clout & Lowe 2000). In Europe, the Black-shouldered Kite *Elanus caeruleus* is expanding its range because of land-use change in the Iberian Peninsula (Balbontín *et al.* 2008). Such changing distributions alter local species composition and thus may have adverse consequences for species with restricted ranges through predation, spread of disease, niche displacement or interspecific competition (Mooney & Cleland 2001). Where range expansion results in novel contact between morphologically similar congeners that evolved in allopatry, there is the potential for competition through resource depletion, antagonistic interactions and interference, and/or territorial exclusion and displacement (Orians & Willson 1964, Cody 1969).

The Sardinian Warbler *Sylvia melanocephala* is the most widespread *Sylvia* warbler in the Mediterranean, and has been expanding its range since the late 19th century (Fraissinet & Sultana 1997, Bulyuk & Leoke 2010). In 1994, it started to breed in Cyprus, the third largest island in the Mediterranean, having until then been just a winter visitor (Frost 1994). By 2001 its breeding range covered 600 km^2 in the Pafos district in the west of the island (Pomeroy & Walsh 2002), but its recent extent of occurrence, particularly beyond the Pafos district, was poorly known prior to this study. Elsewhere in the Mediterranean, the Sardinian Warbler coexists with other *Sylvia* species through differential habitat use (Martin & Thibault 1996, Pons *et al.* 2008). Concern has been expressed that novel contact during the breeding season may cause decline of an endemic congener, the Cyprus Warbler *Sylvia melanothorax*, although no significant decline of this species has yet been recorded (Pomeroy & Walsh 2000, 2002, Jones 2006). The Cyprus Warbler is a Category 2 Species of European Conservation Concern (SPEC 2), is listed on Annex I of the EU Birds Directive and has the most restricted range of any species in its genus (Shirihai *et al.* 2001, Burfield & van Bommel 2004). It is widespread across Cyprus and is a partial migrant, with the majority of the population thought to overwinter in the Middle East and northeast Africa (Flint & Stewart 1992). In contrast, the Sardinian Warbler population on Cyprus appears to be sedentary and is perhaps augmented in winter by birds from elsewhere.

Shifts in migratory strategy in response to climate amelioration can give sedentary populations a competitive advantage over migrants through earlier territory settlement (Berthold 2001). Cyprus Warbler and Sardinian Warbler are both species associated with scrub (Shirihai *et al.* 2001) and there is overlap in the habitat types in which they have been recorded in the Pafos district, including semi-natural and agricultural habitats (Pomeroy & Walsh 2000). However, there is evidence to suggest the two species may be selecting subtly different habitat features. The Cyprus Warbler was found to be more numerous than the Sardinian Warbler in low-intensity farmland and in grazed thorny scrub habitats (Pomeroy & Walsh 2000), with no evidence of inter-specific territoriality and no indication that breeding success and nestling condition of one species was affected by the presence of the other (Jones 2006). Ecologically similar species that are competing with one another can coexist through adjustment of the niche of one species in response to the other (Mooney & Cleland 2001); reciprocal removal can demonstrate such niche displacement (e.g. Martin & Martin 2001). Alternatively, niches of possible competitors can be compared between areas where they occur in sympatry and in allopatry. The breeding distribution of Cyprus Warbler and Sardinian Warbler in Cyprus, with Cyprus Warbler found across the island and Sardinian Warbler restricted to the west, allowed us to adopt the latter approach.

The study had the following aims: (1) to quantify the current range and extent of overlap of the two species in the area of Cyprus that is under the direct control of the government of the Republic of Cyprus; (2) to establish the habitat associations of each species across a wide range of land-use and vegetation structures; (3) to compare the habitat associations of the two species to assess evidence of niche overlap; and (4) to assess evidence for niche shift in Cyprus Warbler in the area of sympatry with Sardinian Warbler consistent with the hypothesis of competitive displacement.

2.3 Methods

2.3.1 Site selection

As part of a study of the effects of land-use change, bird surveys were undertaken along line transects at 202 localities, widely distributed across Cyprus (Fig. 2.1). Each locality received a single visit between 29 March and 30 June 2009 to record breeding individuals of both *Sylvia* species, although some migrant Sardinian Warblers may have been recorded in April (Cramp 1992, Flint & Stewart 1992, Shirihai *et al.* 2001). To avoid regional differences being confounded by seasonal effects, we returned to sample each administrative district on three to four occasions within the survey period. Sampling was stratified by district and within each of these, localities for survey were located across the range of land cover types available, including areas of scrub, forest, fallow land and all major cultivation types found on the island (olive, carob and citrus groves, cereals, and viticulture). However, because of the difficulty of surveying the north part of the island where a population of Sardinian Warbler also exists (Pomeroy & Walsh 2002), surveys were conducted in the area controlled by the government of the Republic of Cyprus in the south of the island, with the exception of nine sites in the Mesaoria plain. This flat region, which is predominantly under cereal cultivation, represents a landscape type not found elsewhere on the island. To survey a large number of localities in a season, site selection was constrained to those where vehicle access was possible to within 100 m of the survey start point. A network of farm roads and tracks extends throughout the countryside, providing access to all types of land-use. However, as no reliable maps of this network were available, locating survey start points pre-selected using GIS would have been prohibitively time consuming. Therefore, an element of opportunism was introduced, exploring the network of unmapped farm roads to locate examples of each major land-use type within each district.

The mean distance between nearest localities was 2.7 km (sd = 1.8 km) and no transects overlapped or intersected. In 21 cases (< 11%), survey localities were closer than 1 km to each other (mean distance to nearest locality = 0.68 km ± 0.19) but the shortest distance between

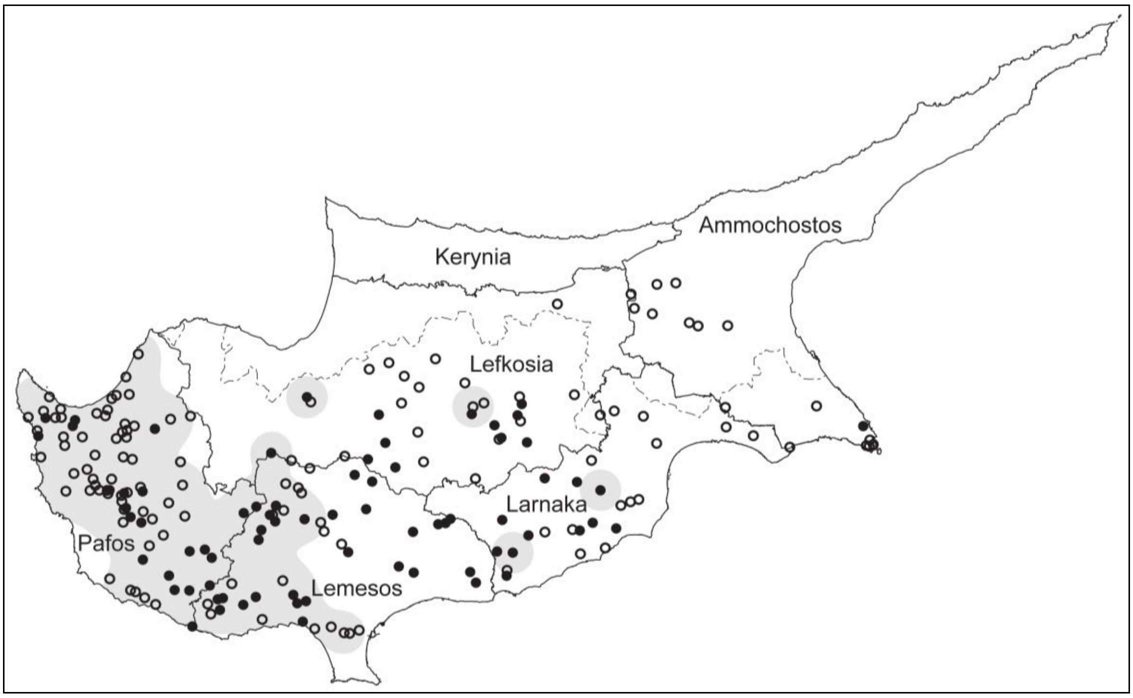

Figure 2.1. *Survey localities on Cyprus. These were spread across the island and included all administrative districts under the direct control of the government of the Republic of Cyprus. Nine localities were situated in other parts of Cyprus (dashes represent the approximate ceasefire line). Sardinian Warbler range, calculated as 95% density kernel (shaded), comprises 123 of 202 survey localities. Cyprus Warbler was recorded at 74 localities (filled circles; open circles indicate not detected).*

these (480 m) was four to six times the length of a Sardinian or Cyprus warbler territory (Jones 2006), so that survey localities could be considered discrete. The elevation of each locality was obtained from the Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM: Jarvis *et al.* 2008) and ranged from 10 to 1695 m, with 44% of survey localities at 249 m or lower, 34% between 250 m and 499 m, 17% between 500 m and 999 m, and 5% at 1000 m or greater.

2.3.2 Bird and habitat surveys

The fine-scale of the heterogeneity of land-uses in Cyprus precluded us from carrying out separate point samples within patches of discrete habitat, so line transects were used. At each survey locality, a 500-m line transect was walked cross-country in as straight a line as possible (unless terrain was impassable) oriented away from any roads and away from the early morning sun to facilitate visibility. The transect length of 500 m was chosen as an appropriate distance over which the fine-scale agricultural heterogeneity of the Cypriot landscape could be captured.

Coordinates of transect start and end points were recorded using a handheld GPS receiver, and waypoints along the transect were recorded automatically at 20-m intervals.

Bird surveys were conducted from 30 min to 3 h after sunrise, recording all birds seen or heard and assigning them to perpendicular distance bands (< 25, 25–50, 50–100 and > 100 m) with the assistance of a laser rangefinder, while walking the transect at a steady pace (mean survey duration = 28 min, sd = 15 min). All surveys were conducted by a single observer (C.I.), experienced in identifying the two species. Most birds were initially detected by auditory cues with the majority then confirmed visually, especially if there was any uncertainty in identification. Female Cyprus Warblers were identified by the presence of under-tail covert markings and absence of red orbital ring. Rüppell's Warbler *Sylvia rueppeli* occur on passage but were scarce (only nine confirmed individuals) and could be identified reliably. Most individuals were detected within 50 m of the transect line (Cyprus Warbler: 81.5%; Sardinian Warbler: 85.5%). Nevertheless, vocalization and therefore detectability could potentially vary among habitats due to differences in predation risk, status (e.g. paired, unpaired), or visibility of the surveyor. This was examined by fitting models of detectability in DISTANCE software (Thomas *et al.* 2009); models for both species had better fit (Cyprus Warbler: ΔAICc = 35; Sardinian Warbler: ΔAICc = 9) when not stratified by land cover type (EU CORINE, Co-ordination of Information on the Environment, Land Cover classes: MANRE 2009). We were therefore confident that detectability did not differ between habitats and data were analysed in terms of the total number of registrations per transect without truncation by distance.

Land-use and habitat features (Table 2.1) were recorded at 11 points along the transect, at the start and end points and at 50-m intervals while retracing the route following completion of the bird survey. At each point, the presence of scrub vegetation, forest and agricultural land-uses was recorded within a radius of 30 m. Land-use was classified as: fallow (land cultivated not < 1–2 years previously, characterized by annual grasses and a tall herb layer), tilled land, horticulture, cereal cultivation, tree groves and viticulture.

Tree groves were recorded as either (1) olive *Olea europaea* and/or carob *Ceratonia siliqua*, or (2) citrus. Olive and carob groves are structurally similar, traditionally forming open multipurpose agro-forestry plantations that include field crops and pasture (Delipetrou *et al.* 2008) and were therefore merged into a single category. In contrast, citrus groves are intensive monocultures, often irrigated and not usually multi-purpose. Almond groves were not analysed owing to their variable structure, ranging from boundary features lining terraces in vineyards to intensive irrigated plantations. Other fruit groves were scarce, being restricted to higher elevations, and were also not analysed.

Table 2.1. *Land-use and habitat variables, showing frequency range, incidence (% of transects with non-zero frequencies), mean and standard deviation (sd) of percentage cover of habitat features (% of transect survey points where present) and mean and standard deviation of tree density (trees per ha) and elevation.*

Variable	Range	Mean (%)	sd (% points)	Incidence (%)
Horticulture (incl. potato)		5.4	15.0	17.8
Fallow land		40.1	32.0	76.2
Tilled land		22.5	26.7	56.9
Cereal (incl. harvested crop)		38.9	36.7	67.8
Olive and carob groves		36.9	38.2	59.9
Citrus groves		7.7	21.8	14.8
Viticulture		20.0	33.4	36.1
Rotovated		13.7	27.3	26.7
Unrotovated		3.4	9.1	17.3
Abandoned		5.3	13.5	19.3
Scrub		48.5	40.9	74.3
Post-cultivation growth	0–30	52.1	33.6	88.1
Semi-natural scrub	0–89	71.7	31.6	95.0
Open woodland shrub layer	0–28	22.9	33.4	52.0
Forest		16.3	29.8	40.1
Boundary features		66.7	37.5	84.2
Tree density (ha^{-1})	0–8.69	0.698	1.158	100
Elevation ($x10^2$ m)	0.10–16.95	3.53	3.20	100

All variables ranged from 0 to 11 prior to transformation, except tree density and elevation, which were not transformed, and scrub vegetation types.

Vineyards (viticulture) were divided into three categories: abandoned, unrotovated and rotovated. Most vineyards are rotovated in both winter and spring, to improve rainwater absorption and air circulation and for weed management. Rotovated viticulture was characterized by loose bare ground and fresh re-growth of weeds, whereas unrotovated viticulture had compact soil and a taller herb layer. Both differed from abandoned vineyards where there was mature regeneration of scrub vegetation among unproductive vine plants. The three individual categories of viticulture were not strongly inter-correlated, but all paired inter-correlations had $r < 0.5$, so the three categories were considered as independent predictor variables in the same models.

Density of trees (woody plants at least 3 m in height) at each point was estimated using the point-quarter method (Cottam & Curtis 1956), a commonly used and robust plotless density estimator. The presence of boundary features within 30 m of the point, including terraces, stone walls, herbaceous edges, fences, tree windbreaks and streams or gorges, was recorded.

Within a 10-m radius of each point, scrub composition was quantified by recording the presence of common indicator scrub species (Table 2.2) characteristic of (1) post-cultivation and field margin growth (six species); (2) semi-natural scrub (13 species); and (3) open woodland and forest edge shrub layer (three species), following Meikle (1977, 1985) and Davies *et al.* (2004). For analysis, species incidence was summed within each scrub category, at each sampling point (Table 2.1).

2.3.3 Regional variation in land-use

The west and southwest of the island are topographically heterogeneous, and comprise a complex land-use mosaic, with natural vegetation interspersed with cultivated fields. Excluding the central Troodos mountain range, central and eastern Cyprus is less varied topographically, with cereal and vegetable cultivation dominating and with considerable areas of olive groves (MANRE 2009).

Although many of the land-uses and habitats recorded were widespread (e.g. cereal, tilled land, olive and carob groves, and scrub), a few were localized (Fig. 2.2). Horticulture, which requires fertile soil, mainly occurred at low elevations. Fallow land was widespread, but was concentrated in the west of the island. Both citrus groves and viticulture were largely restricted to the Pafos and Lemesos districts in the west of the island. Forest was restricted to the Troodos mountain range and a few coastal sites.

Not surprisingly, many land-use and habitat variables were weakly to moderately inter-correlated ($r < 0.5$). These are nevertheless included in candidate models, as this is preferable to regression of residuals (Freckleton 2002). Strongly inter-correlated variables ($r > 0.5$) were not included simultaneously in the models. To aid interpretation, we considered it preferable to retain individual land-use and land cover variables rather than using data reduction techniques such as principal components analysis.

2.3.4 Analysis

We first quantified the breeding season range of the Sardinian Warbler and modelled habitat associations of both species within this range. Cyprus Warbler habitat association was then modelled separately outside the Sardinian Warbler’s breeding range to test for evidence of niche displacement. However, if there are differences in habitat composition and availability inside and outside the range of the Sardinian Warbler, these may affect detection of niche displacement, so that results must be interpreted with caution.

Table 2.2. *Scrub plant species used as indicators of differing anthropogenic or semi-natural Mediterranean scrubland habitats.*

	Scrub species	Fallow and field margin	Phrygana	Garrigue	Maquis	Coniferous woodland and forest edge
Post-cultivation growth	*Ziziphus lotus*	x				
	Rhus coriaria	x				
	Rubus sanctus	x				x
	Crataegus azarolus	x				
	Ferula communis	x				
	Asparagus acutifolius	x				
	Urginea maritima	x				
Semi-natural scrub	*Cistus* spp.		x	x	x	x
	Rhamnus oleoides		x		x	
	Pistacia lentiscus		x	x	x	x
	Pistacia terebinthus			x	x	x
	Calicotome villosa		x	x	x	x
	Genista sphacellata	x	x	x	x	
	Ceratonia siliqua	x			x	
	Sarcopoterium spinosum	x	x		x	
	Helichrysum stoeachas			x	x	x
	Olea europaea	x			x	
	Lithodora hispidula		x			x
	Thymus spp.	x	x	x	x	
	Asphodelus aestivus	x		x		
Woodland shrub layer	*Pinus brutia*					x
	Cupressus sempervirens					x
	Juniperus phoenicea			x	x	x

Classification based on Meikle (1977, 1985), and on European Nature Information System (EUNIS) habitat types (Davies *et al.* 2004). Phrygana consists of an open stand of sclerophyllous bushes up to 0.6 m in height, taller open stands (0.6–2 m) form garrigue, and thick stands around 2 m in height form maquis (Tomaselli 1977).

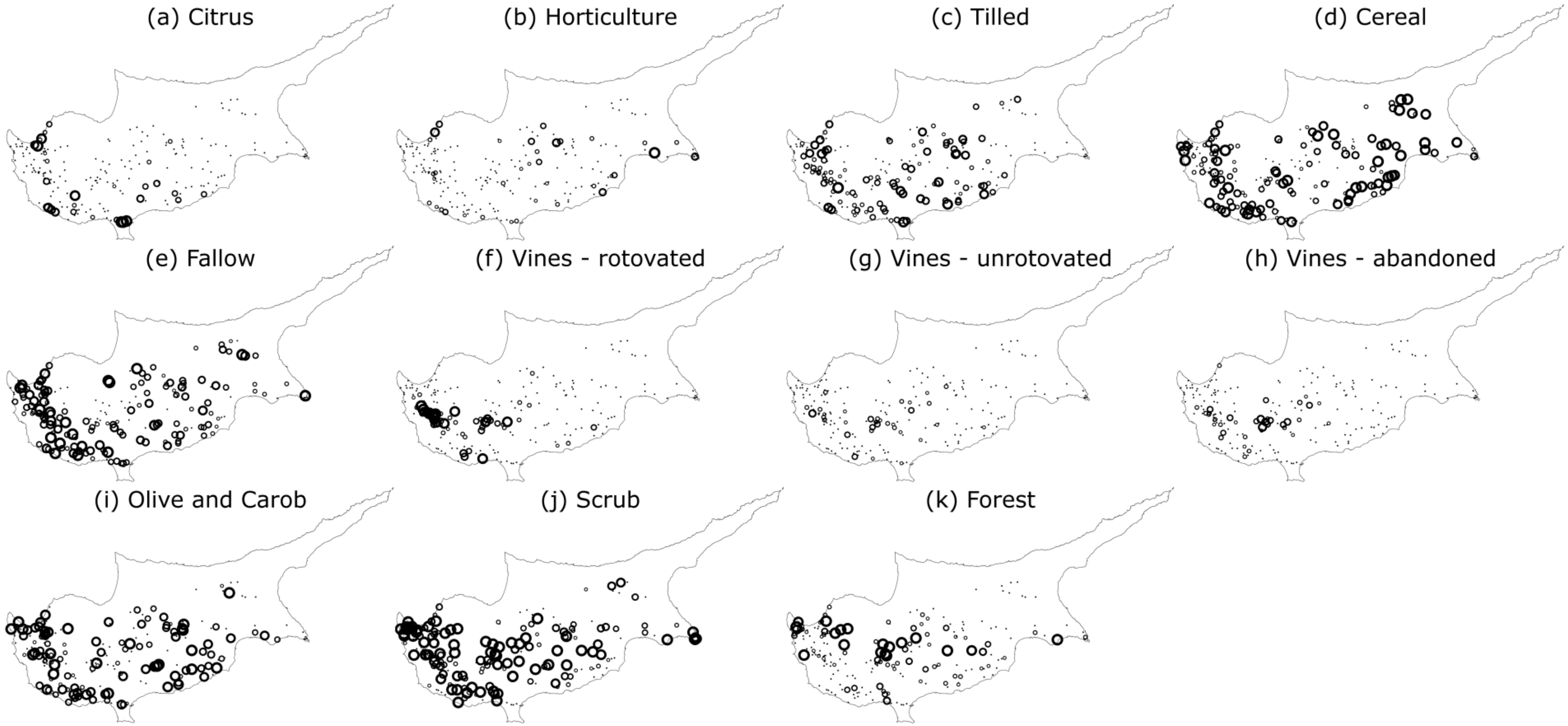

Figure 2.2. *Habitat variables on each transect. Symbols are graduated according to the frequency values of the habitat variables along the transect (0–11), and zero frequencies are marked with points.*

The Sardinian Warbler's breeding range was estimated by calculating the 95% contour of the fixed bivariate normal kernel density estimate applied to the distribution of occupied localities where Sardinian Warbler was present, using least-squares cross-validation to select the smoothing parameter (Horne & Garton 2006). While this may underestimate the full extent of occurrence of Sardinian Warbler, as non-surveyed landscapes were not classified, it serves to distinguish which survey localities potentially fall within the area of sympatry of the two species. The Sardinian Warbler's breeding range included 123 survey localities, leaving 79 survey localities outside the range (Fig. 2.1). We assessed whether Cyprus Warbler abundance was related to Sardinian Warbler abundance within the latter's breeding range, using Pearson's correlation, r. We hypothesized that (1) if Sardinian and Cyprus Warbler strongly selected the same vegetation characteristics and inter-specific competition was negligible, then abundances should be positively correlated; (2) if Sardinian Warbler was displacing Cyprus Warbler, abundances should be negatively correlated; and (3) if the two species occupied different vegetation structures, abundances would not be related.

Abundance of Cyprus and Sardinian Warblers, in terms of the number of detections (of either sex) at each locality, was separately related to the land-use and habitat variables using generalized linear models (GLMs) with a log-link function and negative binomial error term. The latter error structure provided better fit, as judged by the second-order Akaike's information criterion (AICc) and the ratio of deviance to degrees of freedom than a Poisson error term. Minimal adequate models were developed using backward selection from the full model, which included all land-use and habitat variables, survey start time and day since start of field season. Any habitat or land-use variable which on removal led to a substantial increase in the value of AICc > 1: Burnham & Anderson 2002) was retained; time and day were retained as control variables in all models.

Frequencies (0–11) of each recorded land-use and habitat variable (Table 1) were considered as predictors, square-root transformed to reduce leverage effects of outlying scores, and then z-transformed to allow comparability among regression coefficients (Schielzeth 2010). All candidate variables used in modelling had high variance and were recorded on more than 10% of transects (Table 1). Owing to low incidence (< 15%), horticulture was not included in the abundance models for either species within the Sardinian Warbler's range, while the viticulture categories were pooled and citrus was not included in the Cyprus Warbler models outside the Sardinian Warbler's range.

One set of models included scrub frequency, and a second set considered the frequency of the three separate types of scrub vegetation – post-cultivation growth, semi-natural scrub and woodland shrub layer – but excluded the strongly inter-correlated variables: forest (woodland shrub layer: $r = 0.83$, $P < 0.001$), boundary features (post-cultivation growth and woodland shrub layer: $r = 0.51$ and $–0.52$, respectively, $P < 0.001$), and merged viticulture (post-cultivation growth: $r = 0.54$, $P < 0.001$).

2.4 Results

2.4.1 Relative warbler range and abundance

The 95% kernel of Sardinian Warbler breeding distribution covered a continuous area of 1859 km^2, including 89% of Pafos district and 41% of Lemesos district, plus four disjunct areas further east in Lefkosia and Larnaka districts with a combined area of 200 km^2 (Fig. 2.1). The Sardinian Warbler was found at 96 of the 123 survey localities within its estimated breeding range (including the two disjunct outlying areas), with a mean of 5.0 (sd = 4.7) detections at each locality. Cyprus Warblers were recorded at 43 localities within the Sardinian Warbler's breeding range, and 31 of 79 localities outside it (Fig. 2.1), with a mean of 1.0 (sd = 1.8) detections at each locality inside, significantly fewer than Sardinian Warbler ($t_{158} = 8.84$, $P < 0.001$), and 1.4 (sd = 2.5) detections outside the range. The mean number of Cyprus Warblers recorded at sites where they were detected did not differ significantly inside (2.8 ± 0.3 se, $n = 43$) and outside (3.6 ± 0.5 se, $n = 31$) the breeding range of Sardinian Warbler ($t_{72} = 1.56$, $P = 0.124$), but was significantly less than the number of Sardinian Warblers recorded at sites where the latter species was detected (6.4 ± 0.4 se, $n = 96$; $t_{152} = 6.20$, $P < 0.001$). There was no correlation between the abundance of the two species ($r = –0.12$, $P = 0.200$, $n = 123$) within the Sardinian Warbler's range.

2.4.2 Models of warbler abundance

Within its range, Sardinian Warbler was more abundant at sites with a greater frequency of fallow land, rotovated vines and scrub, and was less abundant at higher elevation. In models that considered scrub type, the Sardinian Warbler was more abundant at sites with a greater frequency of post-cultivation and semi-natural scrub vegetation and less abundant at sites with a greater frequency of citrus groves and at higher elevations (Fig. 2.3).

The most important predictor of Cyprus Warbler abundance within the range of the Sardinian Warbler in models that did not include scrub type was the frequency of scrub vegetation. In models that included scrub type, Cyprus Warbler abundance responded most strongly to the abundance of semi-natural scrub, with a weaker positive association with post-cultivation growth, as indicated by the relative changes in AICc on variable removal (Fig. 2.3). In both sets of models, within the area of breeding sympatry the Cyprus Warbler was less abundant at sites with greater tree density. In models that included scrub type, the Cyprus

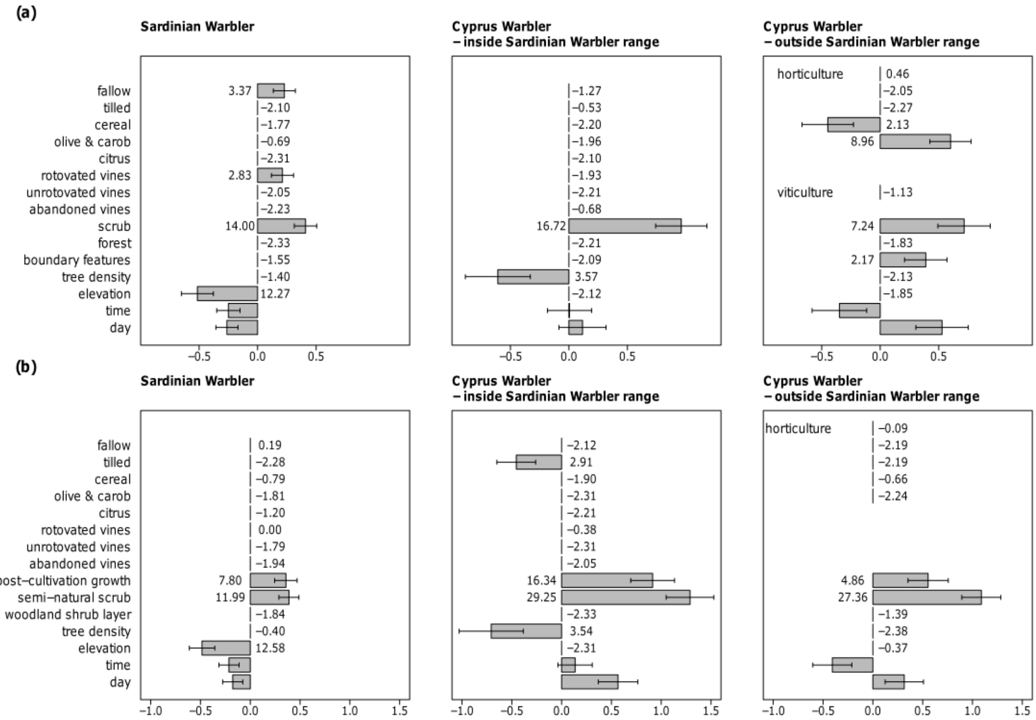

Figure 2.3. *Minimal generalized linear models of abundance, with negative binomial error structure and log link, for Sardinian Warbler within its current range, and Cyprus Warbler inside and outside the current Sardinian Warbler range. Regression coefficients and standard errors are presented as bars and error-bars for retained habitat and land-use variables (units for all variables are standardized z-scores); absence of a bar indicates the variable was not retained. In the first set of models (a) frequency of scrub is considered as a composite habitat variable. In the second set of models (b) post-cultivation growth, semi-natural scrub, and woodland shrub layer are considered in place of the scrub habitat variable. In these models, forest, boundary features, rotovated vines and viticulture (outside the Sardinian Warbler's range) were not considered as candidate variables owing to strong inter-correlation with the scrub types. The numbers shown alongside the regression coefficient bars of each variable represent the magnitude of the change in second-order Akaike's information criterion (ΔAICc), on removal of each habitat variable from either the minimal model that includes it or a minimal model with it added; positive values indicate deterioration of model fit on variable removal and negative values indicate model improvement.*

Warbler was less abundant at sites with a greater frequency of tilled land.

Although elevation did not differ (t_{200} = 1.77, P = 0.078), land-use and habitat differed at survey points inside and outside the Sardinian Warbler's range. Within that range there were more citrus fruit ($t_{197.0}$ = 2.83, P = 0.005), more viticulture ($t_{198.7}$ = 4.72, P < 0.001; rotovated vines: $t_{187.8}$ = 5.23, P < 0.001; abandoned: $t_{200.0}$ = 2.71, P = 0.007), more semi-natural scrub and post-cultivation growth ($t_{200 \text{ and } 190.9}$ = 4.05 and 3.70, respectively, P < 0.001) and marginally higher tree density ($t_{198.8}$ = 1.89, P = 0.060).

Outside the Sardinian Warbler's range, Cyprus Warbler abundance was strongly and positively associated with olive and carob groves and with scrub, and was also positively associated with boundary features, but negatively associated with cereal cultivation. In models that considered scrub type, Cyprus Warbler abundance was again strongly positively associated with greater frequency of semi-natural scrub and more weakly with post-cultivation growth (Fig. 2.3). Association of Cyprus Warbler abundance with olive and carob groves and boundary features differed inside and outside the Sardinian Warbler's breeding range. However, these variables were not positively associated with Sardinian Warbler abundance and therefore this could not be interpreted as evidence of competitive displacement.

2.5 Discussion

The recently established Sardinian Warbler and the endemic Cyprus Warbler both occurred in greater abundance at sites with greater frequency of post-cultivation growth and semi-natural scrub, reflecting their use of scrub for both nesting and foraging (Jones 2006). However, the Sardinian Warbler was less strongly associated with scrub than its congener and responded positively to other habitat types, suggesting more generalist habitat associations, whereas the Cyprus Warbler showed a stronger selection for scrub. The abundance of the two species, where sympatric, was not correlated, but inside its breeding range the Sardinian Warbler was more abundant than the endemic congener, with five times as many registrations per transect. Contrasting patterns of Cyprus Warbler habitat association inside and outside the Sardinian Warbler's range provided no evidence of competitive displacement, as the differing elements were not those selected by the latter species, suggesting that the two species have differing ecologies and requirements.

The habitat association models as used in this study are correlative and do not necessarily reflect causation. With the exception of forest and natural scrub, the variables investigated represent different land-use practices that in themselves may not affect the abundance of the warblers but more likely act as proxies for the landscape or scrub associated with them. We interpret our results in light of this caveat by considering land-use in terms of related habitat structure.

Within the Sardinian Warbler’s range, both species were positively associated with greater frequency of post-cultivation growth and semi-natural scrub. However, the Cyprus Warbler was much more strongly associated with both types of scrub, as shown by the larger coefficients and ΔAICc values. In addition, it was less abundant at sites with greater tree density, indicating an association with more open habitats, avoiding dense groves and forest, and was also negatively associated with a greater frequency of tilled land, whether this occurred in arable fields or as grove understorey. In contrast, tree density and tilled land were not retained as important predictors in models of Sardinian Warbler distribution. Unlike the Cyprus Warbler, the abundance of Sardinian Warblers was greater at lower elevations, as also found by Pomeroy and Walsh (2002).

The Sardinian Warbler was positively associated with greater frequencies of rotovated viticulture and fallow land. However, their importance was only evident when scrub type was not included in the models, suggesting that these habitat elements may have been proxies for regeneration of natural vegetation and associated scrub along terrace and vineyard margins. Active viticulture was also found to be important for Sardinian Warbler by Symes (2006), who recorded nearly twice as many Sardinian Warblers as Cyprus Warblers in managed vines and found that the Cyprus Warbler was positively associated with greater scrub cover within active vineyards but was more abundant in semi-natural scrub developed on vine terraces abandoned decades previously. In contrast to Sardinian Warbler, the Cyprus Warbler was not associated with fallow land or with viticulture in the current study. This suggests that the Cyprus Warbler is more of a scrub specialist than the Sardinian Warbler, which appears to be able to exploit recent disturbance and scrub regeneration in currently managed (rotovated viticulture and fallow land) agricultural landscapes.

Outside the Sardinian Warbler’s range, the Cyprus Warbler’s abundance was again greater at sites with a greater frequency of scrub vegetation. It was also positively associated with boundary feature frequency, most probably a proxy for remnants of scrub along terraces and field boundaries. Cyprus Warbler abundance was negatively associated with cereal cultivation; this may reflect a lack of semi-natural scrub vegetation in arable landscapes in this part of the island ($r = -0.40$, $P < 0.001$), as cereal cultivation was no longer retained when scrub type was included in the model. Although Pomeroy and Walsh (2002) found that Cyprus Warbler was less numerous at lower elevations, we found no effect of elevation, perhaps because elevation is a proxy for the habitat variables which are the direct causes of variation in Cyprus Warbler abundance. The Cyprus Warbler was more abundant in transects with greater frequency of olive and carob groves outside, but not inside, the Sardinian Warbler’s range. There is more land under olive and carob groves in Lefkosia and Larnaka districts (outside the Sardinian Warbler breeding range) than in Pafos and Lemesos (Statistical Service 2005, MANRE 2009), so there may be more power to detect this effect outside the range. Previous work inside the sympatric breeding range found that Cyprus Warbler was strongly positively associated with abandoned rather than managed groves (Symes 2006), reflecting the scrub vegetation that develops in such situations. In the current study, groves were associated with semi-natural scrub ($r = 0.33$, $P < 0.001$), particularly on shallow rendzina soils unsuitable for cultivation (C. Ieronymidou pers. obs.). That olive and carob groves were not retained in the model that included scrub type suggests that it is the scrub rather than the groves that are important to the Cyprus Warbler. The differences between the models of Cyprus Warbler abundance inside and outside the Sardinian Warbler's range show no evidence consistent with niche displacement by Sardinian Warbler, as the habitat elements differentially associated with Cyprus Warbler (olive and carob groves and boundary features) are not positively associated with Sardinian Warbler abundance. Instead, their differential selection is most probably due to differences among landscapes and habitats available for settlement in different parts of the island. While confirmation would require reciprocal removal experiments, the conclusion that active displacement is not occurring is supported by the lack of any relationship between the abundance of the two species within their sympatric range, and by the lack of inter-specific territoriality between the two species (Jones 2006).

This lack of evidence of niche displacement suggests that the perceived, although non-significant, decline in Cyprus Warbler in the areas where Sardinian Warbler has been expanding its range (Pomeroy & Walsh 2002, Jones 2006) is unlikely to be attributable to inter-specific competition. Sardinian Warbler expansion has probably been mediated through its more generalist habit, as reflected by its greater overall abundance in the area of shared range.

The abundance of both species will have been differentially affected by recent changes in land-use. Management of remaining areas of semi-natural sclerophyllous scrub habitat has changed greatly, with the loss of extensive goat grazing (Christodoulou 1959). Historically, free-ranging flocks of goats were grazed on semi-natural scrubland, but legislation in 1935 regulated goat distribution, causing a decline in goat numbers (by 33% between 1930 and 1975) and a shift in husbandry towards tethering (Christodoulou 1959). Data for the numbers of free-range goats are not available after 1960, but today most animals are tethered with a limited extent of grazing (Economides 1997, C. Triantafyllidou *in litt.* 2011). This decline in grazing intensity will have caused a structural and successional shift from compact, tightly grazed dwarf-shrub phrygana to taller, open-structured garrigue and maquis, as has occurred in Crete (Papanastasis & Kazaklis 1998). Change in scrub structure may have reduced habitat suitability for Cyprus Warbler, which appears to favour lower, more compact scrub structures (C.

Ieronymidou and P.M. Dolman pers. obs.) that depend on regular browsing. The Cyprus Warbler has been found to be more numerous than the Sardinian Warbler in semi-natural scrub habitat and low-intensity agriculture, both of which were grazed (Pomeroy 1997, Pomeroy & Walsh 2002). In contrast, loss of extensive grazing could be an important driver for the expansion of the Sardinian Warbler, which breeds at higher densities in scrub plots with taller vegetation (Martin & Thibault 1996, Shirihai *et al.* 2001, Jones 2006). Notably, Preiss *et al.* (1997) found that the Sardinian Warbler was the only Mediterranean scrub bird species to increase following a 14-year period of grazing abandonment in southern France, whereas Sirami *et al.* (2007) found its population at the same locality was stable 11 years on, unlike most other scrub bird species. Ungrazed scrub offers taller and diffuse structures suitable for the Sardinian Warbler, whether this is in patches of semi-natural garrigue and maquis vegetation or along field margins of cultivated land-uses.

As elsewhere in Europe, low-intensity farmland in Cyprus faces the twin threats of intensification and regional homogenization in productive land, and abandonment of marginal lands. Between 1985 and 2003, irrigation has increased by 55% and agricultural machinery by 58%, whereas the extent of uncultivated farmland increased by 36% (Department of Statistics and Research 1987, 1996, Statistical Service 2005). Overall, the area of land under agriculture declined by 42%, from 2000 km^2 in 1975 to 1160 km^2 in 2008 (FAOSTAT 2009) due to a combination of coastal and urban development and considerable abandonment of marginal land.

Loss of low-intensity farmland in Cyprus is likely also to affect a number of other priority (SPEC) species, such as European Roller *Coracias garrulus*, Black-headed Bunting *Emberiza melanocephala* and Eurasian Linnet *Carduelis cannabina*. While abandonment of marginal farmland may be beneficial to scrub-dwelling species such as the Cyprus Warbler (Symes 2006), uncultivated land is more likely to be built on.

Such changes in farmland management are likely to be exacerbated by the entry of Cyprus to the EU in 2004. For example, elements of the Common Agricultural Policy (CAP) offer subsidies for enhanced production and market competitiveness through Priority Axis I of the Rural Development Programme, whereas previous government policies to support marginal agriculture have been reduced (Department of Agriculture 2004). However, on-going reform of the CAP, including decoupling of Pillar I payments from production, introduction of cross-compliance and the proposed 'Greening' scheme, along with extension of the Rural Development Programme (Pillar II) and further development of the Agri-Environment Programme, may offer mechanisms to sustain High Nature Value farming (Stoate *et al.* 2009, European Commission 2011). However, to achieve this will require careful targeting and development of appropriate prescriptions that, for example, incentivise preservation of scrub vegetation and boundary features on farmland and that support extensive grazing.

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Chapter 3

Heterogeneous farmed land-use benefits eastern Mediterranean bird assemblages more than natural habitats

Cyprus agricultural landscape – Lasa village, Pafos

3.1 Abstract

In Europe, conservation initiatives to mitigate declines in birds caused by intensifying agriculture are embedded in agricultural policy, but evidence to support policy on farmland birds is lacking from the eastern Mediterranean. We therefore sampled bird assemblages and land-use along line transects at 202 localities across Cyprus in both summer and winter, relating abundance and richness within bird categories to habitat and land-use using Generalised Linear Models in an information theoretic framework. A wide range of habitat and land-use elements proved important in both seasons and habitat diversity was found to be of key value in the winter. Farmland habitats were particularly valuable, being positively associated with more categories than semi-natural habitats, indicating a land-sharing rather than land-sparing approach is appropriate in this region. Mechanisms to support maintenance of this mosaic are necessary if agri-environment measures are to be effective in the conservation of farmland birds.

3.2 Introduction

Low-intensity farming supports important elements of biodiversity, particularly in Europe, Africa and Asia (van Swaay *et al.* 2006, Wright *et al.* 2012). Farmland biodiversity is threatened by both agricultural intensification and, conversely, land abandonment, in both developed (e.g. Ford *et al.* 2001, Sirami *et al.* 2008, Flohre *et al.* 2011) and developing (Wright *et al.* 2012) countries. In the European Union (EU), North America and Australia, agri-environment measures are intended to mitigate such threats (Attwood *et al.* 2009), but their effectiveness is controversial (Kleijn *et al.* 2011) and varies with landscape context (Batáry *et al.* 2011). Optimization of these measures requires understanding which land-use practices are important for biodiversity. Effects of agricultural change are better understood for birds than for other biodiversity elements, for which birds can be effective surrogates and indicators (Gregory *et al.* 2008, Larsen *et al.* 2012), but while bird–habitat associations in farmed landscapes of temperate north-western Europe are well researched, responses of avian assemblages to land-use in the eastern Mediterranean farmland remain poorly understood (Tryjanowski *et al.* 2011; but see Kati & Sekercioglu 2006). Furthermore, except in the UK (e.g. Robinson & Sutherland 2002, Siriwardena *et al.* 2007), there is scant understanding of land-use associations outside the breeding season (but see Geiger *et al.* 2010), although landscape elements differ in value to bird species between breeding and non-breeding seasons (Block & Brennan 1993).

Key landscape features and threats to farmland birds differ among regions. Agricultural intensification has contributed to species declines across north-western and central Europe (Verhulst *et al.* 2004, Donald & Evans 2006, Reif *et al.* 2008). In western Mediterranean landscapes land-use abandonment resulting in habitat homogenization and loss of open habitats is a particular problem (Suárez-Seoane *et al.* 2002, Laiolo *et al.* 2004, Coreau & Martin 2007). Eastward enlargement of the EU is producing rapid land-use change (Herzon *et al.* 2008, Reif *et al.* 2008, Department of Environment 2010), but also extending agri-environment measures to new accession states, including Cyprus. For these measures to be effective, region-specific evidence is required (Báldi & Batáry 2011, Tryjanowski *et al.* 2011). Compared with the rest of the Mediterranean and other European regions, the eastern Mediterranean differs in its hotter, drier climate (Vogiatzakis *et al.* 2008) and in its biota, with contrasting fauna and assemblage composition (Covas & Blondel 1998, Moreira & Russo 2007). Importantly, it also differs in socio-economic context, with crop types such as carob, and contrasting patterns of land-tenure that are dominated by small, highly fragmented land parcels, and few consolidated farms (Christodoulou 1959, Grove & Rackham 2001, Vogiatzakis *et al.* 2008). We hypothesise that this local landscape complexity and structural heterogeneity will be valuable to the avian assemblage in the eastern Mediterranean, due to the juxtaposition of habitats offering contrasting complementary resources.

Here we examine the habitat associations of farmland birds in Cyprus, the region's largest island. We sampled the summer and winter bird assemblages at sites in complex agricultural and semi-natural landscapes across the island, and related species richness and the aggregate abundance of individuals within separate avian categories, defined by habitat requirements, to land-uses at multiple spatial scales, and explicitly tested the importance of local land-use diversity.

3.3 Methods

3.3.1 Bird and habitat surveys

We surveyed birds at 202 localities widely distributed across Cyprus (Fig. 3.1). Owing to difficulties with fieldwork in the north, surveys were confined to terrain controlled by the Republic of Cyprus, apart from nine localities in the Mesaoria plain, a landscape of predominantly cereal cultivation not represented elsewhere. Surveys were stratified by five administrative districts (Fig. 3.1), within each of which we selected localities to capture areas of scrub, forest, fallow and all major cultivation types on the island (Table 3.1). Mean distance between nearest localities was 2.7 (SD 1.8) km. In 21 cases (< 11%) where localities were closer than 1 km (mean = 0.68 [SD 0.19] km), surveys were conducted on different days. Locality selection is detailed in Ieronymidou *et al.* (2012).

Point counts within single land-use types were not achievable owing to the fine-scale heterogeneity and small patch size, so at each locality a 500 m line transect was walked that

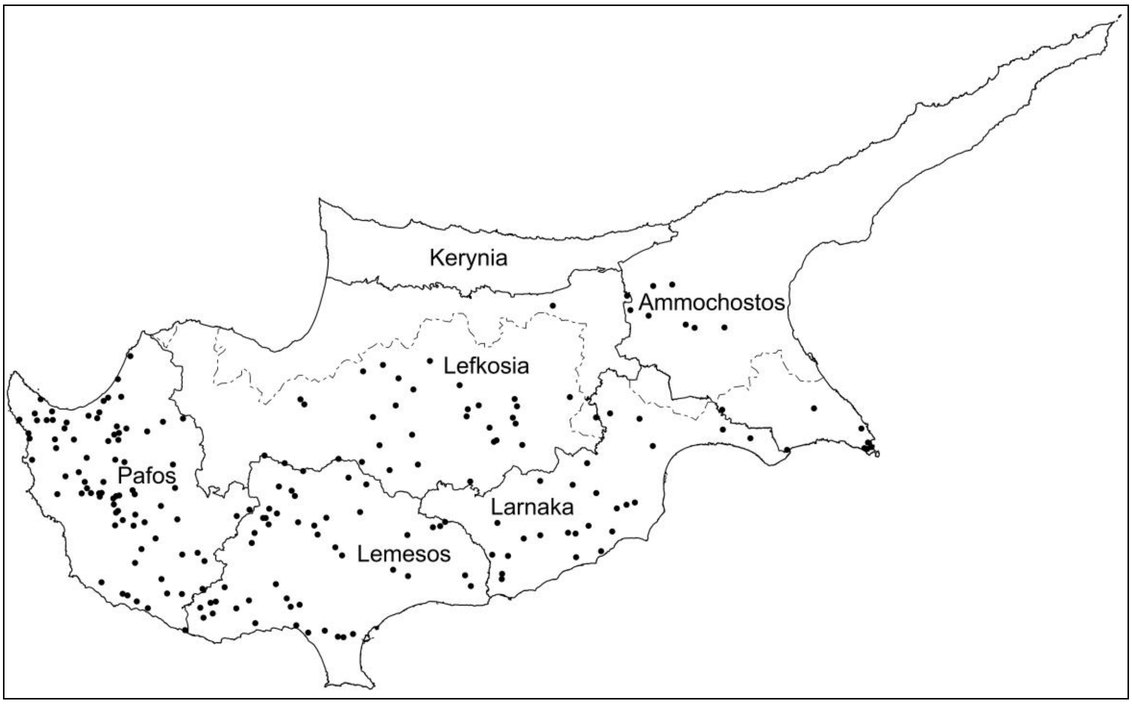

Figure 3.1. *Survey localities on Cyprus were spread across the island and included all administrative districts under control of the government of the Republic of Cyprus, as well as nine localities situated elsewhere (dashes represent approx. ceasefire line).*

traversed multiple small-scale land-uses. Surveys were conducted by a single observer (C.I.) in summer 2009 (29 March to 30 June) and in winter 2009–2010 (16 November to 30 January). Each locality was surveyed once during each season, but to avoid confounding possible regional and seasonal effects, each district was visited on three–four temporally well-spaced occasions within each period. Surveys were conducted between 30 minutes and three hours after sunrise, recording all birds seen or heard in 3 distance intervals: 0–25 m, 25–50 m, and 50–100 m from the transect line.

Land-use and habitat features were recorded every 25 m along each transect, sampling 11 points in summer (each separated by 50 m) and the 10 intervening points in winter. At each point, we recorded scrub vegetation, forest, and agricultural land-uses (defined in Table 3.1) within a radius of 30 m. 'Groves' consisted of olive (*Olea europaea*); carob (*Ceratonia siliqua*); citrus (*Citrus* spp.); or almond (*Prunus dulcis*) and other non-citrus fruit. Viticulture (vineyards) was divided into two categories: active and abandoned. At each point, we estimated tree density (woody plants at least 3 m in height) using the point-quarter method (Cottam & Curtis 1956) and recorded presence of boundary features (terraces, stone walls, herbaceous edges, fences, and tree windbreaks) within 30 m. Most habitat elements and land-uses are consistent among seasons and so were pooled for analysis, except arable (cereal, fallow, tilled and horticulture).

Table 3.1. *Land-use and habitat variables used in analysis, showing incidence of non-zero values, mean and standard deviation of percentage cover of land-use and habitat features (% of transect survey points where present) and mean and standard deviation of tree density (trees per ha), elevation and habitat diversity.*

Habitat variable	Range [a]	Mean	sd	Incidence (%)
Horticulture (incl. potato)				
summer	0–11	5.4	15.0	17.8
winter	0–10	4.7	11.0	20.8
Fallow land [b]				
summer	0–11	40.1	32.0	76.2
winter	0–10	32.3	29.9	70.8
Tilled land				
summer	0–11	22.5	26.7	56.9
winter	0–10	33.7	34.9	64.8
Cereal (incl. harvested crop)				
summer	0–11	38.9	36.7	67.8
winter	0–10	24.4	34.0	47.0
Groves	0–21	55.3	39.3	78.2
Olive	0–21	30.3	31.9	66.8
Carob	0–21	14.8	28.9	28.2
Citrus	0–21	8.3	22.1	18.8
Almond and other fruit	0–21	20.1	28.5	55.0
Viticulture				
Active	0–21	16.5	29.7	34.2
Abandoned	0–15	4.9	11.7	24.2
Scrub	0–21	50.5	38.4	81.2
Forest	0–21	11.8	24.8	40.1
Boundary features	0–21	77.4	27.0	94.6
Tree density (ha^{-1})	0–8.69	0.698	1.158	98.5
Elevation ($x10^2$ m)	0.10–16.95 [c]	3.535	3.201	100
Habitat diversity [d]				
summer	0–0.75	0.540	0.174	95.5
winter	0–0.75	0.537	0.189	93.6

[a] Range prior to transformation.

[b] Land cultivated not less than 1–2 years previously, characterised by annual grasses and a tall herb layer.

[c] 44% of survey localities at 249 m or lower, 34% between 250 m and 499 m, 17% between 500 m and 999 m, and 5% at 1000 m or greater.

[d] Simpson's diversity index calculated from frequencies of forest, scrub, viticulture, groves and pooled arable land-uses (cereal, tilled, fallow, horticulture).

The resulting frequencies for each transect (0–21 except arable: 0–11 in summer, 0–10 in winter) were square-root transformed to reduce leverage and used to quantify local habitat (hereafter 'habitat' variables) in analyses (Table 3.1). Season-specific habitat heterogeneity for each transect was calculated, as the Simpson diversity index derived from the frequencies of forest, scrub, viticulture, groves and pooled arable land-uses.

Landscape composition around localities was extracted from the 2006 satellite-generated CORINE (Coordination of Information for the Environment) Land Cover (CLC) map of Cyprus (CLC 2006: MANRE 2009). CLC distinguishes 44 land-cover classes. The minimum mapping unit is 25 ha; smaller features are either subsumed within the dominant land-cover class or, where complex mosaics occur, distinguished as aggregate land-cover classes in their own right (e.g. CLC class 241, 242, 243; Table 3.2). As different bird categories may respond to land-cover at different spatial scales (Bayard & Elphick 2010), we merged CLC classes into nine 'land-cover' variables (Table 3.2) and extracted the proportion of each from buffers of 0.5 km, 0.75 km, 1 km and 1.25 km radius around each transect line. The elevation of each transect was obtained from the Shuttle Radar Topography Mission Digital Elevation Model (Jarvis *et al.* 2008).

3.3.2 Data analysis

We allocated each bird species recorded to one of eight categories, as determined from Tucker and Evans (1997) and Snow and Perrins (1998), according to foraging habitats: closed-canopy forest ('forest'); open woodland and wood edge ('woodland'); shrub layer and scrublands ('shrub'); dense herbaceous vegetation ('herb'); open steppic habitats ('steppe'); 'complementing passerines'; and large-area species ('large-area') (Table 3.3). 'Complementing passerines' (*sensu* Dunning *et al.* 1992) comprised three species that require contrasting habitat patches in close juxtaposition. 'Large-area' species range across landscape- rather than local habitat-patch scales. Water and wetland species (uncommonly encountered) were excluded from analysis. For six of the remaining seven categories, species richness and aggregate abundance were related to local habitat and landscape-scale variables; for complementing passerines only models of abundance were created.

Associations were examined separately for summer and winter, using Generalised Linear Models (GLMs), with a negative binomial (abundance) or Poisson (richness) error and a log link function. All predictor variables were *z*-transformed to allow comparability among coefficients (Schielzeth 2010). We considered as predictors transect elevation, mean tree density, the habitat variables, habitat diversity (Table 3.1), the land-cover in each buffer radius

(Table 3.2), and an autocovariate to account for spatial autocorrelation (Augustin *et al.* 1996, Keitt *et al.* 2002). The autocovariate, A, was calculated as

$$A_i = \sum_{j=1}^{4} w_{ij} y_j \,,$$

where y_j is the response value at transect j, one of transect i's set of four nearest neighbours, and w_{ij} is the weight given to transect j, calculated as

$$w_{ij} = \frac{d_{ij}}{\sum_{j=1}^{4} d_{ij}} \,,$$

where d_{ij} is the distance between transects i and j.

Multiple-covariate distance sampling (Marques & Buckland 2003) was used to model the potential effects of habitat structure on detectability. Half-normal detection functions were fitted to category-specific count data in DISTANCE (Thomas *et al.* 2009) and model fit (estimated as Akaike's Information Criterion, AIC) was assessed with and without scrub or tree density covariates, the main habitat variables considered likely to explain differences in detectability of birds among habitats. Covariates did not improve model fit (ΔAIC > 1.10) except for shrub birds in winter (ΔAIC > 5.82), for which an estimate of the detection probability ($\hat{p}$) along each transect was log-transformed and used as an offset in models of abundance (Renwick *et al.* 2011).

For each dependent variable (richness or abundance, in summer or winter, of each category), the full model, including all variables that were not strongly inter-correlated ($r < 0.6$), potentially consisted of 24 potential predictors. To select the best set of models we used multi-model inference (MMI) based on second-order AIC (AICc) and model-averaging, which allows consideration of multiple models, weighted by their relative explanatory power (Burnham & Anderson 2002). MMI and model-averaging perform best when applied to as small a set of candidate models as possible (Whittingham *et al.* 2005), while the number of candidate models scales exponentially with increasing numbers of predictors. To reduce the size of the full model, variable filtering was necessary. Removal of weakly to moderately inter-correlated variables was not appropriate, as all variables were expected to have independent effects (Freckleton 2002, 2011). Therefore we used backward elimination, with a conservative criterion for variable retention (Wald $p < 0.2$), to filter predictors with the least impact on the response (Grueber *et al.* 2011), while controlling for the other variables.

For each dependent variable, we filtered potential habitat and land-cover variables in two stages. First, we excluded habitat variables by backward elimination from an initial model comprising all habitat variables, habitat diversity, tree density, elevation, and the spatial

Table 3.2. *Landscape-scale land cover variables were derived by merging relevant CORINE (Coordination of Information for the Environment) Land-cover 2006 classes (Büttner et al. 2006).*

Land-cover variable	CORINE Land-cover 2006	
	Class	Code
Forest land-cover	Coniferous forest	312
	Broad-leaved forest	311
Scrub land-cover	Sclerophyllous vegetation	323
	Transitional woodland-scrub	324
Not vegetated land	Sparsely vegetated areas	333
	Beaches, dunes, sands	331
	Bare rocks	332
Grassland	Natural grasslands	321
	Pastures	231
Arable land-cover	Non-irrigated arable land	211
	Permanently irrigated land	212
Complex agriculture	Complex cultivation patterns	242
	Land principally occupied by agriculture, with significant areas of natural vegetation	243
	Annual crops associated with permanent crops	241
Vineyard land-cover	Vineyards	221
Fruit tree plantations	Fruit trees and berry plantations	222
Artificial land-cover	Discontinuous urban fabric	112
	Industrial or commercial units	121
	Sport and leisure facilities	142
	Mineral extraction sites	131

autocovariate, resulting in first-stage minimum adequate models (MAMs). Second, the most informative buffer dimension to extract and model land-cover (CORINE) was determined separately for each dependent variable. Sets of land-cover proportions extracted from the four buffer radii were included in turn with the variables from the first-stage MAMs. The buffer radius resulting in the multi-scale model with the lowest value of AICc or, where models differed by ΔAICc < 2, the smaller buffer, was selected for subsequent consideration in multi-model inference. The resulting multi-scale model, comprising retained habitat variables and all candidate land-cover variables, was subject to further reduction by backward elimination with the same conservative criterion (Wald $p < 0.2$) to arrive at final-stage MAM. The spatial autocovariate was not subject to elimination at either filtering round.

Two refinements to this approach were required. (1) To determine whether it was appropriate to model combined groves or to consider separate grove types, we compared

Table 3.3. *Bird species were classified into eight categories on the basis of their habitat requirements.*

Species categories	SPEC [a]	Summer Transects [b]	Summer Records [c]	Winter Transects [b]	Winter Records [c]
Closed-canopy forest					
No. of species		6		4	
Total		27	148	21	127
Common Nightingale		7	10	0	0
Wood Warbler	x	5	6	0	0
Coal Tit		18	96	20	92
Short-toed Treecreeper		6	15	4	14
Eurasian Jay		8	17	10	17
Red Crossbill		1	4	1	4
Open woodland or wood edge					
No. of species		26		16	
Total		185	2176	190	6848
Eurasian Sparrowhawk		0	0	2	2
Levant Sparrowhawk	x	0	0	1	1
Common Cuckoo		2	3	0	0
Great Spotted Cuckoo		13	22	0	0
Eurasian Scops Owl	x	1	1	0	0
Little Owl	x	3	5	1	1
European Bee-eater	x	2	49	0	0
Eurasian Hoopoe	x	12	25	0	0
Woodlark	x	0	0	45	292
Tree Pipit		11	19	0	0
European Robin		4	6	171	914
Common Redstart	x	1	1	0	0
Cyprus Wheatear		91	235	0	0
Common Blackbird		0	0	74	200
Redwing		0	0	1	1
Song Thrush		10	32	127	555
Eastern Olivaceous Warbler	x	81	231	0	0
Eurasian Blackcap		15	35	74	440
Common Chiffchaff		19	62	118	287
European Pied Flycatcher		8	10	0	0
Spotted Flycatcher	x	20	44	0	0
Great Tit		127	459	135	462
Red-backed Shrike	x	1	2	0	0
Lesser Grey Shrike	x	1	1	0	0
Woodchat Shrike	x	6	6	0	0
Masked Shrike	x	20	43	0	0
Eurasian Golden Oriole		6	9	0	0
Eurasian Magpie		105	312	103	308
Common Chaffinch		28	150	168	1844
Hawfinch		0	0	9	47
European Serin		26	112	105	1105

Table 3.3.

European Greenfinch		84	302	96	389
Shrub layer and scrublands					
No. of species		14		6	
Total		159	1072	179	1329
European Turtle Dove	x	32	74	0	0
Eurasian Wren		10	11	2	2
Dunnock		0	0	1	1
European Stonechat		0	0	133	316
Icterine Warbler		2	2	0	0
Subalpine Warbler		2	8	0	0
Spectacled Warbler		13	51	16	51
Common Whitethroat		6	8	0	0
Lesser Whitethroat		12	38	0	0
Rüppell's Warbler		7	9	0	0
Sardinian Warbler		95	596	113	611
Eastern Orphean Warbler	x	1	2	0	0
Cyprus Warbler		71	223	101	348
Unidentified Sylvia warbler		12	39	0	0
Eastern Bonelli's Warbler	x	1	1	0	0
Cretzschmar's Bunting		7	10	0	0
Dense herbaceous vegetation					
No. of species		8		4	
Total		122	344	104	252
Black Francolin	x	12	15	4	6
Common Quail	x	17	28	2	3
Whinchat		9	14	0	0
Zitting Cisticola		41	72	49	86
Cetti's Warbler		82	161	86	157
Sedge Warbler		2	2	0	0
Eurasian Reed Warbler		10	19	0	0
Black-headed Bunting	x	16	33	0	0
Open steppic habitats					
No. of species		10		10	
Total		57	457	152	2735
Eurasian Stone-curlew	x	2	3	0	0
Eurasian Skylark	x	0	0	46	612
Crested Lark	x	41	154	35	164
Calandra Lark	x	6	49	3	11
Meadow Pipit		7	35	112	490
Red-throated Pipit		0	0	1	1
White Wagtail		0	0	38	105
Western Yellow Wagtail		1	1	0	0
Black Redstart		0	0	48	83
Northern Wheatear	x	5	10	0	0
Isabelline Wheatear		2	2	0	0
Black-eared Wheatear	x	2	3	0	0

Table 3.3.

Finsch's Wheatear		0	0	2	2
Common Rock Thrush	x	1	1	0	0
Blue Rock Thrush	x	0	0	1	1
Corn Bunting	x	16	199	65	1266
Complementing passerines					
No. of species		3		3	
Total		172	2997	166	3150
House and/or Spanish Sparrow	x	152	2439	133	2099
European Goldfinch		88	356	111	645
Common Linnet	x	51	202	74	406
Large-area					
No. of species		15		10	
Total		146	1346	123	1141
Common Buzzard		0	0	4	5
Red-footed Falcon	x	3	4	0	0
Common Kestrel	x	21	23	18	21
Eurasian Hobby		1	1	0	0
Eleonora's Falcon	x	1	1	0	0
Chukar Partridge	x	39	133	68	269
Common Wood Pigeon		72	242	21	410
Feral Pigeon		20	221	16	167
Eurasian Collared Dove		37	66	21	57
Common Swift		10	42	0	0
European Roller	x	8	14	0	0
Red-rumped Swallow		2	3	0	0
Barn Swallow	x	47	245	0	0
Common House Martin	x	1	4	0	0
Fieldfare		0	0	4	8
Mistle Thrush		0	0	4	5
Western Jackdaw		18	240	11	105
Hooded Crow		42	102	31	94
Ortolan Bunting	x	2	5	0	0
Water					
No. of species		1		0	
Total		1	4	0	0
Wood Sandpiper	x	1	4	0	0

[a] Species of European Conservation Concern, categories 1–3 (BirdLife International 2004).

[b] Number of transects at which each species or category was recorded.

[c] Number of birds recorded.

alternative full models of habitat variables that included either the composite measure or individual types. The resulting first-stage MAM with the lowest AICc was then carried forward for multi-scale modeling. Where composite groves and separate grove types resulted in equally plausible models (ΔAICc < 2), we retained separate grove types as potentially more informative. (2) Where the full multi-scale model initially included strongly inter-correlated pairs ($r > 0.6$) of habitat and land-cover variables (active viticulture habitat with viticulture land-cover, forest habitat with forest land-cover), we constructed alternative versions using either the habitat or the land-cover variables as follows: (a) active viticulture and forest habitats, (b) forest and viticulture land-cover variables, (c) active viticulture habitat and forest land-cover, and (d) forest habitat and viticulture land-cover. In each case models then underwent the second phase of backward elimination. The resulting minimal model with the lowest AICc or all equally plausible models (ΔAICc < 2) were then retained as final-stage MAMs. In the models of forest bird abundance in summer and winter, it was not possible to include arable land-cover as a predictor, as model convergence was then not achieved. The same was true of tree density in the model of steppe bird abundance in winter.

We then used MMI to examine the relative support for all variables retained in the final-stage MAMs after filtering, and calculated model average parameters and unconditional confidence intervals for the confidence set of models, defined as the smallest subset of models for which relative likelihood was 0.125 or greater (Burnham & Anderson 2002).

3.4 Results

A total of 28 296 birds of 108 species were recorded during the surveys, of which 36 species were recorded in both seasons. In summer, 11 702 birds of 88 species were recorded, of which 51 (58%) were summer-only species. In winter, 16 594 birds of 57 species were recorded, of which 19 (33%) were winter-only species (Table 3.3). Species richness of forest, herb, large-area and complementing passerines was greater in summer than winter, while the reverse was true for woodland, shrub and steppe species (square-root transformed, paired t-tests all $p < 0.01$).

Land-cover variables contributed more to models of abundance or richness within bird categories when extracted from smaller buffers. For most models, the most appropriate buffer scale was 0.5 km. Exceptions were: models of summer complementing passerine abundance (0.75 km); abundance of forest and woodland species in winter and summer, respectively (both 1 km); summer abundance of scrub and large area species, abundance in both seasons and winter richness of steppe species (all 1.25 km). The number of candidate models comprising the confidence set varied among categories and seasons, with most in the range 4–28 (see Appendix

Table 3.4. Models of abundance (a) and species richness (b) showing standardised model averaged effect sizes for those variables with relative importance ≥ 0.7, shaded in a colour scale, with green being the most positive and red the most negative.

(a)	Abundance models															
	Forest		Woodland		Scrub		Herb		Complementing		Steppe		Large-area		No. +ve	
	Summer	Winter	Summer[a]	Winter	Summer	Winter[c]	Summer[b]	Winter	Summer	Winter[c]	Summer	Winter	Summer	Winter	Summer	Winter
Land-cover buffer (km):	0.5	1	1	0.5	1.25	0.5	0.5	0.5	0.75	0.5	1.25	1.25	1.25	0.5		
Variable effect sizes																
Artificial land-cover					0.214	-0.092			0.156				0.134	0.134	3	1
Arable land-cover			-0.434										-0.122	-0.345	0	0
Cereal			-0.085	-0.125		-0.196							0.197		1	0
Tilled	0.931										-0.943	0.459		0.202	1	2
Fallow							0.167					0.184			1	1
Horticulture							0.128	0.093	0.336	0.284	0.294				3	2
Grassland land-cover									-0.232			0.358	-0.161		0	1
Fruit tree land-cover				0.158		-0.098										
Groves					0.245				0.298				0.352			
Olive			0.184	0.306											6	5
Carob										0.298						
Citrus			0.265	0.104			0.195	0.258			-0.911	-0.458				
Almond & other	0.754	1.196		0.160			0.188	0.183		0.298				0.380		
Vineyard land-cover				0.303											1	4
Active viticulture					0.216	0.102				0.245		0.398				
Abandoned viticulture															0	0
Boundary features			0.212	-0.313		-0.183	0.402	0.371		-0.193					2	1
Complex agriculture			-0.122	0.184											0	1
Scrub land-cover		-1.314								-0.160	-0.789				3	1
Scrub habitat	1.191	1.320	0.097		0.429			-0.215								
Tree density				-0.131	-0.304	-0.314								-0.181	0	0
Forest land-cover	1.241					-0.219				-0.799	-1.038				1	1
Forest habitat		1.584						-0.218				-0.456	-0.239			
Unvegetated land													-0.101		0	0
Elevation			0.141			-0.331					-0.528	-0.846	-0.154	-0.589	1	0
Habitat diversity				0.356		0.299		0.548			-0.458		0.106	0.277	1	4
Spatial autocovariate	0.706			0.191	0.475	0.176	0.292	0.115								

(b)

	Species richness models															
	Forest		Woodland		Shrub		Herb		Complementing		Steppe		Large-area		No. +ve	
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter[d]	Summer	Winter	Summer	Winter[b]	Summer	Winter[d]	Summer	Winter
Land-cover buffer (km):	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1.25	0.5	0.5		
Variable effect sizes																
Artificial land-cover			0.457						0.087				0.386		3	0
Arable land-cover				-0.565				-0.125	-0.127	-0.242				-0.455	0	0
Cereal			-0.707		-0.160	-0.143	-0.322		-0.097		-0.208			0.268	0	1
Tilled											-0.185	0.270	0.429	0.181	1	2
Fallow															0	0
Horticulture															0	0
Grassland land-cover												0.311			0	1
Fruit tree land-cover						-0.233										
Groves			0.888	1.434	0.171							-0.665				
Olive															5	4
Carob								-0.169	0.093							
Citrus							0.250				-0.164					
Almond & other	0.048							0.168		0.270	-0.183			0.191		
Vineyard land-cover												-0.234				
Active viticulture			0.676	0.659	0.308				0.137						3	1
Abandoned viticulture								-0.131							0	0
Boundary features					-0.244	-0.197									0	0
Complex agriculture															0	0
Scrub land-cover	-0.072	-0.086			0.111						-0.099					
Scrub habitat				0.322	0.198			-0.149			-0.256	-0.471			1	1
Tree density					-0.197	-0.137				-0.094	-0.164	-0.299			0	0
Forest land-cover						-0.320				-0.355		-0.390				
Forest habitat	0.234	0.286	0.570				-0.364	-0.138							2	1
Unvegetated land															0	0
Elevation				-0.383		-0.143							-0.412	-0.231	0	0
Habitat diversity						0.291		0.233					0.371		1	2
Spatial autocovariate	0.338	0.202		0.494	0.115	0.109	0.375	0.145	0.099		0.087		0.332	0.124		

[a, b, c, d] Model formulations used on the basis of inter-correlations between local habitat and landscape-scale land-cover as described in Chapter 3. Alternate formulations gave similar results (Appendix 1).

1), supporting the use of MMI and model averaging. The most important variables (with relative importance ≥ 0.7) and their effect size (standardised coefficients) in each model are summarised in Table 3.4 (see Appendix 1 for details of all candidate models). The spatial autocovariate was supported for the majority of models and had a relatively large effect size for many, reflecting regionally aggregated land-use patterns.

Different bird categories were associated with a wide range of variables at multiple scales, but local habitat was generally more important than landscape-scale extent of land-cover. Most categories had positive associations with several land-use elements (both habitat and land-cover variables), consistent with a requirement for complex landscapes. In addition, habitat diversity was valuable in its own right, especially in winter. Results identified key variables that were important for many categories. Localities with greater frequency of grove habitat had greater abundance and/or richness of shrub birds in the summer, and of complementing passerines, large-area, woodland and herb species in both seasons. Active but not abandoned viticulture was positively associated with abundance of shrub species in both seasons, winter abundance of complementing passerines and steppe birds, richness of woodland birds in both seasons and summer richness of complementing passerines and shrub birds. Not surprisingly, forest birds were positively associated with forest (richness in both seasons and winter abundance with forest habitat; summer abundance with forest land-cover). However, the only other category positively associated with forest was woodland birds (species richness in summer).

Habitat associations differed between seasons for some categories. For example, habitat diversity was more important in winter for woodland, shrub and herb species. Tilled land was positively associated with steppe species' abundance and richness in winter but negatively associated in summer, while shrub species' abundance and richness were positively associated with a greater extent of scrub habitat in summer but not winter.

3.5 Discussion

This is the first study to examine bird–habitat associations of both breeding and wintering assemblages in the eastern Mediterranean. Natural forest and semi-natural scrub had limited importance for just a few bird categories, in contrast to the overwhelming value of a range of farmland habitats. Of these, characteristic Mediterranean land-uses, especially groves and viticulture, supported the most avian diversity and were positively associated with multiple categories. In contrast, arable land-uses were less valuable. Greater small-scale heterogeneity of land-uses increased the abundance within a number of categories, particularly in winter.

It was not possible to adjust the species richness measure to account for incomplete detection of species (Boulinier *et al.* 1998), as each transect received a single visit in each of the breeding and wintering seasons. This limits the utility of the species richness analyses for drawing firm conclusions on the habitat associations of the bird categories and the results should be interpreted in the light of this caveat, with more weight given to the models of abundance.

Farmland habitats were positively associated with more bird categories than were semi-natural habitats (forest and scrub), as in Greece (Kati & Sekercioglu 2006), although scrub has value for nocturnal bird species (Moreno-Mateos *et al.* 2011), which were not surveyed in this study. This emphasises the importance of farming to biodiversity in the eastern Mediterranean, reflecting the ancient nature of the region's anthropogenic landscape (Wright *et al.* 2012). Only forest birds were strongly associated with forest extent; however this is a low-priority category for bird conservation (only one Species of European Conservation Concern and neither of the two Cyprus endemics). Similarly, agricultural abandonment and subsequent vegetation succession to forest has produced a shift in the western Mediterranean bird species assemblage to one of lower conservation importance (Preiss *et al.* 1997, Moreira & Russo 2007).

Groves and viticulture were important in maintaining breeding and wintering bird assemblages in the eastern Mediterranean, even for species associated with semi-natural habitats such as woodland birds, which showed stronger positive associations with agricultural habitats than with forest. Actively managed rather than abandoned vineyards were of value, particularly for complementing passerines, woodland and shrub birds. Groves, both as a grouped variable and as separate types, provided valuable habitat for these categories, as well as for herb, forest and large-area species. Even intensively managed land-uses such as citrus and horticulture were valuable for farmland birds.

No single land-use was consistently selected across categories, and most categories showed a positive association with numerous different land-use habitats within models in a single season. Most categories were most strongly associated with local-scale habitat rather than landscape-scale land-cover types. Furthermore, many categories were positively associated with local habitat diversity in winter. These points combine to demonstrate the key value of the locally complex farmland mosaic to avian biodiversity. Counter-intuitively, however, the landscape-scale extent of 'complex agriculture' was not supported as an important predictor for any bird category, except for winter abundance of woodland species. This may be because habitat variables were better predictors than a single land-cover variable, and because complex juxtaposition of different land-uses occurred within other CLC classes, not just 'complex agriculture'.

Cereal cultivation, by contrast, negatively affected abundance and richness of many categories at both local and landscape scales. In north-western and in Central and Eastern Europe (e.g. Kleijn & Sutherland 2003, Stoate *et al.* 2009, Tryjanowski *et al.* 2011, Concepción *et al.* 2012a) as well as in Western Mediterranean regions (e.g. Brotons *et al.* 2005, Moreira *et al.* 2005, Concepción *et al.* 2012b) research on farmland birds and land-use has often had a strong arable and grassland focus. Our study indicates this is less relevant to the eastern Mediterranean, where groves and viticulture were found to support most avian diversity.

Habitat associations in summer and winter were broadly consistent, with a few exceptions where categories showed contrasting responses. For steppe birds tilled land was avoided in summer, but positively associated with both abundance and richness in winter, suggesting its value in providing winter food for birds (Field *et al.* 2007). Woodland birds were positively associated with boundary features in summer but negatively in winter. In addition, habitat diversity was only valuable in winter for woodland, shrub and herb birds (although in both seasons for large-area species). These contrasts could be due to differences in the composition of the breeding and wintering assemblages.

3.5.1 Recommendations

Our results suggest that homogenisation of the farmed landscape, either through intensification or abandonment, will have adverse effects on farmland bird biodiversity, as elsewhere in Europe (Donald *et al.* 2002, Stoate *et al.* 2009). Land under agriculture in Cyprus decreased by 31% between 1975 and 2010. Much of this decrease is due to a decline in viticulture, which fell by 78% in the 35 years 1975–2010 (Department of Statistics and Research 1987, 1996, Statistical Service 2005, 2007, 2010, 2011, 2012).

The complexity of the farmland mosaic in the Mediterranean is the result of traditional low-intensity farming practices that are often not economically viable (European Environment Agency 2004). Therefore, agri-environment measures in the eastern Mediterranean must provide support if this mosaic and its associated farmland biodiversity are to be maintained. Support for agriculture in marginal areas is included in the agri-environment prescriptions of the Cyprus Rural Development Plan (RDP) in the form of payments for rotovation (replacing herbicide treatment of traditional crops) and subsidised maintenance of traditional grape varieties (Department of Agriculture 2010). These payments could safeguard against abandonment, thus maintaining habitat for many bird species. Unfortunately, the Cyprus RDP also subsidises the afforestation of abandoned farmland and economically marginal land-uses, including viticulture and montane fruit orchards (Department of Agriculture 2010). Such afforestation will be predictably unfavourable to avian biodiversity.

Furthermore, there are currently no provisions in the Cyprus RDP targeting the maintenance of the current farmland mosaic. This could, however, be achieved by supporting farmers who maintain multiple land-uses on their agricultural holdings, or by providing incentives for land-uses targeted to regions where they are not economically viable. Much of Cypriot farm owners' income is derived from non-agricultural activities (Department of Agriculture 2004), particularly in marginal areas. The current CAP reform proposal for a more stringent definition of "active farmers" for the purposes of payment eligibility (European Commission 2011) could therefore exclude many farmers and lead to greater rates of land-use abandonment. Instead, those who continue such uneconomic agriculture should be given incentives as their activities help maintain the range of land-uses and habitat heterogeneity that support farmland bird biodiversity.

3.6 Supporting Information

Additional supporting information may be found on the CD accompanying this thesis:

Appendix 1. Confidence sets of models resulting from the information theoretic approach and multi-model inference.

3.6 References

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Chapter 4

Species models demonstrate the value of traditional farmland mosaics to avian biodiversity in the eastern Mediterranean

Cyprus Warbler

Eurasian Hoopoe

Cyprus Wheatear

European Roller

Masked Shrike

Black Francolin

Black-headed Bunting

Great Spotted Cuckoo

Woodlark

Photos © D. Occhiato, G. Brett, R. Lourenco, J. Oláh, S. Rogers, T. Sani, P. Wezelman.

4.1 Abstract

Agri-environment measures to mitigate the adverse effects of changing agricultural practices on biodiversity form an important part of the European Union Common Agricultural Policy, but evidence to support their efficiency for farmland birds in the eastern Mediterranean is lacking. We sampled breeding and wintering avian assemblages and land-use along 202 line transects across Cyprus. Bird community structure (comprising 59 species), and incidence and abundance of 24 priority species, were related to habitats and land-use using Generalized Linear Models in an information theoretic framework. Multiple habitat and land-use elements were important in both seasons. However, more priority species were associated with Mediterranean land-uses such as viticulture and groves, rather than cereals. Semi-natural scrub was important to many, while forest (habitat or land-cover) was associated with few species. Local (< 500 m) habitat diversity was of key value. Results demonstrate the high value of heterogeneous farmland mosaics to avian biodiversity in the eastern Mediterranean. Land extent under agriculture in Cyprus has decreased substantially, with declines in traditional low-intensity crop types making up much of this decrease. Mechanisms to support the complex farmland mosaic of small-scale and marginal agriculture are necessary for effective conservation of priority birds in the eastern Mediterranean.

4.2 Introduction

Many important biodiversity elements depend on low-intensity farming (van Swaay *et al.* 2006, Wright *et al.* 2012) and are threatened by land-use change (e.g. Ford *et al.* 2001, Sirami *et al.* 2008, Flohre *et al.* 2011). In north-western and central Europe, agricultural intensification is the main driver behind widespread species declines (Verhulst *et al.* 2004, Donald *et al.* 2006, Reif *et al.* 2008), while farmland abandonment is adversely affecting biodiversity in marginal and/or montane areas, particularly in the western Mediterranean (MacDonald *et al.* 2000, Suárez-Seoane *et al.* 2002, Laiolo *et al.* 2004, Coreau & Martin 2007).

Enlargement of the European Union (EU) to central and eastern Europe has accelerated agricultural change (Herzon *et al.* 2008, Reif *et al.* 2008), but provides access to agri-environment measures under the Common Agricultural Policy (CAP) that offer a mechanism to mitigate the subsequent adverse effects. The effectiveness of agri-environment measures is variable (Kleijn & Sutherland 2003, Kleijn *et al.* 2011), and their optimization requires an understanding of the influence of different land-use practices and landscape elements (Siriwardena 2010, Batáry *et al.* 2011, Whittingham 2011).

Responses of farmland bird species to land-use change are better understood than other elements of biodiversity, for which birds are often used as indicators (Gregory *et al.* 2008). Although bird–habitat associations have been extensively researched in north-western Europe, there is scant understanding in the eastern Mediterranean (Tryjanowski *et al.* 2011, but see Kati & Sekercioglu 2006), which differs from other Mediterranean and European regions in its hotter, drier climate (Vogiatzakis *et al.* 2008), biogeography (Covas & Blondel 1998, Moreira & Russo 2007), and agriculture, for example with fragmented land holdings and distinct crop types such as carob (Christodoulou 1959, Grove & Rackham 2001, Vogiatzakis *et al.* 2008). Regionally-specific evidence is required for agri-environment schemes to be effective, as threats to avian biodiversity and the value of landscape features differ among regions (Báldi & Batáry 2011, Guerrero *et al.* 2011, Tryjanowski *et al.* 2011). Moreover, although research often focuses on breeding season habitats, it is important also to consider the wintering assemblage (Geiger *et al.* 2010).

We identify habitat associations of priority farmland birds in Cyprus, the largest island in the eastern Mediterranean, to provide an evidence base for appropriate regional agri-environment measures. We sampled summer and winter bird assemblages of agricultural and semi-natural landscapes across the island and related bird community structure, and the incidence and abundance of priority species, to habitats and land-uses at multiple spatial scales. We investigated changes in Cyprus agriculture and consider how these may affect priority farmland birds.

4.3 Methods

4.3.1 Agricultural change

The total area of major crop types and agricultural land-uses in the Republic of Cyprus, the proportion of crop areas under irrigation, and average land-parcel size from 1975–2010 were extracted from agricultural censuses (Department of Statistics and Research 1987, 1996, Statistical Service 2005, 2012) and other government publications (Akkelidou *et al.* 2004, Statistical Service 2007, 2010a, b, 2011). Land-use diversity of the areas of the main crop types, fallow, grazing and unproductive (unused) land across the Republic of Cyprus was calculated as Simpson’s index. Temporal trends were investigated using linear or non-linear (polynomial) ordinary least-squares regression models, selecting that with the smallest second order Akaike’s Information Criterion, AICc (or where ΔAICc < 2, the model with the smallest degree of polynomial).

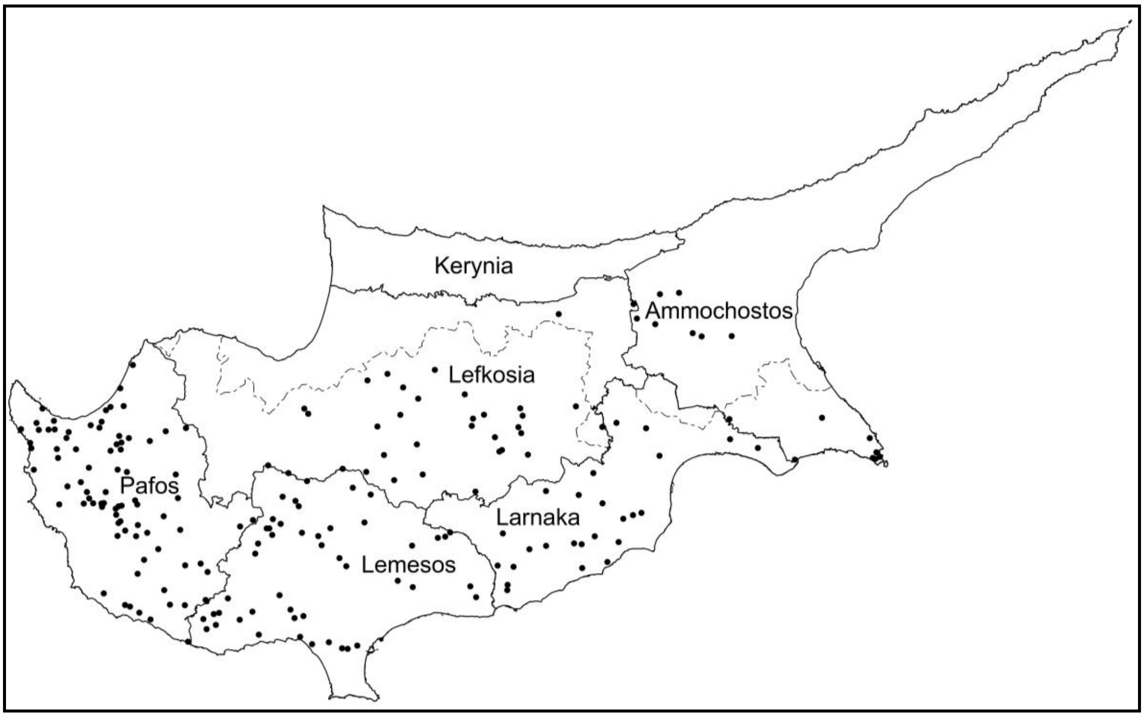

Figure 4.1. *Survey localities were spread across Cyprus and included all administrative districts under control of the government of the Republic of Cyprus, as well as nine localities situated elsewhere (dashes represent approximate ceasefire line).*

4.3.2 Bird and habitat surveys

Birds were surveyed at 202 localities across Cyprus, selected to represent areas of scrub, forest, fallow and all major cultivation types (Table 4.1) within each of five administrative districts (Fig. 4.1). At each, a 500–m line transect traversing small-scale land-uses, was walked once in summer (29 March to 30 June) 2009 and once in winter (16 November to 30 January) 2009–2010, by one observer (C.I.). Surveys between 30 minutes and three hours after sunrise recorded all birds seen or heard in four distance intervals (0–25, 25–50, 50–100 and > 100 m). House and Spanish Sparrows *Passer domesticus* or *P. hispaniolensis* were pooled as they could not be easily distinguished in large mixed flocks and will hereafter be referred to as "Sparrows".

Land-use and habitat features were recorded every 25 m, sampling 11 points in summer and the 10 intervening points in winter. At each, presence of scrub, forest, agricultural land-uses (defined in Table 4.1) and boundary features (terraces, stone walls, herbaceous edges, fences, and tree windbreaks) were recorded within a 30 m radius, and density of trees (≥ 3 m in height) measured using the point-quarter method (Cottam & Curtis 1956).

Habitat elements and land-uses consistent across seasons were pooled for analysis, but for

Table 4.1. *Land-use and habitat variables used in analysis, showing incidence of non-zero values, mean and standard deviation of percentage cover of land-use and habitat features (% of transect survey points where present) and mean and standard deviation of tree density (trees per ha), elevation and habitat diversity.*

Habitat variable	Range [a]	Mean	SD	Incidence (%)
Horticulture (incl. potato)				
summer	0–11	5.4	15.0	17.8
winter	0–10	4.7	11.0	20.8
Fallow land [b]				
summer	0–11	40.1	32.0	76.2
winter	0–10	32.3	29.9	70.8
Tilled land				
summer	0–11	22.5	26.7	56.9
winter	0–10	33.7	34.9	64.8
Cereal (incl. harvested crop)				
summer	0–11	38.9	36.7	67.8
winter	0–10	24.4	34.0	47.0
Groves	0–21	55.3	39.3	78.2
Olive	0–21	30.3	31.9	66.8
Carob	0–21	14.8	28.9	28.2
Citrus	0–21	8.3	22.1	18.8
Almond and other fruit	0–21	20.1	28.5	55.0
Viticulture				
Active	0–21	16.5	29.7	34.2
Abandoned	0–15	4.9	11.7	24.2
Scrub	0–21	50.5	38.4	81.2
Forest	0–21	11.8	24.8	40.1
Boundary features	0–21	77.4	27.0	94.6
Tree density (ha^{-1})	0–8.69	0.698	1.158	98.5
Elevation ($x10^2$ m)	0.10–16.95 [c]	3.535	3.201	100
Habitat diversity [d]				
summer	0–0.75	0.540	0.174	95.5
winter	0–0.75	0.537	0.189	93.6

[a] Range prior to transformation.

[b] Land cultivated not less than 1–2 years previously, characterised by annual grasses and a tall herb layer.

[c] 44% of survey localities at 249 m or lower, 34% between 250 m and 499 m, 17% between 500 m and 999 m, and 5% at 1000 m or greater.

[d] Simpson's diversity index calculated from frequencies of forest, scrub, viticulture, groves and pooled arable land-uses (cereal, tilled, fallow, horticulture).

Table 4.2. *Landscape-scale land-cover variables derived by merging relevant CORINE (Coordination of Information for the Environment) Land Cover 2006 classes (Büttner et al. 2006).*

	CORINE Land-cover 2006	
Land-cover variable	Class	Code
Forest land-cover	Coniferous forest	312
	Broad-leaved forest	311
Scrub land-cover	Sclerophyllous vegetation	323
	Transitional woodland-scrub	324
Not vegetated land	Sparsely vegetated areas	333
	Beaches, dunes, sands	331
	Bare rocks	332
Grassland	Natural grasslands	321
	Pastures	231
Arable land-cover	Non-irrigated arable land	211
	Permanently irrigated land	212
Complex agriculture	Complex cultivation patterns	242
	Land principally occupied by agriculture, with significant areas of natural vegetation	243
	Annual crops associated with permanent crops	241
Vineyard land-cover	Vineyards	221
Fruit tree plantations	Fruit trees and berry plantations	222
Artificial land-cover	Discontinuous urban fabric	112
	Industrial or commercial units	121
	Sport and leisure facilities	142
	Mineral extraction sites	131

cultivation (cereal, fallow, tilled and horticulture) season-specific data were used. For each transect, square-root transformed frequencies were used to quantify local land-use (hereafter 'habitat') (Table 4.1) and season-specific heterogeneity was quantified as the Simpson diversity index of frequencies of forest, scrub, viticulture, groves and pooled cultivation classes.

Landscape composition was extracted from the 2006 CORINE (Coordination of Information for the Environment) Land Cover (CLC) map of Cyprus (MANRE 2009). The 44 classes derived from remote sensing were merged into nine broad 'land-cover' variables for analysis (Table 4.2). The proportionate area of each was extracted from buffers of 0.5, 0.75, 1 and 1.25 km radius around each transect line, as bird species may respond to land-cover at different spatial scales (Bayard & Elphick 2010). Elevation of each transect mid-point was obtained from the Shuttle Radar Topography Mission Digital Elevation Model (90 m resolution, 16 m vertical error; Jarvis *et al.* 2008).

4.3.3 Bird data analysis

4.3.3.1 Avian assemblage

Avian assemblage composition was examined separately for summer and winter using Detrended Correspondence Analysis (DCA) ordination of square-root transformed count data of species recorded in at least 10 transects, down-weighting rare species (Lepš & Šmilauer 2003). Species were allocated among seven foraging habitat guilds: closed-canopy forest ('forest'); open woodland or wood edge ('woodland'); shrub layer and scrublands ('scrub'); dense herbaceous vegetation ('herb'); open steppic habitats ('steppe'); 'complementing' species (that require contrasting habitats in close juxtaposition, *sensu* Dunning *et al.* 1992) and 'large-area' species (that range across landscape rather than local habitat-patch scales) (Table 4.3). The first two DCA axes for each season were related to local habitat and landscape-scale land-cover by Generalized Linear Models (GLMs) with normal error.

4.3.3.2 Priority species

GLMs were constructed for priority species, defined as Species of European Conservation Concern (SPEC 1–3: BirdLife International 2004), characteristic Mediterranean species (as classified by Moreira and Russo 2007) and Cyprus endemics (Cyprus Warbler *Sylvia melanothorax* and Cyprus Wheatear *Oenanthe cypriaca*), provided sufficient data were achieved (Supplementary Information Table S1). For these, season-specific count data were truncated to 100 m, except for five larger (length > 25 cm) species with a conspicuous call or aerial habit (Common Kestrel *Falco tinnunculus*, Black Francolin *Francolinus francolinus*, Chukar *Alectoris chukar*, European Roller *Coracias garrulus*, Eurasian Hoopoe *Upupa epops*). Incidence was modelled for all priority species recorded at 15 or more transects after truncation, and models of abundance for those recorded at 20 or more transects.

Potential effects of habitat structure on detectability of each species were examined using multiple-covariate distance sampling (Marques & Buckland 2003). Half-normal or hazard rate detection functions were fitted using DISTANCE 6.0 (Thomas *et al.* 2009). Model fit (Akaike Information Criterion, AIC) was assessed with and without scrub habitat or tree density covariates, considered likely to affect bird detectability among transects. For most species, covariates did not improve model fit (ΔAIC < 2). Exceptions were: Eastern Olivaceous Warbler *Hippolais pallida* (tree density), Zitting Cisticola *Cisticola juncidis*, European Roller, Barn Swallow *Hirundo rustica* (scrub habitat) in the summer and Common Linnet *Carduelis cannabina* (tree density) in the winter. For these, log-transformed estimated transect-specific

Table 4.3. *Bird species were classified into seven guilds on the basis of their habitat requirements, as determined from Tucker and Evans (1997) and Snow and Perrins (1998). Species of European Conservation Concern (SPEC: BirdLife International 2004), characteristic Mediterranean species, as classified by Moreira and Russo (2007), and species endemic to Cyprus (*) are identified. For each species, the number of transects on which it was recorded and the total number of registrations (records) are shown. Count data were truncated to 100 m (in brackets) for analysis of incidence and abundance of selected priority species.*

Species guilds	SPEC [a]	Med. spp.	Summer Transects	Summer Records	Winter Transects	Winter Records
Closed-canopy forest						
Common Nightingale			10	15	0	0
Coal Tit			22	121	20	127
Eurasian Jay			8	17	10	18
Open woodland or wood edge						
Great Spotted Cuckoo		x	23	37	0	0
European Bee-eater [b]	3		19 (2)	192 (49)	0	0
Eurasian Hoopoe	3		27	43	0	0
Woodlark [b]	2		0	0	50 (45)	319 (292)
Tree Pipit			16	28	0	0
European Robin			4	6	171	930
Cyprus Wheatear *			102 (91)	284 (235)	0	0
Common Blackbird			0	0	78	245
Song Thrush			11	35	129	586
Eastern Olivaceous Warbler [b]	3	x	83 (81)	243 (231)	0	0
Eurasian Blackcap			15	35	75	441
Common Chiffchaff			20	70	124	329
Spotted Flycatcher [b]	3		20 (20)	46 (44)	0	0
Great Tit			139	527	152	576
Masked Shrike [b]	2	x	20 (20)	45 (43)	0	0
Eurasian Magpie			118	440	124	455
Common Chaffinch			35	191	176	2127
Hawfinch			0	0	10	59
European Serin			29	140	113	1203
European Greenfinch			106	479	113	450
Shrub layer and scrublands						
Eurasian Wren			10	13	2	2
European Stonechat			0	0	135	331
Spectacled Warbler		x	14 (13)	54 (51)	16 (16)	51 (51)
Lesser Whitethroat			13	39	0	0
Sardinian Warbler		x	96 (95)	613 (596)	113 (113)	615 (611)
Cyprus Warbler *			74 (71)	233 (223)	104 (101)	362 (348)
Unidentified Sylvia warbler			12	39	0	0
Cretzschmar's Bunting		x	11 (7)	15 (10)	0	0

Table 4.3.

Dense herbaceous vegetation						
Black Francolin	3		48	79	8	13
Common Quail [b]	3		18 (17)	30 (28)	2 (2)	3 (3)
Zitting Cisticola		x	84 (41)	183 (72)	55 (49)	101 (86)
Cetti's Warbler			102	232	106	244
Eurasian Reed Warbler			10	19	0	0
Black-headed Bunting [b]	2	x	23 (16)	53 (33)	0	0
Open steppic habitats						
Eurasian Skylark [b]	3		0	0	56 (46)	1021 (612)
Crested Lark [b]	3		46 (41)	204 (154)	44 (35)	252 (164)
Meadow Pipit			10	47	124	526
White Wagtail			1	1	43	118
Black Redstart			0	0	50	86
Corn Bunting [b]	2		23 (16)	256 (199)	83 (65)	1539 (1266)
Complementing						
European Turtle Dove [b]	3		34 (32)	91 (74)	0	0
House and/or Spanish	3	x	166 (152)	3257 (2439)	143 (133)	2749 (2099)
European Goldfinch			118	574	122	715
Common Linnet [b]	2		80 (51)	373 (202)	81 (74)	463 (406)
Large-area						
Common Kestrel [b]	3		54	84	60	76
Chukar [b]	3	x	49	150	71	284
Common Wood Pigeon			106	775	46	1082
Feral Pigeon			68	699	49	800
Eurasian Collared Dove			71	168	28	81
Common Swift			48	700	0	0
European Roller [b, c]	2		17	32	0	0
Red-rumped Swallow			18	33	0	0
Barn Swallow [b]	3		119 (47)	935 (245)	0	0
Common House Martin	3		18 (1)	63 (4)	0	0
Western Jackdaw			44	474	32	488
Hooded Crow			94	316	75	272

[a] 1: globally threatened; 2: unfavourable conservation status in Europe and global population concentrated in Europe; 3: unfavourable conservation status is Europe but global population not concentrated in Europe.

[b] SPEC 1–3 that are associated with farmland (Tucker & Evans 1997).

[c] Near Threatened (IUCN 2012).

detection probability, log ($\hat{p}$), was included as an offset in the GLMs (following Renwick *et al.* 2011).

4.3.3.3 Modelling procedure

Associations of the first two DCA axes, species incidence and abundance, with transect elevation, mean tree density, habitat variables, habitat diversity (Table 4.1) and land-cover in each buffer radius (Table 4.2), were examined separately for summer and winter. GLMs incorporated normal (DCA axes), binomial (incidence) or negative binomial (abundance) error. For species models, a spatial autocovariate (the distance-weighted mean seasonal abundance across the four nearest neighbours of each transect) was included to account for spatial autocorrelation (Augustin *et al.* 1996; Keitt *et al.* 2002). Predictors were z-transformed for comparability of coefficients (Schielzeth 2010).

The best set of models was selected using multi-model inference (MMI) based on second order AIC (AICc), which perform best when applied to a small set of candidate models (Whittingham *et al.* 2005). Candidate variables that were not strongly inter-correlated ($r < 0.6$) comprised 23–24 potential predictors for each dependent variable. Numbers of candidate models scale exponentially with additional predictors, so the candidate variable set was reduced by backward elimination with a conservative criterion for retention (Wald $p < 0.2$) (Grueber *et al.* 2011).

Habitat variables were filtered from an initial model comprising all habitat variables, habitat diversity, tree density, elevation and, for species models, the spatial autocovariate, giving first-stage minimum adequate models (MAMs). The most informative buffer scale was determined by sequentially incorporating into the first-stage MAMs the full set of candidate land-cover variables from each of four radii; the multi-scale model with the lowest AICc (or, where ΔAICc < 2, the smaller radius) was selected. This multi-scale model was further reduced by backward elimination (at Wald $p < 0.2$) providing a final-stage MAM. The spatial autocovariate was retained in all species models and not subject to filtering, except where it had a negative effect size, which is biologically implausible at the between-transect scale, and was removed from the final stage MAM. Two refinements to the filtering approach were required. (1) To determine whether it was appropriate to model combined groves or to consider separate grove types, we compared alternative full models of habitat variables that included either the composite measure or individual types, taking forward the resulting first-stage MAM with the lowest AICc for multi-scale modeling. Where composite groves and separate grove types resulted in equally plausible models (ΔAICc < 2), we retained separate grove types as potentially more informative. (2) Where the full multi-scale model initially included strongly inter-correlated pairs ($r > 0.6$) of habitat and land-cover variables (active viticulture habitat with viticulture land-cover, forest habitat with forest land-cover), we constructed alternative versions using either the habitat or the land-cover variables as follows: (a) active viticulture and forest habitats, (b) forest and viticulture land-cover variables, (c) active viticulture habitat and forest land-cover, and (d) forest habitat and viticulture land-cover. In each case models then underwent the second phase of backward elimination. The resulting minimal models with the lowest AICc or all equally plausible models (ΔAICc < 2) were then retained as final-stage MAMs (Appendix 2).

MMI was then used to examine the degree of support for each of the retained variables. All possible unique models involving these variables were built and their relative likelihood (exp(-ΔAICc/2) was calculated (following Burnham & Anderson 2002). Relative importance of each variable was calculated as the sum of the relative evidence weight (relative likelihood normalized to sum to one) across all models in which the variable appeared. Model average parameters and unconditional confidence intervals were calculated for the confidence set of models, defined as the smallest subset of models for which relative likelihood was 0.125 or greater (Burnham & Anderson 2002).

4.4 Results

4.4.1 Agricultural change

Total extent of agriculture declined by 31% in the 35-year period 1975–2010 (Fig. 4.2). The only land-use to have increased was olive groves, which nearly trebled in area. Most other crop types declined in area, but with contrasting temporal trends. Vines, carob groves and cereals showed the largest declines (78%, 79% and 42% respectively, Fig. 4.2). Grazing land, fallow and unused land all showed large apparent declines; however this may be affected to an unknown extent by reporting biases (see Chapter 5 for detailed assessment). For the majority of crop types, the proportion irrigated did not change, although this fluctuated for nut trees and horticulture. Exceptions were olives and vines, for which irrigation increased ($t_{1 \text{ and } 17}$ = 14.15 and 3.87, $p < 0.05$ and 0.01, respectively). Average land-parcel area was stable at 0.73 (± 0.03 s.d.) ha on average and overall land-use diversity did not change appreciably (–0.2%) although it did show a quadratic trend over time (Fig. 4.2).

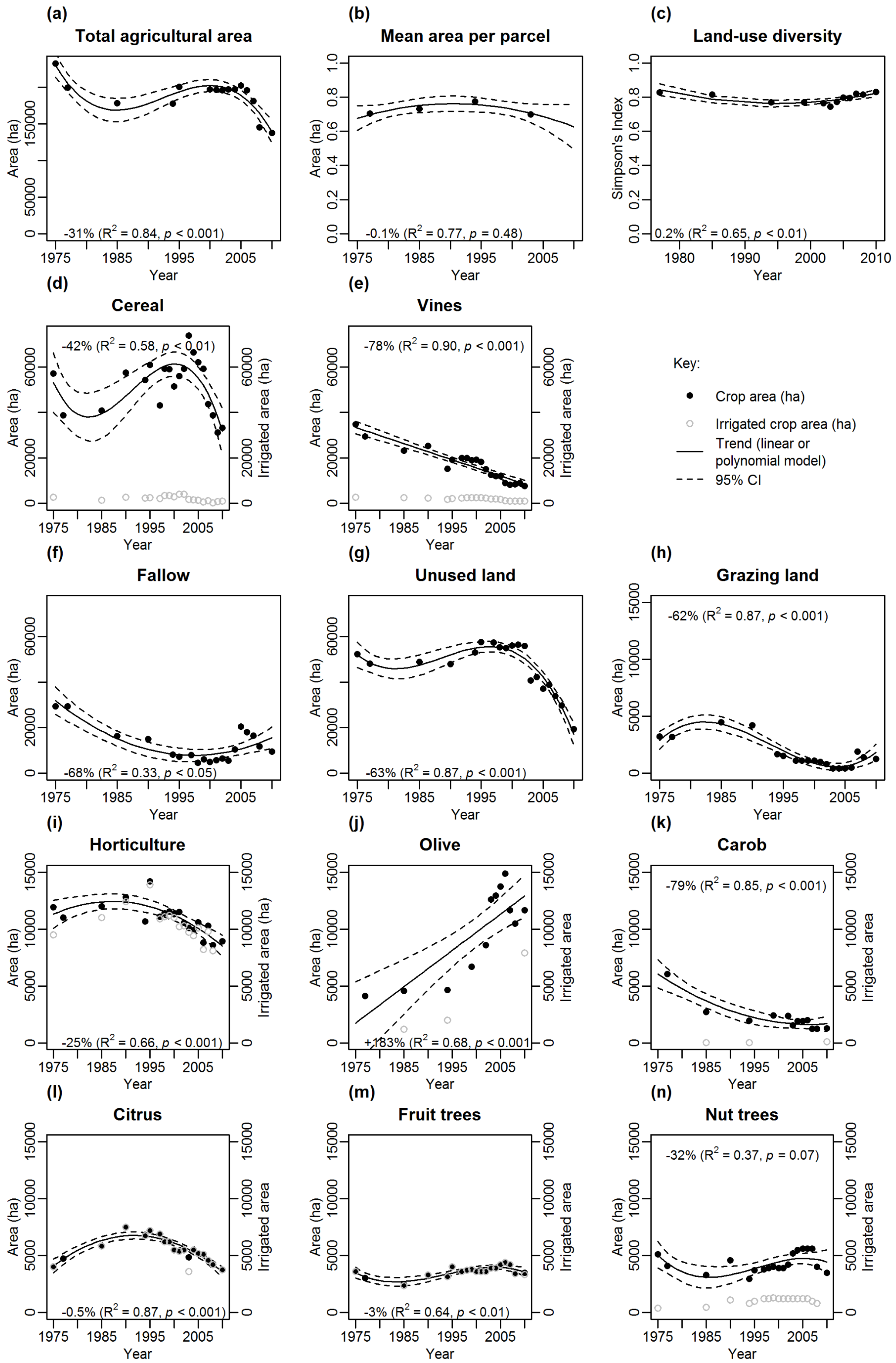

Figure 4.2. *Area (ha) of major crop types and agricultural land-uses in Cyprus from 1975–2010, showing percentage change, Pearson's* r^2 *and significance* (p-value) *of the trend. The proportion of crop area under irrigation is shown where there was a significant* ($p < 0.05$) *trend: olive groves and vines.*

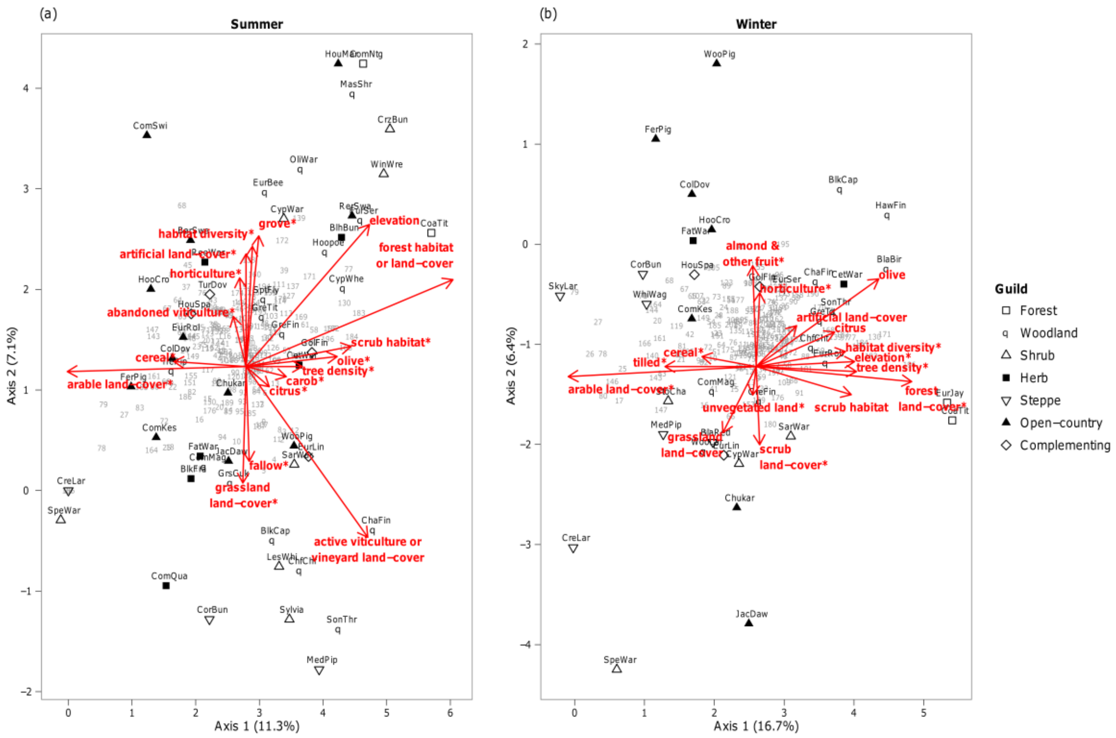

Figure 4.3. *Detrended Correspondence Analysis ordination plots for summer (a) and winter (b) bird community composition, showing percentage variance explained by each axis, foraging habitat guild of each species, and models of ordination scores for each axis. Variables with relative importance ≥ 0.5 are shown as vectors with length relative to effect size. Variables denoted with an asterisk (*) were predictors in the model of ordination scores for one of the two axes, but have been spread out for clarity.*

4.4.2 Bird models

4.4.2.1 Avian assemblage

Registrations of 33,973 individuals of 59 species were analysed, comprising 13,834 registrations of 53 species in summer and 20,139 from 39 species in winter, with 33 species recorded in both seasons (Table 4.3).

The first two DCA ordination axes explained 18.4% of the variance in summer species composition and 23.1% for winter. In both seasons, species placement within the ordination primarily differentiated birds of steppe (low scores on the second axis in summer and on the first in winter) and forest (high scores on both axes in summer and on the first axis in winter), with remaining foraging guilds poorly resolved and overlapping in the centre of the ordination (Fig. 4.3). In models of transect sample ordination scores, the most appropriate land-cover buffer was 1.25 km for the first axis and 1 km for the second, in both seasons. In both seasons the first DCA axis was negatively associated with arable habitats and land-cover, consistent with the ordination of steppe birds, and positively associated with other agricultural and semi-natural habitats, including forest land-cover, consistent with the placement of forest birds. For the summer ordination, the second axis was negatively associated with fallow and grassland and positively associated with forest habitat and elevation, consistent with the ordination placement of steppe and forest birds respectively.

4.4.2.2 Priority species

Of the 27 species that met criteria for priority classification, three could not be analysed due to insufficient data, nine were analysed in both seasons, 12 in summer only, and three in winter only. Most confidence sets comprised 9–42 candidate models (see Appendix 3), supporting the use of MMI and model averaging. The most informative landscape buffer was 0.5 km for most models. Support for habitat and land-cover effects was broadly consistent between models of incidence and abundance. For simplicity, therefore, only the models of abundance are presented; except for four species in summer and two in winter, that were recorded on fewer than 20 transects (Table 4.3), and Eurasian Skylark *Alauda arvensis* and Corn Bunting *Miliaria calandra* in winter for which abundance models did not converge, for which incidence models are presented. Effect sizes (standardized coefficients) of variables with relative importance ≥ 0.5 are summarized in Table 4.4 (for details of all candidate models see Appendix 3). The spatial autocovariate was supported for 63% of all candidate models (Appendix 3), reflecting regional aggregation of land-uses.

Most species were positively associated with multiple variables. In addition, many species had greater incidence or abundance in localities with greater landscape heterogeneity (local habitat diversity and/or land-cover extent of ‘complex agriculture’; Table 4.4), including Cyprus Warbler, Zitting Cisticola, Crested Lark *Galerida cristata* (all in both seasons), Common Linnet (in winter), and Great Spotted Cuckoo *Clamator glandarius*, European Roller, Black Francolin, Common Kestrel and Barn Swallow (all in summer).

Six species were positively associated with local forest habitat in summer, including Eurasian Hoopoe, Cyprus Wheatear, Eastern Olivaceous Warbler, Masked Shrike *Lanius nubicus* and Common Kestrel, but none was associated with forest in winter (Table 4.4, Appendix 3). By contrast, incidence or abundance of many species (12 in summer, five in winter) was greater on transects with greater frequency of semi-natural scrub (most often as a local habitat rather than land-cover variable) in both seasons (Table 4.4, Appendix 3), e.g.

Table 4.4. *Generalized Linear Models of abundance (or incidence, indicated by superscript a) of priority species in summer (a) and winter (b). Models including detectability as an offset are indicated by superscript b. Standardized model averaged effect sizes for those variables with relative importance ≥ 0.5 are shaded in a colour scale, with red being the most negative and green the most positive.*

(a) Summer

	Common Kestrel	Black Francolin	Chukar	Common Quail[a]	European Turtle Dove	Great Spotted Cuckoo	European Roller[a,b]	Hoopoe	Crested Lark	Barn Swallow[b]	Cyprus Wheatear	Zitting Cisticola[b]	Eastern Olivaceous Warbler[b]	Sardinian Warbler	Cyprus Warbler	Spotted Flycatcher	Masked Shrike	House Sparrow	Common Linnet	Black-headed Bunting[a]	Corn Bunting[a]		
Land-cover buffer (km):	0.5	0.5	0.5	1	0.5	0.75	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1.25	0.75	0.5	0.5	0.5		
Variable effect sizes																						+	-
Artificial land-cover				-0.038				0.467		0.302	0.255		0.095			0.998		0.121	0.385			8	1
Arable land-cover						2.768	0.066			0.730	-0.510							0.108				4	2
Cereal		-0.217	0.136	-0.064		-0.147					-0.075		-0.170				-0.379		-0.495			2	7
Tilled				-0.056	0.369		0.034	0.438					0.219	-0.072			0.710					5	2
Fallow	0.141								-0.405			0.420		0.293								3	1
Horticulture			0.385	0.033											-0.362			0.360			0.052	4	2
Grassland land-cover						0.797											0.444	-0.226				2	1
Fruit tree land-cover													0.145								-0.046	13	7
Groves										1.141								0.445					
Olive	-0.155	-0.143	-0.482	0.057									0.191		0.361	-1.170	1.165						
Carob			0.598			0.674					0.071			0.083									
Citrus												0.420	0.337	0.238									
Almond & other fruit	-0.155		0.657						-0.861		0.099		0.356		0.270	0.765							
Vineyard land-cover						2.189	0.019	0.451			0.157											8	1
Active viticulture			-1.151		1.070									0.469					1.047		0.050		
Abandoned viticulture			0.809													-1.842			0.421	0.086		5	1
Boundary features													0.400				0.473	-0.072		0.022		3	3
Complex agriculture		0.187	-0.475			2.238		0.331	0.429	0.180		0.274			-0.374							7	2
Scrub land-cover				-0.039		1.567		0.613	-0.389			-0.675		0.461						0.049		12	7
Scrub habitat	-0.216	-0.603	0.551		0.392				0.470		0.643				1.179		0.475						
Tree density	-0.665			-0.012					-2.988		0.104	-0.917										1	6
Forest land-cover			-0.552							-5.745				0.075			1.034	-0.498				7	6
Forest habitat	0.527	-0.226						1.110			0.214	-0.611	0.466		-0.390								
Unvegetated land					-0.489									-0.496	0.081				-1.652			3	3
Elevation		-0.797			-1.490				-0.808							-0.970	0.895		-0.754	0.030		4	6
Habitat diversity		0.354		-0.096			0.050		-0.504		0.556	0.271	0.293		0.440	2.576					-0.068	9	3
Spatial autocovariate	0.202								0.185	0.396			0.489	1.199	0.538						0.065		
Intercept	-1.381	-1.531	-0.979	0.084	-2.039	-3.127	0.079	-2.371	-2.594	-2.680	-0.657	-1.987	-0.664	0.053	-0.859	-3.641	-3.160	2.164	-1.280	0.079	0.079		

(b) Winter

	Common Kestrel[a]	Chukar	Eurasian Skylark[a]	Woodlark	Crested Lark	Zitting Cisticola	Spectacled Warbler[a]	Sardinian Warbler	Cyprus Warbler	House Sparrow	Common Linnet[b]	Corn Bunting[a]		
Land-cover buffer (km):	0.5	0.5	1.25	0.5	1	0.5	0.5	0.5	0.5	0.75	1	0.5		
Variable effect sizes													+	-
Artificial land-cover		-0.335		-0.566								-0.058	0	4
Arable land-cover		-0.217			1.972				0.189		-0.247		2	2
Cereal			0.126				0.025						3	0
Tilled			0.065	0.478	0.414	-0.148							3	1
Fallow										0.415			2	0
Horticulture		0.167								0.419			2	0
Grassland land-cover			0.078		0.826					-0.431	0.175		3	1
Fruit tree land-cover		-0.402	-0.045	-1.519					-0.169					
Groves								0.443						
Olive					-1.189				0.329					
Carob	-0.020	0.112			-0.197		-0.038			0.293			5	10
Citrus	-0.022				-0.237							-0.046		
Almond & other fruit					-1.032	0.556	-0.055							
Vineyard land-cover						0.477							5	1
Active viticulture	0.141			0.513				0.282	-0.277	0.217				
Abandoned viticulture						-0.448			0.414				1	1
Boundary features					-0.877			-0.275					0	2
Complex agriculture			-0.087		1.631		-0.014						1	4
Scrub land-cover		0.365			0.948				0.150				5	2
Scrub habitat		0.463	-0.113			-0.630	0.054	0.128	0.452					
Tree density			-0.055		-2.490		-0.039	-0.499		-0.253		-0.034	0	6
Forest land-cover									-0.476	-1.236		-0.100	0	7
Forest habitat		-0.780									-0.822			
Unvegetated land			-0.044		0.531	-0.282			0.180				2	2
Elevation	-0.100		0.067		-0.603	-1.094					0.501		2	3
Habitat diversity			-0.115		1.384	0.764							3	1
Spatial autocovariate		0.424	0.021			0.081	0.029	1.009	0.421		0.703			
Intercept	0.257	-0.222	0.228	-0.304	-3.533	-1.715	0.079	0.467	0.050	1.647	0.017	0.322		

Sylvia warblers, Crested Lark, Chukar (all in both seasons), European Turtle Dove *Streptopelia turtur*, Cyprus Wheatear, Masked Shrike, Eurasian Hoopoe and Great Spotted Cuckoo (all in summer).

Grove habitats were important in the summer, with more species positively associated with groves (either overall or specific types), than with any other habitat or land-use (Table 4.4, Appendix 3). Across both seasons, 13 species were positively associated with active viticulture habitat and/or landscape-scale vineyards (Table 4.4, Appendix 3), including summer abundance or incidence of Great Spotted Cuckoo, Eurasian Hoopoe, European Roller, Cyprus Wheatear, European Turtle Dove, Sardinian Warbler *Sylvia melanocephala*, Corn Bunting and Common Linnet, and winter abundance or incidence of Woodlark *Lullula arborea*, Sparrows, Common Kestrel and Zitting Cisticola. In contrast, few species were associated with abandoned viticulture (Table 4.4, Appendix 3), although these included Black-headed Bunting *Emberiza melanocephala* and Chukar (both in summer) and the endemic Cyprus Warbler (in both seasons).

Arable land-cover was important for six species across both seasons, including European Roller and Great Spotted Cuckoo in summer and Crested Lark in winter, while five species were positively associated with cereal habitat, including Chukar in summer and Eurasian Skylark in winter (Table 4.4, Appendix 3). Tilled soil was important for eight species across both seasons (Table 4.4, Appendix 3), including Eurasian Hoopoe, Eastern Olivaceous Warbler, Masked Shrike, European Turtle Dove, European Roller (all in summer), and Woodlark and Eurasian Skylark (both in winter). Across both seasons, five species were positively associated with fallow, including Zitting Cisticola and Sardinian Warbler in summer and Sparrows in winter, and four species with horticulture, including Chukar, Common Quail and Corn Bunting in summer and Sparrows in both seasons (Table 4.4, Appendix 3).

4.5 Discussion

The majority (80%) of SPEC recorded in this study are considered farmland birds (Table 4.3, Tucker & Evans 1997). Most species showed a positive association with multiple land-uses or habitats within each season, and no single land-use was consistently important across species. For nearly half (11 of 24) of species, multiple habitats were complementary rather than supplementary, as heterogeneity was also important, in terms of either local habitat diversity or landscape-scale extent of complex agriculture.

These findings suggest that heterogeneous farmland mosaics are of key value to avian biodiversity in the eastern Mediterranean. Local habitat diversity was supported for nine species in summer and three in winter and complex agriculture land-cover was important for six species in summer and one in winter. The heterogeneous farmed landscape was particularly important for breeding priority species, such as Great Spotted Cuckoo, Black Francolin, Crested Lark and both endemics. In terms of individual land-use elements, groves, viticulture and retained patches of semi-natural scrub were of the highest value, with cereals relevant to fewer priority species, emphasizing the importance of distinctive Mediterranean land-use types.

Analyses relating the overall composition of the breeding and wintering bird assemblages to land-use emphasized the importance of arable land-uses to steppe birds and of landscape-scale forest extent to forest species. Different grove types, viticulture, horticulture and semi-natural scrub as well as habitat diversity, all had significant and distinct effects on the composition of the breeding and wintering bird assemblages. However, the large overlap of different bird guilds in ordination space, and high variability among species within guilds, supported the use of species-specific models. Species models achieved a greater level of detail and understanding than previous analysis of guilds (see Chapter 3).

Farmland habitats are more valuable to avian biodiversity than semi-natural habitats in Greece (Kati & Sekercioglu 2006) and in Cyprus (see Chapter 3). In this study, however, many species (11 in summer and five in winter) were positively associated with scrub. These included scrub specialists (e.g. European Turtle Dove, Chukar, *Sylvia* warblers) and others associated with agricultural land-uses, such as Great Spotted Cuckoo and Crested Lark. This emphasizes the importance of scrub remnants in the agricultural matrix for priority species.

Remnant scrub along terrace field margins may also explain the positive associations of some species (eight in summer and five in winter) with viticulture, particularly of species such as Sardinian Warbler. The open structure of ground cover and extensive bare ground in vineyards also allows accessibility to invertebrate prey or weed seeds for species such as Woodlark and the Sparrows in winter and Eurasian Hoopoe in summer, as shown in Switzerland (Schaub *et al.* 2010, Arlettaz *et al.* 2012, Tagmann-Ioset *et al.* 2012). Woodlark requirement for sparsely vegetated or bare ground has also been demonstrated in the UK (Bowden 1990, Mallord *et al.* 2007). The open structure of vineyards and availability of perches could similarly explain the positive association with this land-use of Corn Bunting (Snow & Perrins 1998, Vallecillo *et al.* 2008). Eurasian Hoopoe was strongly positively associated with forest habitat also, possibly as a result of availability of prey such as pupae of the Pine Processionary Moth *Thaumetopoea pityocampa* (Barbaro & Battisti 2011), and of nesting cavities. Cyprus Wheatear was also positively associated with forest and viticulture; and although it is considered primarily a forest bird (Snow & Perrins 1998, Randler *et al.* 2009) it was most strongly associated with habitat diversity and scrub habitat, both characteristic of vine terraces. Similarly, vineyards in Italy support many woodland birds, but mostly in winter (Laiolo 2005).

Habitat heterogeneity allows low-intensity vineyards in Hungary to support many bird species (Verhulst *et al.* 2004), as could be the case for the complementing species in this study, Turtle Dove, Common Linnet in summer and Sparrows in winter, all of which require juxtaposition of scrub and open land for foraging (Snow & Perrins 1998, Fuller *et al.* 2004). The main determinant of Common Linnet summer incidence and abundance in Cyprus was viticulture, unlike its preference for scrubland in Spain (Vallecillo *et al.* 2008), suggesting that the heterogeneous vineyard habitat provides the range of resources required by this category 2 SPEC.

Black-headed Bunting, Cyprus Warbler and Chukar were positively associated with abandoned rather than active viticulture, probably as a result of scrub encroachment and, for the latter, a dense herb layer. Black-headed Bunting is a characteristic species of rural agricultural mosaics (Kati & Sekercioglu 2006) and forages in cultivated vineyards and groves (Snow & Perrins 1998, Symes 2006), but abandoned vineyards may in this case provide the dense scrub it requires for nesting (Snow & Perrins 1998).

Groves had more species associated with them than other land-uses in summer (13) and also were important for five species in winter. Numbers of species positively associated with the different grove types were similar, except citrus groves in winter, which were not selected by any species. Masked Shrike was strongly positively associated with olive groves, which clearly provide valuable habitat for this declining SPEC 2 species (BirdLife International 2004), as also found by Moskát and Fuisz (2002). Species such as Chukar, Cyprus and Sardinian Warblers probably use remnant scrub patches in and around extensively managed groves, Common Quail may be selecting for associated grassy understorey in open groves, as it was negatively associated with tree density, and European Turtle Dove probably uses boundary features for nesting and open or tilled grove understorey for foraging (Browne & Aebischer 2004).

Even intensively managed groves were valuable for a number of species. For example, Zitting Cisticola, Eastern Olivaceous Warbler and Spotted Flycatcher were positively associated with the more intensively managed citrus and other fruit groves, probably owing to the herb- and presumably invertebrate-rich ground layer that results from irrigation. However, all three species were also positively associated with habitat diversity, Zitting Cisticola with complex land-cover and fallow, and Eastern Olivaceous Warbler with boundary features, suggesting that patches of intensive land-use within a heterogeneous matrix can provide habitat for these species. Chukar, Corn Bunting and Sparrows were positively associated with horticulture, another irrigated land-use.

Arable land-uses (land-cover and cereal habitat) supported six species in summer and five in winter. However, even those species associated with the CORINE arable land-cover class (e.g. Great Spotted Cuckoo, European Roller, wintering Crested Lark) were also positively associated with local habitat diversity and/or complex agriculture land-cover, suggesting a greater association with arable habitats within heterogeneous landscapes. European Roller, a globally 'Near Threatened' species (IUCN 2012), requires open areas with good perch availability over which to forage (Snow & Perrins 1998; Avilés *et al.* 2000) within several kilometers of suitable nesting sites. In Iberia European Rollers inhabit extensive dehesa, comprising cork oak and olives with pastoral and cereal land-uses. However, the species was not associated with groves in this study, likely due to their small patch extent, and was instead associated with habitat diversity, again emphasising the importance of the agricultural mosaic. In addition, more species were positively associated with local-scale arable habitats, which can be found as patches of cereal or tilled fields within the farmland mosaic, than were associated with landscape-scale arable land-cover. Importantly, more species were positively associated with tilled ground than cereal, including Masked Shrike and Eurasian Hoopoe, which were also positively associated with groves. As a 'sit and wait' predator, Masked Shrike requires suitable perches with access to open ground (Lefranc 1997), while Eurasian Hoopoe requires open ground structure for foraging (Schaub *et al.* 2010, Tagmann-Ioset *et al.* 2012). Although traditional grove management includes a cereal rotation, aftermath grazing and ploughing of stubbles, where groves are not inter-cropped with cereals the herb layer is often tilled for weed management. The resulting soil disturbance may be beneficial for these species.

4.5.1 Recommendations

As elsewhere in Europe, homogenization of the farmed landscape, whether through abandonment, intensification, or regional specialization, would have negative effects on priority species for conservation and avian biodiversity in general (Donald *et al.* 2002, Stoate *et al.* 2009). Regional specialization of agricultural production, as would result from a 'land-sparing' approach (Green *et al.* 2005), does not therefore appear appropriate. This supports the use of agri-environmental measures, which promote 'land-sharing', as a mechanism for biodiversity conservation in the eastern Mediterranean. There are, however, no provisions in the current Cyprus Rural Development Plan (RDP) for maintenance of the heterogeneous farmland mosaic. Mechanisms to achieve this could include subsidies for maintaining crops and land-uses targeted on regions where they are not economically viable, and incentives for agricultural holdings that consist of multiple land-uses.

Agriculture has declined in Cyprus (Fig. 4.2), with viticulture decreasing by 78% between 1975 and 2010, amounting to habitat loss for many priority species. The increasing proportion of vine area that is irrigated, although still low (14%), suggests the loss of low-intensity and marginal vineyards. Agri-environment prescriptions subsidising traditional grape varieties may allow such vineyards to remain active, but the RDP simultaneously supports afforestation of marginal and abandoned agriculture (Department of Agriculture 2010). Loss of high nature value farmland to forest, a habitat of low conservation importance for priority bird species, will have adverse effects on avian biodiversity.

The main mechanisms for supporting traditional low-intensity farming in the Cyprus RDP consist of agri-environment measures that subsidise tilling for weed control in traditional crops in marginal areas (Department of Agriculture 2010). These payments potentially maintain valuable habitat, providing tilled soil in the understorey of groves, beneficial for many priority bird species. Tilling for weed control as part of integrated management is also included in agri-environment schemes for more intensively managed citrus and other groves (Department of Agriculture 2010), where it may benefit insectivorous species (e.g. Genghini *et al.* 2006). A prescription for cultivated arable field margins, which are successful in the UK (Vickery *et al.* 2009), could also be adopted in Cyprus to further support those species positively associated with tilled land.

However, prescriptions directly supporting traditional agriculture are lacking from the Cyprus RDP. Despite support for organic olive cultivation, there has been a trend for development of intensive irrigated plantations of young olive trees (Department of Agriculture 2004, also see Fig. 4.2) that lack the veteran trees important to cavity nesting and perch predators. In contrast, carob groves generally comprise ancient trees, but declined by 79% between 1975 and 2010 (Fig. 4.2). In addition, retention of scrub elements is not addressed by the Cyprus agri-environment prescriptions (Department of Agriculture 2010), despite their importance to numerous priority species. Removal of semi-natural vegetation from field margins and unmanaged areas between land-parcels may be encouraged, as RDP subsidies and CAP Single Farm Payments depend on crop area, excluding non-crop elements over 2 m wide (Cyprus Agricultural Payments Organization 2011). Loss of such boundary features has contributed to species declines elsewhere in Europe (Stoate *et al.* 2009), but the legal proposal on CAP reform regarding mandatory maintenance of Ecological Focus Areas (European Commission 2011) could provide a mechanism for preserving scrub in agricultural holdings.

Agri-environment measures in the eastern Mediterranean must provide support for low-intensity traditional agriculture, in order to maintain the complex farmland mosaic. Only by encouraging economically marginal farming can the range of land-uses and habitat diversity that support priority species for conservation be maintained.

4.6 Supplementary information

Additional supporting information may be found on the CD accompanying this thesis:

Appendix 2. Candidate variable sets used for multi-model inference and model averaging.
Appendix 3. Confidence sets of models resulting from the information-theoretic approach and multi-model inference.

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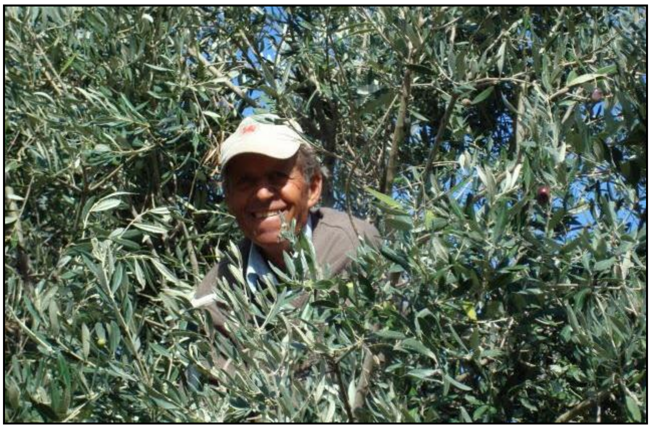
Chapter 5

Magnitude and characteristics of agricultural change in Cyprus, 1975–2010

Grape harvest © cyprusandmore.com

Barley harvest © philKI



Olive harvest © N. Davie

5.1 Abstract

Agricultural land-use change is driven by a number of factors that in Europe include the Common Agricultural Policy, which has resulted in contrasting agricultural intensification and abandonment that have negatively affected farmland biodiversity. Understanding the nature of change in Cyprus, the easternmost Mediterranean New Member State, is necessary to identify potential effects on farmland birds. We use government agricultural census and survey data to examine temporal trends in the area, composition, intensification and value of major crop types, changes in the area of fallow and unused land, and in land-use diversity and parcel size, using polynomial regression. Total agricultural area in the government-controlled area declined by 31% (94,831 ha) between 1975 and 2010, but diversity and parcel size remained stable. The area of olives nearly trebled, but carobs, vines and fallow declined dramatically, representing a loss of traditional Mediterranean anthropogenic habitats. The most valuable crops in terms of producer's price per ton and/or per hectare were olives, citrus, other fruits and horticulture, while cereal, carobs and vines were the least valuable. The proportion of olive and vine irrigated area increased, indicating expansion of intensive olive plantations and replacement of low-intensity vineyards. The reduction in farmland was not matched by an increase in unused land recorded within the agricultural statistics and census data, but it was not possible to quantify abandonment, due to lack of transparency and poor consistency in variable definitions across publications. However, analysis of CORINE (Coordination of Information for the Environment) Land Cover maps showed that conversion to artificial land-cover appears to be an important driver of farmland loss. Conversion of marginal low-intensity agriculture (vines, carobs, non-irrigated olives) to built-up land amounts to habitat loss for many priority bird species. Proposed changes in housing development legislation may limit further conversion, but Rural Development Plan (RDP) subsidies to maintain such agricultural activity should be strengthened. Detailed analysis of agricultural abandonment and socio-economic data will be necessary to optimise and better target the RDP for maintenance of traditional systems to benefit farmland biodiversity.

5.2 Introduction

Previous chapters have explored the importance of traditional land-uses to avian biodiversity in the eastern Mediterranean and established the high value of heterogeneous farmland mosaics and characteristic land-uses. Given the significance of this evidence, it is clearly important to understand the nature and drivers of agricultural change in Cyprus, in order to identify its potential effects on farmland bird assemblages in the future.

Agricultural land-use change is driven by a variety of interacting factors, including world supply and demand, consumer preferences and producer behaviour, commodity and input prices, technology, trade agreements, market intervention through agricultural policy, social and cultural change, demographics of rural populations and rural development policy, environmental policy, competition with other land-uses (e.g. urban, leisure) and effects of climate change on the regional viability of crop types and production systems (Rounsevell *et al.* 2005, Poláková *et al.* 2011). In Europe, the EU Common Agricultural Policy (CAP) has been a major driver of agricultural change. The CAP and other economic and technological instruments have led to profound changes in farm management practices, which have resulted in contrasting intensification and abandonment of traditional low-intensity agriculture (Donald *et al.* 2002) with adverse effects on farmland biodiversity (e.g. MacDonald *et al.* 2000, Suárez-Seoane *et al.* 2002, Laiolo *et al.* 2004, Verhulst *et al.* 2004, Donald *et al.* 2006, Coreau & Martin 2007, Reif *et al.* 2008, Flohre *et al.* 2011). Despite successive reforms of the CAP that sought to mitigate these impacts, agricultural intensification and abandonment continue to pose major threats to European biodiversity (Stoate *et al.* 2009, Poláková *et al.* 2011).

Land-use change in response to the CAP has not been uniform across all parts of the EU, with rates and directions of change varying both within and among regions and countries. Potter (1997) referred to a North/South divide in which the north-western parts of Europe are characterised by large-scale highly productive arable and livestock farming, while the southern Mediterranean region, intensifying later and more slowly, retains higher proportions of small and economically marginal agriculture. EU enlargement in 2004 and 2007 has accelerated agricultural change in those central and eastern European New Member States brought under the CAP (Herzon *et al.* 2008, Reif *et al.* 2008, Stoate *et al.* 2009). Cyprus was one of these states, joining the EU in 2004, but there is scant understanding of agricultural land-use change in this, the easternmost Mediterranean New Member State. However, it is believed that both intensification and abandonment are affecting the Cypriot rural landscape and the biodiversity elements associated with it (Department of Environment 2010).

In this study we aim to use agricultural census and survey data, collected by the government of the Republic of Cyprus, to examine the trajectory and direction of agricultural change in order to inform the development of appropriate policies of mitigation. Specifically, we aim to examine changes in the areal extent of major crop types, fallow and abandoned land, changes in crop diversity and field parcel size and irrigation and to examine changes in crop prices as one potential contributory factor.

5.3 Methods

Crop-specific data were obtained from a series of “Agricultural Censuses”, “Agricultural Statistics” and other relevant publications spanning the period 1975–2010, and examined to quantify agricultural change. Additional information was obtained from the “Farm Structure Survey” (FSS) that provided the sampling framework applied in the Agricultural Statistics. However the FSS did not provide additional data as these were replicated in the Agricultural Statistics. Definitions for land-use variables were available from the 1985 [1], 1994 and 2003 Censuses and, while most variables were consistent across publications and over time, some changed definition, particularly those relating to abandoned and unused land (Table 5.1). Frustratingly, this was not always matched by a clear definition in the text or meta-data of the relevant agricultural publication. Uncertainty in variable definition was investigated through other sources, including key informant interviews. A large decrease in the area of farmland was apparent from the time series. To investigate potential factors that could have contributed to this, and to cross-validate data to support interpretation, we examined CORINE (Coordination of Information for the Environment) Land Cover (CLC) maps of Cyprus (MANRE 2009), Google Earth (Google Inc. 2011) and forestry data.

5.3.1 Data sources and validation

5.3.1.1 Agricultural data

A census of agriculture has been carried out by the Statistical Service of Cyprus (CYSTAT) at intervals of approximately every decade since establishment of the Republic of Cyprus in 1960. Although earlier data spanned the entire island, data from 1975 and subsequently exclude the area in the north of the island that is not under the direct control of the government of the Republic of Cyprus (the area for which information is available is hereafter referred to as ‘government-controlled area’). Therefore, pre-1975 data were excluded from analysis. The four most recent (1977, 1985, 1994, 2003) Censuses were used (Department of Statistics and Research 1987, 1996, Statistical Service 2005), as were preliminary data from the 2010 Census (Statistical Service 2012). Census data were collected through personal interviews (conducted by teams trained in consistent methodology) using a standardised questionnaire and these were tabulated and reported in government publications. In the 1985 and 1994 Censuses, a “post-enumeration survey” was carried out for data evaluation and to quantify under-reporting, using a random subsample of 250 and 2,460 land-holders, respectively, “distributed in all districts” (Department of Statistics and Research 1987, 1996). The results of these surveys are presented

[1] Data for the 1977 Census were included in, and extracted from, the 1985 Census. As no printed version of the 1977 was available, definitions were not known but are assumed to be consistent with the 1985 and 1994 Censuses (Table 1).

Table 5.1. *Definitions of relevant Agricultural Census terms, quoted directly from the Census documents (Department of Statistics and Research 1987, 1996, Statistical Service 2005) with added clarifications in italics.*

	Agricultural Census term definitions		
	1985	1994	2003
Unit of area	The "donum" was the unit of area data enumerated during the Census and which is defined as: 1 donum = 0.133 hectares.	The "donum" was the unit of area data recorded during the Census and which is defined as: 1 hectare (ha) = 7.475 donums *[consistent with 1985 definition]*.	Units of area measurement: 1 decare = 0.75 donums 1 donum = 1.34 decares 1 hectare = 10 decares
Total agricultural area	The total area of a holding is the combined area and all its parcels *[sic]* (cultivated or not).	The total area of a holding is the combined area of all of its parcels (cultivated or not).	The total agricultural area of the holding is the sum of the area of temporary crops, the fallow land, the permanent grassland and pastures, the area with tree (permanent) crops, the vines, the kitchen gardens, woodland of the holding and the agricultural land that is not cultivated for various economic or social reasons (have been abandoned or changed use). Also, the total agricultural land of the holding includes all other areas that take up buildings, yards, roads etc., with the condition that they are used for operational purposes (needs) of the holding.
Holding	A holding is a unit of agricultural production comprising all livestock kept and all land used wholly or partly for agricultural purposes and operated under the management of one person or more, without regard to title, legal form, size or location.	A holding is an economic unit engaged in agricultural production and consists of all livestock kept and all land used wholly or partly for agricultural purposes and operated under the management of one person or more, without regard to title, legal form, size or location.	An agricultural-livestock holding is a single unit, as of technical and as of an economical aspect, under single management that produces agricultural or livestock products. In the Census of Agriculture and Livestock 2003 was included every holding, of which the holder (natural of legal person) used: one (1) or more decares of utilized agricultural area.

Table 5.1.

Mean area per parcel	A parcel of the holding is any piece of land entirely surrounded by land, water etc. Not forming part of this holding. It may consist of one or more cadastral plots *[a cadastre is a set of records showing the precise extent, value and ownership of particular pieces of land (FAO 1995)]* adjacent to each other. Any two parcels of the same holding are not contiguous.	A parcel of the holding is any piece of land entirely surrounded by land, water etc. not forming part of this holding. It may consist of one or more cadastral plots adjacent to each other. Any two parcels of the same holding are non contiguous.	A parcel of the holding is any piece of land entirely surrounded by land, water etc., and not forming part of this holding. It may consist of one or more cadastral plots adjacent to each other. Any two parcels of the same holding are non contiguous.
Fallow land	This is land temporarily intended to rest for a period of time before it is cultivated again. A maximum period of idleness up to five years is specified.	This is land temporarily intended to rest for a period of time before it is cultivated again. A maximum period of idleness up to five years is specified.	Fallow land is the area left uncultivated up to five (5) years, in order to recover, and bearing no crops at all.
Grazing land	This relates to areas used permanently for meadows and pastures growing naturally. It is usually communal land used for grazing purposes.	This related to areas used permanently for meadows and pastures growing naturally. It is usually communal land used for grazing purposes.	Permanent grasslands and pastures are areas not included in crop rotation and are used permanently to grow herbaceous forage crops. This land can be used for grazing or mowed for silage or hay. Rough grazing is a low yielding permanent pasture, usually on low quality soil, unimproved by fertilizer, cultivation, reseeding or drainage and are somehow used from animals of the holding.

Table 5.1.

Uncultivated land	Is the land which has not been cultivated for over five years or land recently deserted and which could become potentially productive without significant costs being required.	Is the land which has not been cultivated for more than five years or land recently deserted and which could become potentially productive without significant costs being required.	Uncultivated agricultural land consists of areas of the holding that have been cultivated in the past and have remained uncultivated for various reasons: *[from census questionnaire]* (a.1) land abandoned, (a.2) land that has changed use (for construction or industrial purposes, etc.), (a.3) unused non-productive grassland, (a.4) land not cultivated for various other reasons (weather conditions, economic or social reasons, etc).
Scrub and deserted land	It refers to areas of the holding which are uncultivable or have remained uncultivated for many years and the exploitation of which for agricultural purposes would require huge costs for land clearance and land improvement.	It refers to areas of the holding which are uncultivable or have remained uncultivated for many years and the exploitation of which for agricultural purposes would require huge costs for land clearance and land improvement.	*[Not included as a category]*
Other	*[Not included as a category]*	*[Not included as a category]*	Other areas *([from census questionnaire]* "includes areas consisting of cowsheds, barns and other buildings, courtyards, tracks, rocky areas etc." *[emphasis added])*
Forest land *[i.e. private, non-government-owned forest]*	It refers to areas of the holding planted with forest trees or areas with naturally grown wild and similar trees.	It refers to areas of the holding planted with forest trees or areas with naturally grown wild and similar trees.	Woodland includes areas of the holding, which are covered with forest trees grown naturally or technically *[sic]* in the holdings own requirements *[sic]* or in a separate parcel.
Irrigated land	Irrigated land refers to the area of the holding purposively and normally provided with water other than rain.	Irrigable land refers to the area of the holding which has irrigation facilities and is normally irrigated with water other than rain.	Irrigated area is the area of crops which have actually been irrigated at least once during the reference period of the Census. If more than once crop is grown in a field during the harvest year, the area should only be indicated once; for the main irrigated crop.

as appendices of adjusted values for total area of different crop types in the respective Censuses. However, the methods for carrying out adjustment calculations were not detailed, and the bulk of the Censuses comprised unadjusted data. No equivalent appraisal exists in the 2003 Census or other surveys, except for the 2007 Farm Structure Survey (see below), for which it was deemed no adjustment was necessary (CYSTAT 2009). It is therefore assumed that no adjustments were made for area values reported in other Censuses or surveys, and unadjusted 1985 and 1994 data were used in analysis.

CYSTAT carried out Farm Structure Surveys in 2003, 2005 and 2007, with the aim of enumerating agricultural holdings and the labour force, in accordance with European Union (EU) regulations (Eurostat 2012). These surveys used a combination of exhaustive assessments of large agricultural holdings (those with standard gross margin, SGM [2] ≥ €19,220) and stratified sampling by crop type and size for other holdings (CYSTAT 2009). Data from the Censuses and the Farm Structure Surveys are used to inform annual surveys of Agricultural Statistics (e.g. economic accounts, production, land-use) between 2003 and 2008 (Statistical Service 2007, 2010a). For these latter surveys, data on areas under cultivation and crop production were collected by sampling agricultural holdings stratified by agricultural region and crop type, and selecting sampling units with probability proportional to holding size as estimated in the 2003 Census. These publications also include summary historical land-use data for 1975, 1985, 1990, 1995 and 2000–2002.

The 2004 report from the Republic of Cyprus to the Interactive European Network for Industrial Crops and Applications (IENICA, funded by the European Commission: Akkelidou *et al.* 2004) presents agricultural areas and economic accounts from CYSTAT for 1999 and 2002. Agricultural Statistics and the IENICA report provide data on the total production (tonnage) for each crop type and "producer prices" per ton of crops, commonly known as "farm-gate values", which amount to the actual or estimated gross sale price of the crops obtained by the farmer, without deduction of production costs and inputs or adjustment for any subsidies (International Monetary Fund 2004). CYSTAT use these values to compute the "gross output" or total value of production for each crop type. Gross output was in turn used in our study, along with the area under cultivation reported in the same publications, to calculate the value per hectare of cultivation for each crop type. Detailed cereal and viticulture (vines) statistics were available between 2006 and 2009, collected by using the same sampling framework as the Agriculture Statistics, with the exception of the 2009 Vines Statistics, which were a census (Statistical Service 2010b, 2011b). All variables extracted from the above publications for analysis are

[2] SGM is defined by Eurostat (2010) as a measure of the economic size of an agricultural holding and represents its expected level of profit.

Table 5.2. *Variables extracted from Agricultural Census, Statistics and IENICA documents for analysis are indicated with 'x'. Where variables were available for the same year in multiple documents, the most accurate document (Agricultural Census or Cereal/Vine Statistics) was selected. Shaded cells indicate variables not available or variables pooled in reporting that could not be disaggregated and were therefore not used in analysis.*

	Agricultural Census					Agricultural Statistics												IENICA		Cereals Statistics				Vines Statistics			
Variables	1977	1985	1994	2003	2010	1975	1985	1990	1995	2000	2001	2003	2004	2005	2006	2007	2008	1999	2002	2006	2007	2008	2009	2006	2007	2008	2009
Total agricultural area	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x								
Mean area per parcel	x	x	x	x																							
Cereal	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x				
Horticulture [a]	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x								
Legumes	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x								
Vegetables and melons	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x								
Vines	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x					x	x	x	x
Olive trees	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x								
Carob trees	x	x	x		x							x	x	x	x	x	x	x	x								
Citrus trees	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x								
Other fruit trees	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x								
Nut trees	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x								
Fallow land	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x								
Grazing land	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x								

Table 5.2.

Unused land [b]	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x								
Uncultivated land	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x								
Scrub and deserted land	x	x	x					x		x	x	x	x	x	x	x	x	x	x								
Forest land	x	x	x	x	x																						
Irrigated land		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Production (tons)												x	x	x	x	x	x	x	x								
Producer price												x	x	x	x	x	x	x	x								

[a] "Legumes" and "vegetables and melons" were treated as a single "horticulture" category.

[b] "Uncultivated land", "scrub and deserted land" and "forest land" from the Agricultural Censuses were pooled for consistency with the pooled values for "uncultivated land" and "scrub and deserted land" (that subsume forest land) from the Agricultural Statistics.

presented in Table 5.2. Where variables were available for the same year in multiple documents, the most accurate document (Census or Cereals/Vines Statistics) was selected.

Census questionnaires and the historical data reported in Agricultural Statistics documents were used to infer interpretations of definitions of unused land from earlier censuses (Table 5.1), but there was no detail of any land-use definitions in the Agricultural Statistics publications to verify consistency among years. For utilised agricultural land, areas reported in the Agricultural Statistics for 1985, 1995 and 2003 were consistent with those reported in the respective or preceding Censuses and therefore it was assumed that definitions used in Agricultural Statistics were consistent with those of the preceding Census.

In contrast, although “uncultivated land” and “scrub and deserted land”, were defined consistently between 1985 and 1994, the classification of unproductive land types differed in 2003 (see Table 5.1). In this latter census, although “uncultivated land” was still reported, “scrub and deserted land” was no longer identified as a separate category, though it may have been subsumed within “other” land (that was not reported as a category in earlier censuses). Furthermore, although “uncultivated”, “scrub and deserted” and “forest” were given separate definitions as three categories in the 1985 and 1994 censuses, the sum of all three categories was equivalent to the sum of just the first two in the Agricultural Statistics, suggesting that “forest” was somehow subsumed within scrub in these data. Mr D. Pitiris (Chief Agricultural Statistics Officer, CYSTAT) and Ms L. Alexandrou (Agricultural Statistics Officer, CYSTAT) were interviewed as key informants to attempt to understand changing definitions and census treatment, particularly relating to abandoned and unused land. Unfortunately, their non-involvement in the compilations of pre-2003 censuses did not allow elucidation of definitions or disaggregation of data into more informative subcategories. Examination of definitions for “uncultivated”, “scrub and deserted”, “forest” (prior to 2003), “woodland” (from 2003), and “other” (in 2003) (Table 5.1), suggest that pooling these categories will capture all reported abandoned land across all census and Agricultural Statistics dates. The sum of these categories is hereafter referred to as “unused” land.

Turkish-Cypriot land located in the government-controlled area is now owned by the government of the Republic of Cyprus. Part of this is rented out to Greek-Cypriot farmers; this rented land is farmed and is subsumed within the Censuses and Agricultural Statistics. However, Turkish-Cypriot land that was not rented (i.e. not used for agricultural purposes) was excluded from the total agricultural area (i.e. it was not included in the estimates of unused land) in the 1977, 1985 or 1994 Censuses, but was reported separately for those years, while the total land area abandoned by Turkish-Cypriots was reported in the 1985 Census (but not in other sources, although the total area will not alter). Treatment or estimation of any such area was not detailed in any other publication and we therefore assume that unrented Turkish-Cypriot land was excluded from agricultural area enumerations and estimates in other Censuses and surveys. This area was effectively abandoned, but as it is not consistently included in the estimates of unused land in government publications (data are only available in a subset of years), we did not include it in the estimate of unused land in this study.

5.3.1.2 Forestry, built-up land and land-cover data

Whereas successional scrub and woodland within agricultural holdings are reported in the Agricultural Statistics (Table 5.1), these do not capture other forest areas (including private forest outside the farm mosaic and government-owned forests). Data relating to the areal extent of forested land were, therefore, extracted from the Environmental Statistics document compiled by CYSTAT (Statistical Service 2006b), a recent report of the Department of Forests (2006), and the latest Global Forest Resources Assessment Country Report for Cyprus compiled by the Department of Forests in collaboration with Food and Agriculture Organization of the United Nations (FAO 2010). Changes in the definition of forest land within these data mean that figures for forest area before and after 1999 are not consistent and cannot be compared. The earlier definition was restricted to government-owned forest, excluding privately owned forested land and thus greatly underestimating forest extent (Department of Forests 2006, Statistical Service 2006b). Therefore the most recent Forest Resources Assessment data (2000–2010), which defines forested land as "land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds *in situ*" (FAO 2010), were used in this study.

An estimate of built-up land by CYSTAT is only available for 2000 (Statistical Service 2006b), but with no information on methodology or definition, so it was not possible to use this value to assess any change in urban extent. The Construction and Housing Statistics (Statistical Service 2004, 2006a, 2011a) report the area built on every year between 2000 and 2010, but this is restricted to the area under houses, offices and industrial buildings and does not include other surfaced land, such as roads, pavements, sports grounds and other related land. The island-wide satellite-generated CLC maps (MANRE 2009) were used to extract the area under different types of land-cover (CLC classes: Table 5.3), including artificial (built-up and unbuilt surfaced areas), forest and agricultural land-cover in the government-controlled area for 2000 and 2006. A map of the change in land-cover across the entire island between 2000 and 2006 is readily available from the European Environment Agency (European Environment Agency 2010b) and was used to extract the changes for the government-controlled area to compare with the changes in agricultural area reported in the CYSTAT documents over the same period. However, the minimum CLC mapping unit is 25 ha (European Environment Agency 2007); smaller features are either subsumed within the dominant land-cover class or, where complex mosaics occur, distinguished as aggregate land-cover classes in their own right (Bossard *et al.* 2000; e.g. CLC class 2.4.1, 2.4.2, 2.4.3; Table 5.3). Thus individual scattered buildings and smaller areas of built up land may not be included within the CLC "artificial" land-cover class. CLC classification accuracy for artificial land-cover was qualitatively explored by overlaying the 2006 CLC map on Google Earth, which consists of high resolution (< 2.5 m) satellite imagery (Google Inc. 2011), to identify areas that are clearly built landscape but not categorised as such by CLC. For illustration purposes, examples of these are presented.

5.3.2 Data analysis

Land-use diversity of the aggregate (country-wide) area of each of the main crop types (cereal, horticulture, olive, carob, citrus, fruit, nuts and vines), fallow, grazing, and unused land across the island was calculated as Simpson's Index. Temporal trends were investigated in: (1) land-use diversity; (2) average parcel size; (3) aggregate area of each of the above land-uses and total area under agriculture; (4) proportion of total utilised agricultural land under each land-use; (5) proportion of area of each crop type under irrigation; (6) proportion of different crops within each multi-crop land-use category (cereal, horticulture, citrus, fruit trees and nut trees) over the years for which data are available from Agricultural Censuses (1985, 1994 and 2003); (7) proportion of national GDP attributable to the agricultural sector; (8) total tonnage and yield (tons per hectare) of each crop type; and (9) value (price per ton and per hectare) of each crop product. Trends were estimated using linear or polynomial (up to 3rd degree) regression with normal error. The model with the smallest second order Akaike's Information Criterion (AICc) – or where ΔAICc < 2, the model with the smallest degree of polynomial – was selected as the most appropriate. For proportion data, regressions of arcsine-transformed data were carried out. Producer prices per ton of production and per hectare of cultivation between 1999 and 2008, available from the Agricultural Statistics (Table 5.2), were standardised to the value of the Euro (€) in 2008, according to price indices provided in the Agricultural Statistics publications. These figures were presented as box-and-whisker plots, relative to the percentage change in area of cultivation during the same period.

Data per administrative district (Nicosia, Famagusta, Larnaca, Limassol and Pafos) were only available from the 1985, 1994 and 2003 Agricultural Censuses and preliminary data from the 2010 Census. These were visually explored to evaluate potential differences in trends for major crop types between regions, which differ in gross topography, geology, water resources and suitability for agriculture.

Table 5.3. *CORINE (Coordination of Information for the Environment) Land Cover (CLC) classes represented in the government-controlled area of Cyprus (for definitions see Bossard et al. [2000]), total area (ha) under each in 2000 and 2006, and change in area (Δ Area).*

CLC classes			Area (ha) 2000	Area (ha) 2006	Δ Area (ha)
1. Artificial surfaces	1.1 Urban fabric	1.1.1 Continuous urban fabric	566.63	566.63	0
		1.1.2 Discontinuous urban fabric	30708.84	34823.87	4115.03
	1.2 Industrial, commercial and transport unit	1.2.1 Industrial or commercial units	7973.46	8845.39	871.93
		1.2.2 Roads and rail networks and associated land	297.24	499.00	201.75
		1.2.3 Port areas	191.59	191.59	0
		1.2.4 Airports	1191.59	1213.73	22.13
	1.3 Mine, dump and construction site	1.3.1 Mineral extraction sites	2426.56	2132.37	-294.19
		1.3.2 Dump sites	146.31	146.31	0
		1.3.3 Construction sites	1124.02	389.82	-734.20
	1.4 Artificial, non-agricultural vegetated areas	1.4.1 Green urban areas	931.62	855.45	-76.18
		1.4.2 Sport and leisure facilities	3833.80	5297.42	1463.61
2. Agricultural areas	2.1 Arable land	2.1.1 Non-irrigated arable land	90170.31	89049.19	-1121.12
		2.1.2 Permanently irrigated land	16030.92	15680.73	-350.19
	2.2 Permanent crops	2.2.1 Vineyards	14133.07	14064.51	-68.56
		2.2.2 Fruit trees and berry plantations	9941.70	9151.83	-789.88
		2.2.3 Olive groves	4719.12	4731.28	12.16
	2.3 Pastures	2.3.1 Pastures	583.84	588.05	4.21
	2.4 Heterogeneous agricultural areas	2.4.1 Annual crops associated with permanent crops	22268.65	21844.45	-424.20
		2.4.2 Complex cultivation pattern with scattered houses	61062.83	61169.25	106.42
		2.4.3 Land principally occupied by agriculture, with significant areas of natural vegetation	35191.00	36471.64	1280.64
3. Forest and semi-natural areas	3.1 Forest	3.1.1 Broad-leaved forest	760.17	752.43	-7.74
		3.1.2 Coniferous forest	129655.25	129594.45	-60.79
		3.1.3 Mixed forest	121.09	121.09	0
	3.2 Shrub and/or herbaceous vegetation associations	3.2.1 Natural grassland	18264.45	17178.08	-1086.36
		3.2.3 Sclerophylous vegetation	107467.89	105931.08	-1536.81
		3.2.4 Transitional woodland/shrub	17820.00	23907.43	6087.43
	3.3 Open spaces with little or no vegetation	3.3.1 Beaches, dunes, and sand plains	2356.45	2356.45	0
		3.3.2 Bare rocks	2135.54	2135.54	0
		3.3.3 Sparsely vegetated areas	6755.45	6685.40	-70.06
		3.3.4 Burnt areas	7783.42	241.27	-7542.15
4. Wetlands	4.1 Inland wetlands	4.1.1 Inland marshes	189.93	189.93	0
	4.2 Coastal wetlands	4.2.1 Salt marshes	1955.23	1955.23	0
5. Water	5.1 Inland waters	5.1.2 Water bodies	1224.56	1224.56	0

5.4 Results & Discussion

5.4.1 Apparent reduction in farmland extent and missing land

Preliminary analysis showed an apparent decline of 31% in the total area under agriculture in the government-controlled area of Cyprus in the 35-year period, from 232,600 ha in 1975 to 137,769 ha in 2010, amounting to a decrease of 94,831 ha (Fig. 5.1). Much of this decrease occurred after the 1994 census. However, this was not matched by a concomitant increase in the extent of unused land reported in the agricultural censuses and statistics (Fig. 5.1). We therefore investigated the potential contribution of different land-use changes, including afforestation, built development and abandonment, to the reduction of agricultural area, and attempted to assess qualitatively the potential for under-reporting of abandoned farmland during the collection of Agricultural Census and survey data.

5.4.1.1 Abandoned Turkish-Cypriot land

Total Turkish-Cypriot land amounted to 49,929 ha, according to the 1985 Agricultural Census. Of this area, 23,067 ha were not rented to Greek-Cypriot farmers or not reported by holders in 1977, rising to 27,452 ha in 1985 and falling to 21,137 ha in 1994. The proportion that was rented in subsequent census periods was not reported. The unrented proportion of Turkish-Cypriot land that presumably remained abandoned (unless illegally farmed without payment of rent) was fairly consistent during this time, in the range 42–55%. Between 1977 and 1994, agricultural land area as estimated by CYSTAT (i.e. excluding unrented Turkish-Cypriot land) declined by 11%, from 199,539 ha in 1977 to 177,732 ha in 1994. Incorporating unrented Turkish-Cypriot land (as additional abandoned area) within the total farmland, predicts a similar decrease of 8% in total agricultural land area.

We investigated whether a substantial reduction in the area of Turkish-Cypriot land rented after 1994, and thus included in the agricultural statistics, could explain the apparent reduction in farmland area. The extreme scenario would be for all of the mean 23,885 ha rented during 1977–1994 to be abandoned and unreported in the latter period. At best, this could potentially explain only 25% of the observed decrease in farmland area. Changes in rental or reporting of Turkish-Cypriot land may have contributed to the decline in agricultural area, but at best only a part of the decline could be attributed to any such change.

For consistency, agricultural land area reported in subsequent analysis excludes unrented Turkish-Cypriot land and thus underestimates unused land by 23,885 ha (± 3,236 s.d.) on average, assuming the proportion of unrented Turkish-Cypriot land remained stable after 1994. Any variations between years in the proportion of the total Turkish-Cypriot land area that is

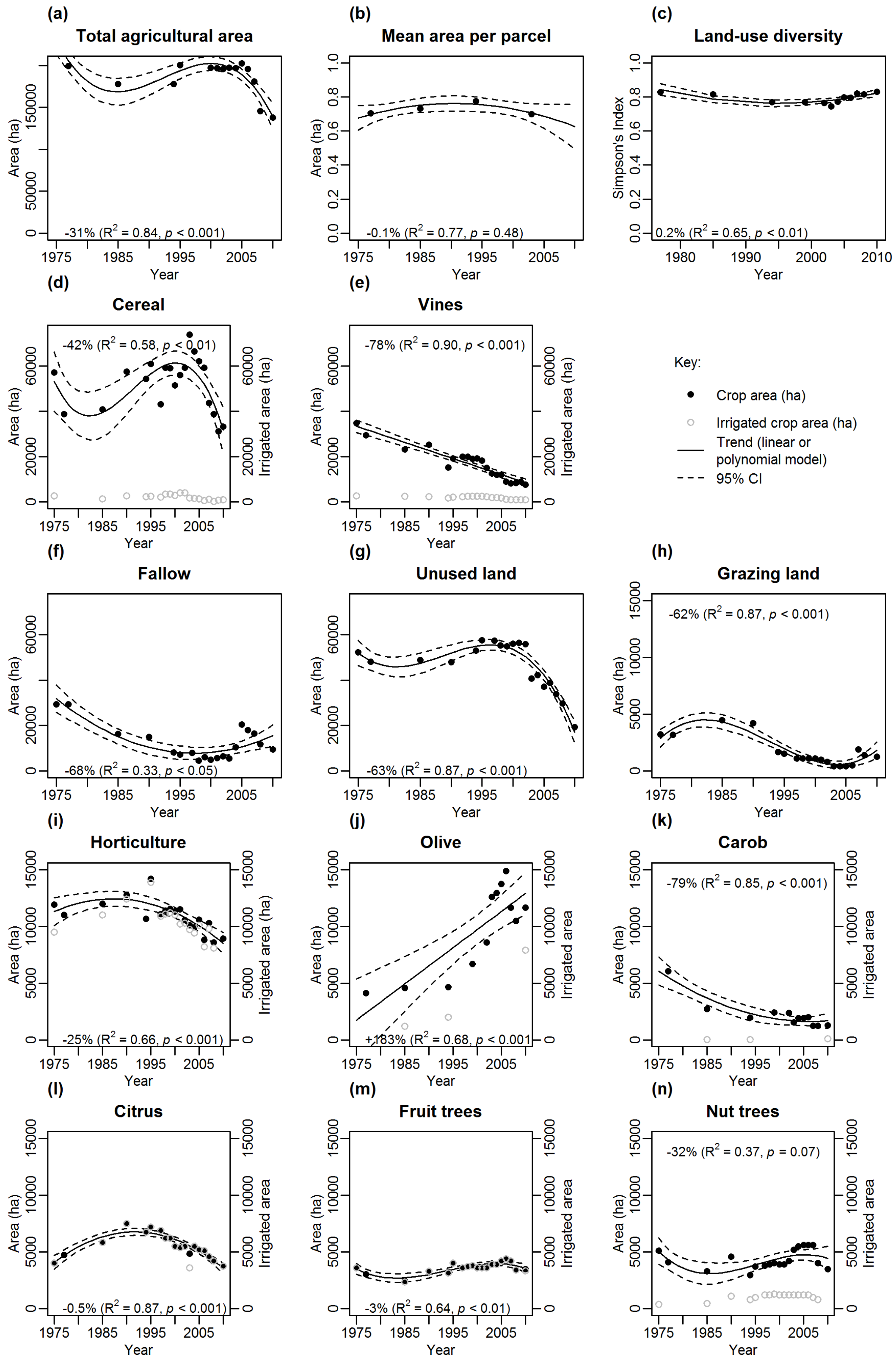


Figure 5.1. *Area (ha) of major crop types and agricultural land-uses (filled black circles) in Cyprus from 1975–2010, showing percentage change,* r^2, *significance* (p-value) *of the trend (solid line) and 95% confidence intervals (dashed line). Irrigated area (ha) for each crop type is shown as open grey circles.*

rented will contribute to fluctuations in the total agricultural area.

5.4.1.2 Under-reporting

The 1985 and 1994 Censuses document a degree of under-reporting in Census questionnaires, amounting to 4% and 6% of respondents, respectively. According to both Censuses, this was "attributed to possible fears for taxation, mis-reporting of some not-owned land or land not considered quite productive (e.g. planted with old or scattered trees, uncultivable areas etc.)". This suggests that at least some proportion of the under-reported land would comprise marginal and/or abandoned farmland, and that abandoned land would therefore be systematically under-reported relative to cropland. Problems with collecting information from holders residing in urban areas were also reported, and such individuals "tended to state that their land was operated by others and didn't consider themselves as holders because of their different main occupation" (Department of Statistics and Research 1987, 1996). This therefore suggests that non-response by these individuals may be compensated for by other respondents who had now taken over this land.

During the 2007 Farm Structure Survey, 9% of the sample failed to respond, for reasons that included "farm no longer active" and "farm temporarily inactive" (109 and 149 cases, respectively, together comprising 25% of the 1,016 cases for which reasons for non-response were known, which in turn comprised 82% of the overall total of 1,232 cases of non-response: CYSTAT 2009); thus in 2007 abandoned farmland may have comprised a disproportionate amount of the unreported land, again suggesting a systematic bias to under-reporting of abandoned land. The "post-enumeration surveys" of the 1985 and 1994 Censuses showed positive adjustments of total areas across crop types (adjusted estimate of total crop area was 29% greater than the unadjusted figure in 1985 and 21% greater in 1994), providing strong evidence for considerable under-reporting of cropland. However, no area adjustments were made for fallow or unused land categories (uncultivated land; forest; scrub and deserted land), indicating the low importance assigned to these categories by the government. Systematic under-reporting of unused or abandoned land is probable, given the reasons presented for under-reporting in the 1985 and 1994 censuses, although it was not possible to quantify to what extent this accounted for the apparent decline in agricultural land area.

Significant non-response relative to land under active production may be less probable, as direct payments under the Common Agricultural Policy (CAP) and the Cyprus Rural Development Plan (RDP) since 2004 are made proportional to the area under cultivation (Cyprus Agricultural Payments Organization 2010), providing an incentive to report all utilised area to the Cyprus Agricultural Payments Organisation (CAPO). It is possible that non-response to CYSTAT for the purpose of enumeration of land under agriculture was greater than non-application to CAPO for payments. Unfortunately, despite repeated requests, it was not possible to examine the data kept by CAPO on the area subject to direct payments. Increased under-reporting of unused land is a plausible explanation that may have contributed to the apparent decline in agricultural area but, owing to the inconsistent definitions (Table 5.1) and the lack of adjustments for under-reporting of unused land, there are no robust credible data available to assess this hypothesis.

CLC (MANRE 2005a, 2009) overestimated total agricultural land when compared to CYSTAT, by about 57,000 ha (2000: CLC = 254,101 ha, CYSTAT = 197,300 ha; 2006: CLC = 252,751 ha, CYSTAT = 195,800 ha). Much of this discrepancy may be due to marginal or abandoned farmland not reported to CYSTAT, and abandoned (unrented) Turkish-Cypriot land not included in the CYSTAT area estimates, but that represent parcels of scrub or fallow land aggregated within complex agricultural landscapes classified by CLC.

5.4.1.3 Expansion of urban extent and forested land

According to CYSTAT (Statistical Service 2006b), built-up land in 2000 amounted to 20,500 ha, which is less than half the CLC estimate of artificial surfaces for the same year (49,392 ha). This discrepancy may be due to differing definitions, with CYSTAT potentially limiting its estimate to major urban agglomerations, unlike CLC (Table 5.3, Bossard *et al.* 2000). However, no details were available on the CYSTAT estimate of built-up land, so it was not possible to evaluate whether this was the case. The total new area built on between 2000 and 2010 in the government-controlled area was 2,717 ha according to the Construction and Housing Statistics (Statistical Service 2004, 2006a, 2011a), equivalent to less than 5% of the total loss of agricultural land in the same period (59,531 ha). This initially suggests that built development does not explain the farmland loss. However, the CLC maps (MANRE 2005a, 2009) for the government-controlled area show an increase of 5,570 ha in extent of artificial surfaces (CLC class 1: Table 5.3) between 2000 and 2006. CLC reports a loss of 1,350 ha of agricultural land-cover over this period (2000–2006) in the government-controlled area, close to the CYSTAT estimate for the same period (1,500 ha). This is suggestive that built development could potentially have contributed to much of the loss of farmland in this period. Furthermore, of the land consumed by artificial land-cover from 2000–2006, 60% consisted of conversion from agricultural land-cover classes, and expansion of built-up and related land was responsible for 77% of the conversion from agricultural land-cover between 2000 and 2006 (Table 5.4). However, projecting a similar rate of expansion in artificial land-cover in the latter years to 2010, could represent only 16% of the loss in farmland over the ten year period. Although both the CYSTAT and CLC data suggest that urban expansion and built development represent only

Table 5.4. *CORINE (Coordination of Information for the Environment) Land Cover changes (ha) between 2000 and 2006 in the government-controlled area of Cyprus.*

		Change to (2006):													
		Artificial surfaces								Agricultural areas				Transitional woodland/shrub	Burnt areas
Change from (2000):	CLC class	112	121	122	124	131	132	133	142	211	212	242	243	324	334
Artificial surfaces	112		6.5												
	121			7.5											
	131											212.4		148.1	
	133	397.1	138.8	226.3					188.6						
	141	34.4							41.9						
Agricultural areas	211	650.6	388.5	27.8		39.5		106.1	46.6			419.5			73.3
	212	201.1	87.1			18.8						49.2			
	221	43.6													
	222	128.2	28.8						13.3			545.6			
	223	49.5	21.7												
	231							9.1	16.9						
	241	213.9	39.9					33.6	55.6			80.8			
	242	1041.4	131.9		14.4	32.0		64.2	442.4		7.0				
	243	319.6				18.9		6.1	15.8			113.8			
Forest	311				7.7										
	312	13.0				22.1						0.7			93.7
Shrub and/or grassland	321	254.1	169.3					175.1	61.8	438.4		40.8			
	323	418.3	79.1			63.1	15.2	73.4	547.7			394.3			39.7
	324	15.8													54.6
Sparsely vegetated areas	333	21.5				9.0								48.3	
Burnt areas	334												1735.3	6048.9	

Figure 5.2. *Comparison of CORINE (Coordination of Information for the Environment) Land Cover (CLC) map (MANRE 2009) and Google Earth (Google Inc. 2011) shows frequent misclassification of built-up land.*

a small proportion (< 20%) of the loss of farmland, two caveats are important. First, CLC underestimates built-up area. For example, CLC frequently misses entire villages, particularly when embedded in complex mosaics (Fig. 5.2; Google Inc. 2011). Given that CLC minimum resolution is 25 ha (European Environment Agency 2007), it is likely that artificial land-cover is underestimated. To quantify the degree of misclassification in CLC, detailed analysis of high-resolution satellite imagery would be required. Second, there is often a long delay between removal of land from agricultural production and completion of planned development.

According to CYSTAT, "residential development, urbanisation and the construction of works, such as roads, buildings, public utility projects etc" contributed to the decline in agricultural area (Statistical Service 2006b), while a recent statement by the Cyprus Scientific and Technical Chamber (ETEK 2012) asserts that inappropriate implementation of relevant legislation has allowed "scattered, uncontrolled and unplanned construction development" and resulted in "wastage of productive land". Similarly, the European Environment Agency characterised land-cover change in Cyprus between 2000 and 2006 as a combination of "diffuse sprawl of residential areas, sport and leisure facilities" and "consumption of agricultural land" (European Environment Agency 2010a).

CYSTAT also states that forest area has increased "at the expense of agricultural land" (Statistical Service 2006b). This was echoed by the Department of Forests (2006), which stated that privately owned forest land derives from abandoned agricultural land and the expansion of forest vegetation ("Η δημιουργία των δασών αυτών [ιδιωτικών] οφείλεται στην αποδημία των ανθρώπων από τις ορεινές ή ημιορεινές περιοχές στις αστικές, την εγκατάλειψη των γεωργικών εκτάσεων που γειτονεύουν με τα κρατικά δάση και τη φυσική επέκταση της δασικής βλάστησης"; "The creation of these [private] forests is due to the emigration of people from mountainous or semi-mountainous areas to urban areas, the abandonment of agricultural lands that neighbour state-owned forests and the natural expansion of forest vegetation"). According to FAO (2010), between 2000 and 2010 forest land was estimated to have increased by 1,572 ha, accounting for less than 3% of the decline in agricultural area over the same period (59,531 ha). In contrast, the CLC maps showed a decrease in forest extent of 69 ha between 2000 and 2006 in the government-controlled area (Table 5.3), probably as a result of FAO (2010) including in their definition of forest young trees with the potential to achieve thresholds of height and canopy cover. However, CLC showed an increase of 6,087 ha in transitional woodland/shrub (CLC class 3.2.4: "bushy or herbaceous vegetation with scatted trees [that] can represent either woodland degradation or forest regeneration/recolonisation": Bossard *et al.* 2000), attributable to regeneration after fire events and afforestation of mineral extraction sites and sparsely vegetated areas (Table 5.4, European Environment Agency 2010b). Together, this

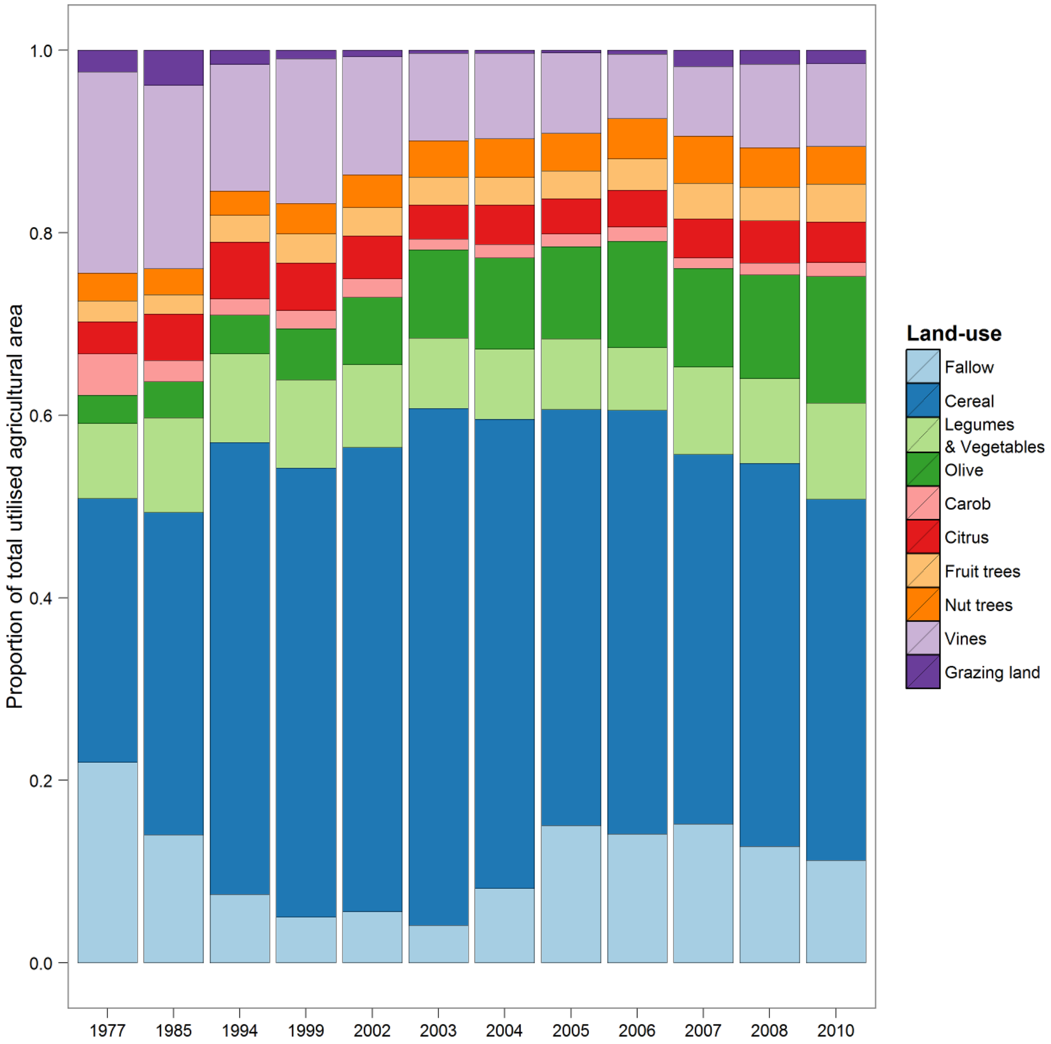


Figure 5.3. *Proportion of total utilised agricultural area under each major crop type and land-use from 1977 to 2010.*

represents a net increase of 6,018 ha of scrub or forest. No conversion from agricultural to forest land-cover was recorded at CLC resolution (Table 5.4, European Environment Agency 2010b). The statements by CYSTAT and the Department of Forests probably reflect historical trends resulting from rural depopulation. Between 1992 and 2011 the proportion of the population residing in rural areas remained constant, at 32% (± 0.5 s.d.) on average (CYSTAT 2012), but had previously declined from 53% in 1975 (The World Bank 2012). However, it is important to note that a prescription exists in the Cyprus RDP to subsidise afforestation of abandoned or marginal agricultural land, and a small area (148 ha) was afforested under this measure between 2004 and 2010 (ΕΤΑΜ ΑΕ & ΛΚΝ ΑΝΑΛΥΣΙΣ ΕΠΕ 2008, ΛΚΝ ΑΝΑΛΥΣΙΣ ΕΠΕ & ΙΤΑΝΟΣ ΛΤΔ 2010).

5.4.1.4 Synthesis: accounting for the loss of farmland

On the basis of the above, forest expansion can only account for a small fraction of the recent observed decline in agricultural area (59,531 ha between 2000 and 2010). Changes in rental or farming patterns of Turkish-Cypriot land cannot explain the large decrease in reported farmland. There is evidence for selective under-reporting of unused or abandoned farmland, the degree of which cannot be quantified. Thus it is possible that a considerable part of the observed decline in farmland may be due to abandonment. There are problems in quantifying the contribution of built development to farmland change, due to non-inclusion of associated developed land in the CYSTAT measure of built-up area and the poor resolution of CLC “artificial surfaces”. While the small reduction in farmland during 2000–2006 was largely related to building, it is unlikely that the much greater drop in reported farmland area by 2010 would be built within that time. However, it is conceivable that much of the land no longer reported as farmland could have been removed from production, with a view to development. Under current legislation (ETEK 2012) it seems likely that abandonment could result in building development.

5.4.2 Changes within the area under agriculture

Land-use diversity and mean parcel area did not change appreciably over the data period (Fig. 5.1), suggesting that the structure of the farmed landscape has not changed substantially. The only land-use to have increased was olive cultivation, which nearly trebled in area (Fig. 5.1). Citrus showed the smallest decrease in area (2%), while carobs and vines showed the largest (79% and 78%, respectively). The extent of fallow, grazing and unused land also declined substantially (68%, 62% and 63%, respectively). The decline in fallow land between 1985 and 1995 (9,172 ha) reflects and can account for nearly half the increase in area under cereal cultivation during the same period (20,011 ha). Although the trend in absolute area under agriculture is not clearly understood owing to uncertainties over under-reporting and unused land (see above), the proportion of reported agricultural area under different land-use types also showed significant trends over time (Figs. 5.3 and 5.4). The proportion of area under carobs, vines, and fallow declined by 69%, 63% and 46%, respectively, while the proportion under olives increased by 310% (Fig. 5.4). This provides strong evidence for a genuine increase in area under olive cultivation and decrease in area under vines, carob and fallow.

Crop composition within major land-use types did not substantially change between 1985 and 2003 (Fig. 5.5). The relative composition of cereal (wheat and barley), citrus fruits (oranges, lemons, grapefruit and mandarines) and nuts (almonds, walnuts, pistachios and hazelnuts) remained constant over time. For other fruit trees, the proportion of area under cherry cultivation halved ($t_1 = -22.13$, $p < 0.05$), while there was a near-significant increase in the

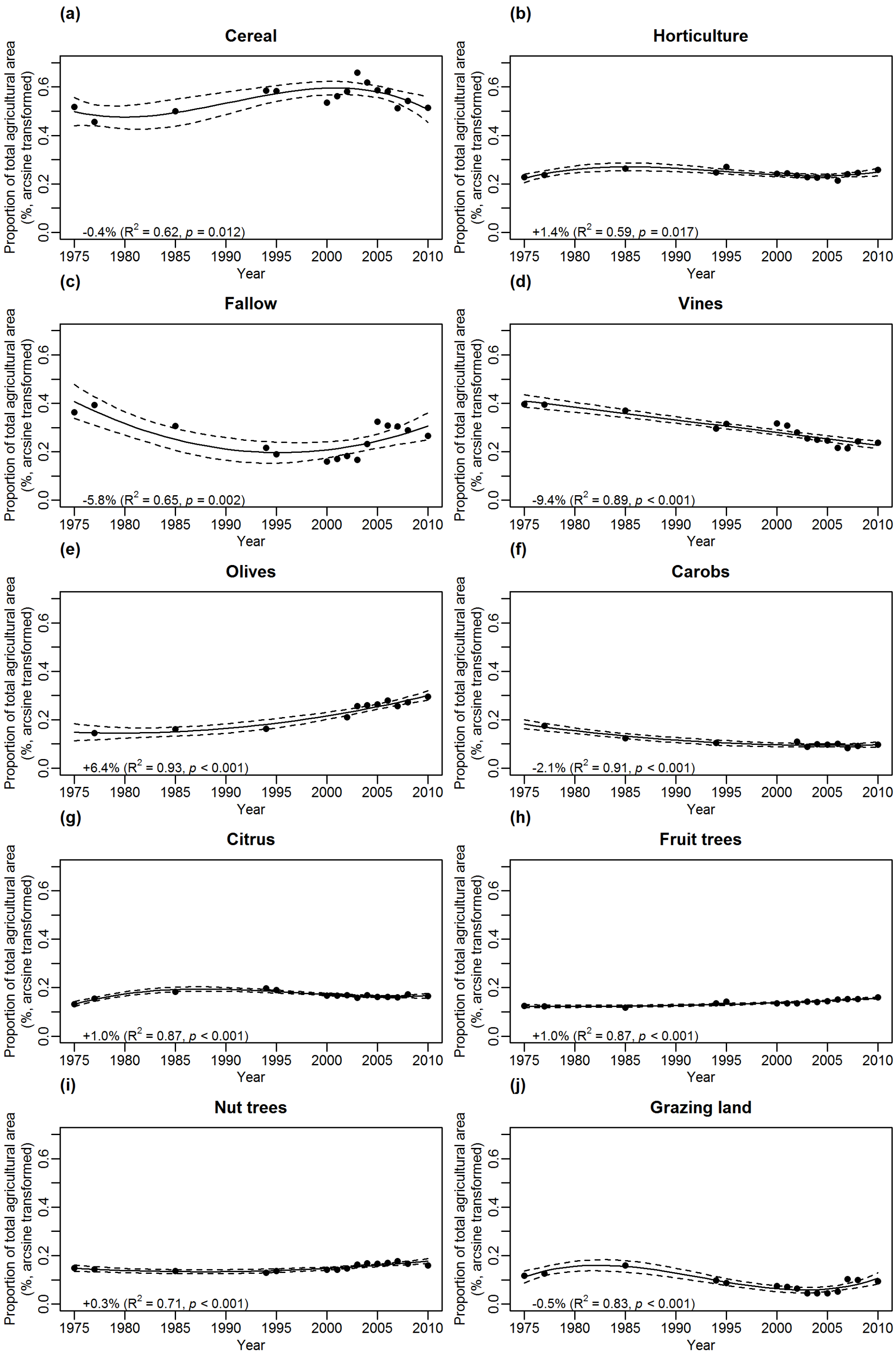


Figure 5.4. *Proportion of utilised agricultural area under each major crop type and land-use from 1975–2010, showing change in percent,* r^2*, significance* (p-value) *of the trend (solid line) and 95% confidence intervals (dashed line).*

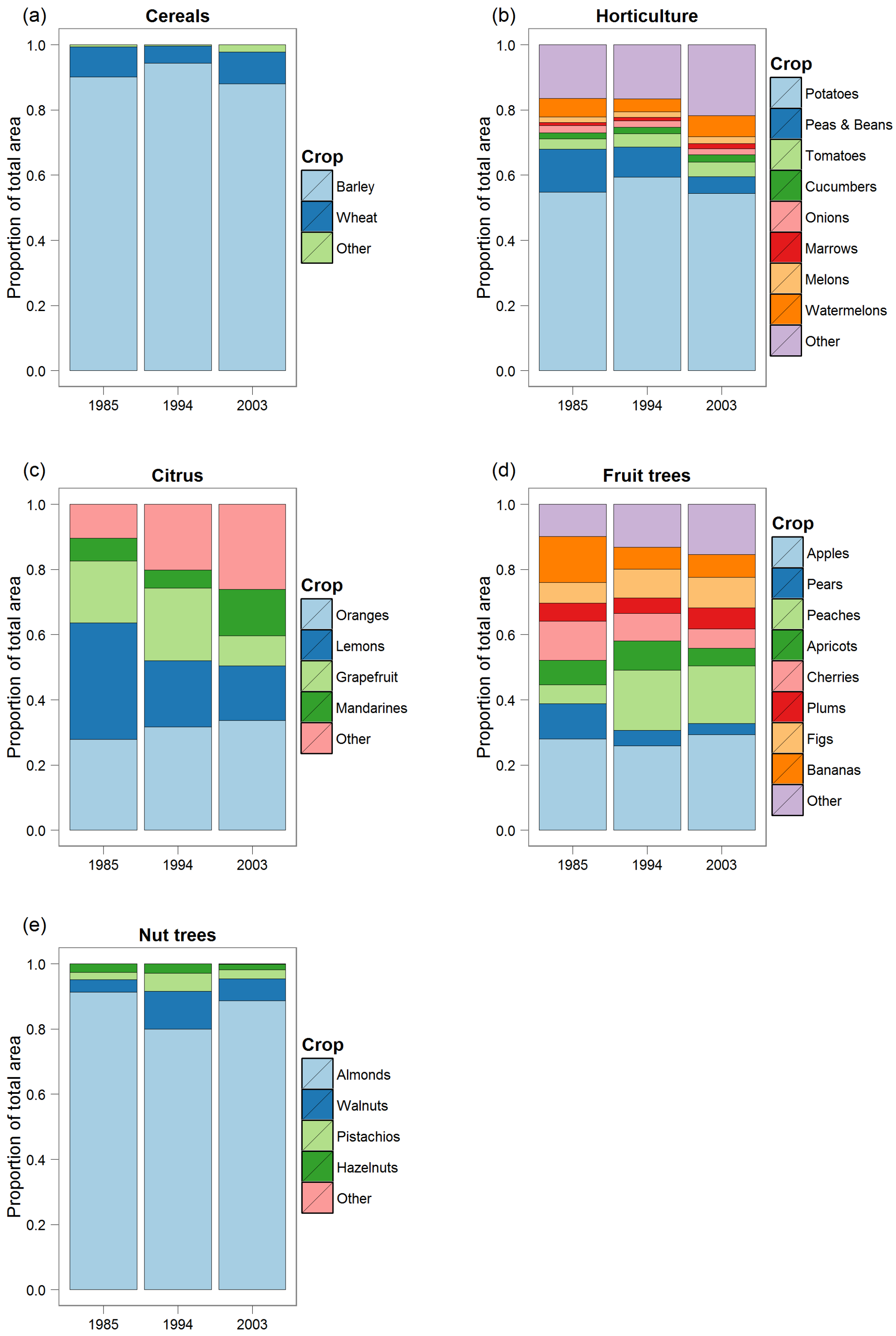


Figure 5.5. *Crop composition of the major crop types from 1985 to 2003 in Cyprus.*

proportion of area under loquats from 1.4% to 1.7% ($t_1 = 11.63$, $p = 0.05$). The proportion of area under the main horticulture crops (potatoes, peas and beans, tomatoes, cucumbers, onions, marrows, melons and watermelons) did not change during the time period, but dasheen and aubergines increased significantly from 0.8% to 1% and from 0.3% to 0.6%, respectively (t_1 = 34.39 and 31.78, p = 0.018 and 0.020, respectively).

5.4.3 Administrative districts

Between 1985 and 2010 agricultural areas in each of the five administrative districts (Nicosia, Famagusta, Larnaca, Limassol, Pafos) showed similar patterns over time for most crop types and land-uses (Fig. 5.6). Regional specialisation was evident, with different crop types characterising different districts, according to topography and suitability for different types of production. For example, over the entire time period 1985–2010, the largest areas of cereal cultivation were in Nicosia and Larnaca, and Famagusta was dominated by horticulture. The majority of vines remain concentrated in Limassol and Pafos, and fruit and nut trees were cultivated mainly in Nicosia, Limassol and Pafos. Limassol had the largest area of citrus cultivation until 1994, but from 2003 this area declined in Limassol more than in Pafos. Limassol also had the largest area of carob throughout the time period, and the decline in carobs was most evident in this district. Grazing land declined dramatically by 2003, and recovered somewhat in Pafos but not Nicosia in 2010, suggesting a potential regional shift in livestock.

5.4.4 Changes in value and intensification

The importance of the agriculture sector to the economy has declined dramatically over time, with its share of the national GDP decreasing from 16% in 1975 to 2% in 2008 (Statistical Service 2007, 2010a), so it would not be surprising if agricultural area has declined. The most valuable crops between 1999 and 2008 were nuts (mean €/ton = 2,923.65 ± 400.74 s.d.), tree fruits (mean €/ton = 1,418.33 ± 132.28 s.d.) and olives (127.77 ± 199.03), while cereal (270.62 ± 69.54), carobs (284.28 ± 60.99) and vines (324.88 ± 64.61) were the least valuable. In contrast, the value of the land under cultivation, measured as price per hectare, was greatest for horticulture (mean €/ha = 16,053.32 ± 1,435.13 s.d.) and citrus (10,180.44 ± 1,365.53), and lowest for cereal (431.11 ± 285.47), nuts (719.92 ± 306.07), carobs (975.05 ± 272.73) and vines (1,699.55 ± 638.80) (Fig. 5.7). The low value of carobs and vines, both in terms of crop and of land-use, is consistent with the negative trend observed in absolute area and in the proportion of agricultural land under these land-uses, while the high value of olives is consistent with the positive trend in area and proportion for this crop.

The producer price per ton of crop between 1999 and 2008 increased by 38% for citrus and

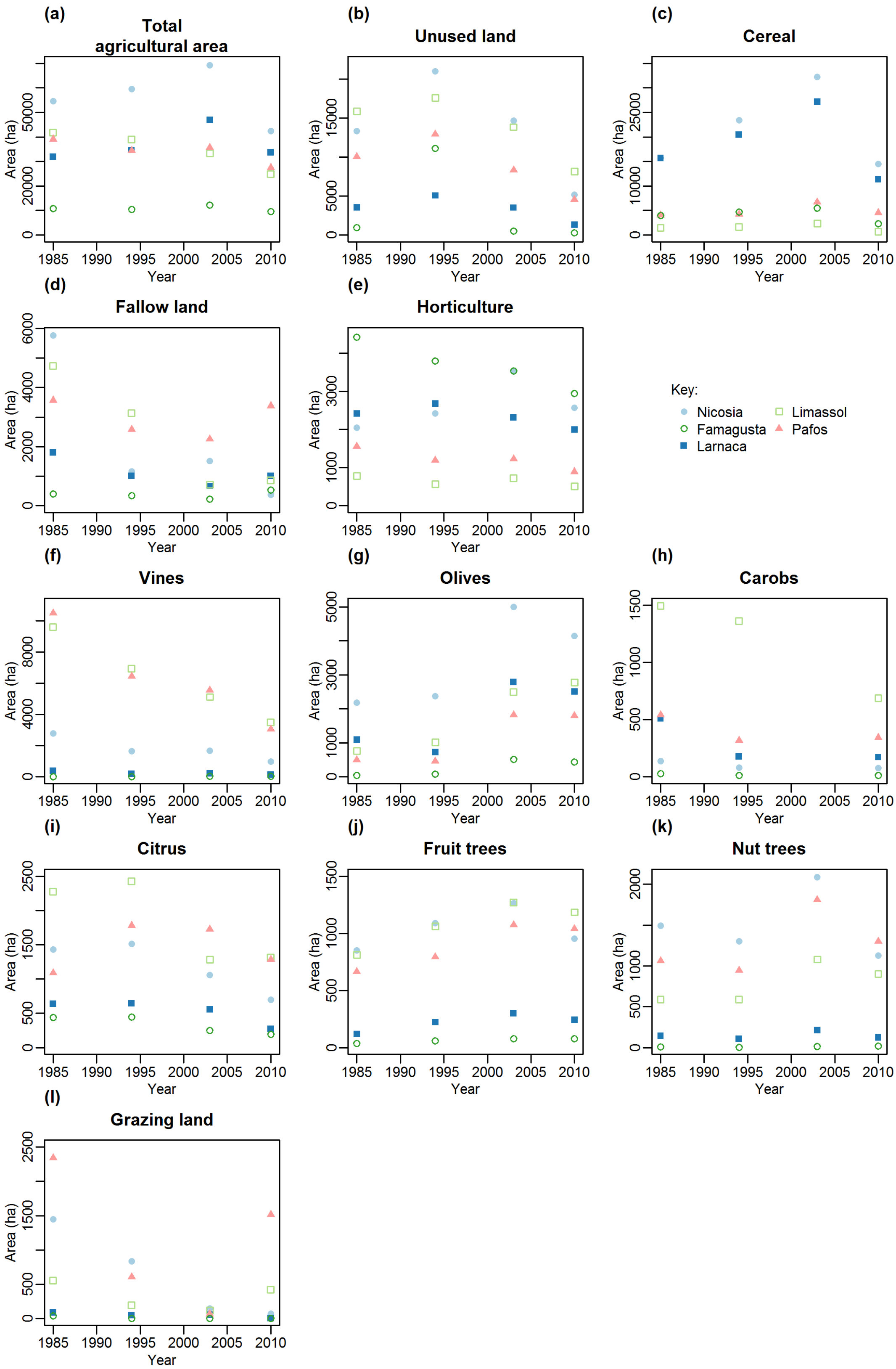


Figure 5.6. *Area (ha) of major crop types and agricultural land-uses in each administrative district (Nicosia, Famagusta, Larnaca, Limassol, Pafos) between 1985 and 2010.*

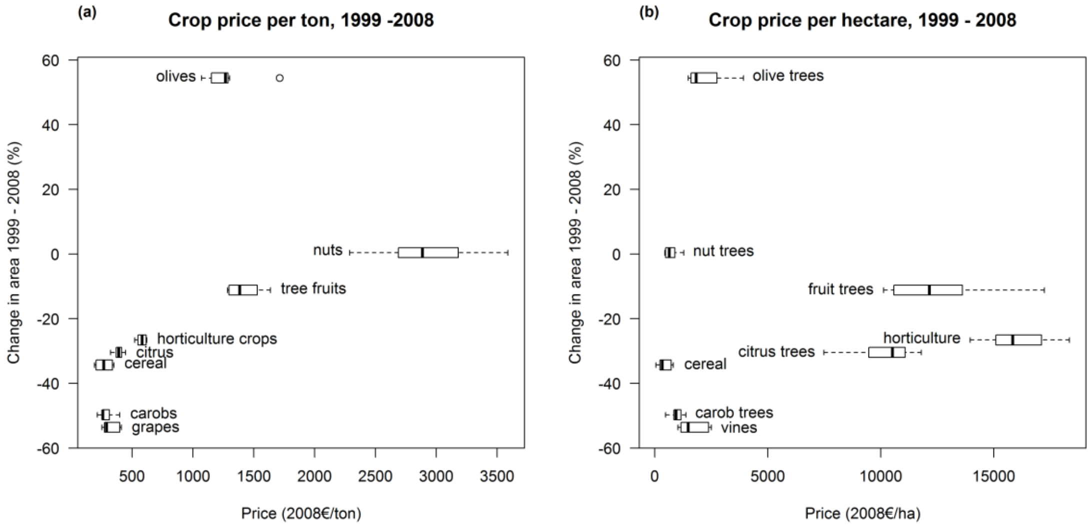


Figure 5.7. *Value (standardised to 2008 €) per ton of product (a) and per hectare of cultivation (b), represented as box-and-whisker diagrams, against percentage change in area between 1999 and 2008.*

decreased by 35% for vines and by 24% for olives (Fig. 5.8). Over the same period, price per hectare declined for cereal, vines, olives, fruit and nut trees by 93%, 55%, 46%, 20% and 58% respectively, but increased for carobs and citrus, by 185% and 57%, respectively (Fig. 5.8). The value of agricultural products, and hence prices per ton and per hectare, is dependent not only on production, but also on variables not included in this study, such as direct government subsidies, national and international demand, world commodity prices, etc.

Production (total tonnage) declined between 1999 and 2008 for all crop types except olives and carobs, which increased by 11% and 21%, respectively. This may be at least partly due to climate, as Cyprus has been experiencing a period of low precipitation since the late 1960s and early 1970s, when rainfall declined to a new average, 20% lower than previously (Pashiardis 2002). There have also been multiple prolonged drought events since the 1980s, the most recent occurring between 1996 and 1999 and between 2004 and 2008, with 2007/2008 having the second lowest rainfall since 1901 (Tsiourtis 1999, Meteorological Service undated). Olives and carobs are drought-resistant (Lo Gullo & Salleo 1988) and this could partly account for their increasing production over the data period, although for olives the increasing area of cultivation was probably the main driver of this trend. Between 1999 and 2008 yield (tons per hectare) declined by 92% for cereal and by 26% for fruit trees, but increased by 14% for citrus (Fig. 5.8). These trends may also be attributable to the long-term drought, especially for cereals, which are rain-fed. Fruit trees are mainly cultivated in marginal mountainous areas, and a decline in yield may result from extreme weather events, e.g. hail, to which these crops are highly vulnerable

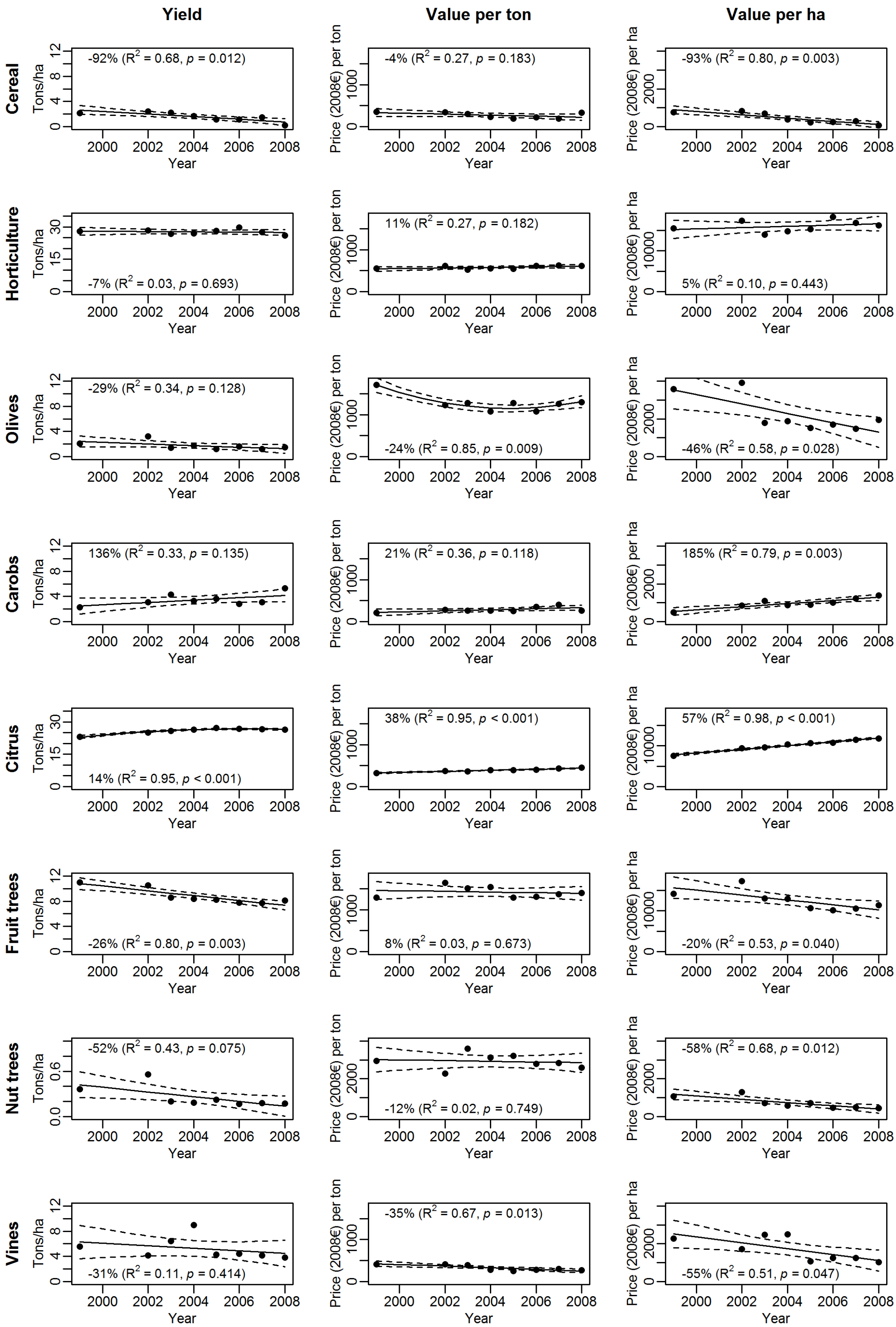


Figure 5.8. *Yield, value (standardised to 2008 €) per ton and per hectare of cultivation from 1999 to 2008, showing percentage change,* r^2*, significance* (p-*value) of the trend (solid line) and 95% confidence intervals (dashed line).*

(Nicolaides *et al.* 2009), although we have not found relevant data for the period under study to assess the degree to which an increase in frequency of such events may the cause behind the decline in yield. Citrus cultivation is almost entirely irrigated and the crop and land-use have also increased in value, which would explain the observed increase in yield. The proportion of area under irrigation did not change for most land-uses, although this fluctuated for nut trees. Exceptions were olives and viticulture, which showed significant increases, from 26% in 1985 to 68% in 2010 ($t_1 = 14.15$, $p = 0.045$) for olives, and from 8% in 1975 to 14% in 2010 ($t_{17} = 3.87$, $p = 0.001$) for vines. For olives, this suggests that the increase in area under cultivation can be attributed to the creation of intensive irrigated plantations, as also stated by the Department of Agriculture (2004). For viticulture, the total area of which has declined, the near doubling of the proportion of vines under irrigation indicates the progressive replacement or loss of less intensive, non-irrigated vineyards.

5.4.5 Conclusions, consequences for biodiversity and recommendations

Agriculture has dramatically decreased in importance for the Cyprus economy, although, according to the Agricultural Research Institute, this was partly due to the rapid expansion of the secondary and tertiary sectors (Papadavid 2008). Therefore, the apparent decline in total land area under agriculture is not surprising, although it may be inflated to some extent by non-reporting. Carob cultivation and viticulture suffered the most important declines, while there is evidence for loss of low-intensity vineyards in particular. In contrast, olive cultivation has increased, with the creation of irrigated, more intensive plantations. The Agricultural Research Institute cites high land-opportunity costs as a contributing factor to the decline in agricultural land area (Papadavid 2008) and conversion to artificial land-cover appears to be at least one important driver of farmland loss.

Unfortunately, it was not possible to quantify reliably the extent to which farmland has been abandoned, whether particular types of agriculture are more vulnerable, and what the fate of this abandoned land has been. Government publications and detailed statistics maintain reliable data on utilised farmland, but unused and abandoned land is inconsistently reported across publications and over time, suggesting that it is assigned low importance. On the basis of the evidence we present in this study, we suggest that abandonment of farmland is prevalent, particularly in marginal and low-intensity systems. However, poor consistency in variable definitions across government publications, lack of definitions altogether in some, and lack of transparency regarding data quality or pre-publication data handling and analysis, do not allow clear understanding of trends in abandoned land. This is confounded by likely systematic under-reporting following abandonment.

Many factors, including the development of non-agricultural sectors, rural depopulation and an ageing agricultural community, have been contributing to the decline in agriculture in Cyprus since before entry to the CAP in 2004, and are issues faced by most other developed countries (Department of Agriculture 2004). More recent problems in the Cyprus agriculture sector can be attributed to poor competitiveness in EU and world markets, which in a large part derives from high government pre-CAP subsidies that encouraged over-production and maintained artificially high product prices (Papadavid 2008). Accession to the EU and entry into the CAP has led to a substantial reduction in the financial support enjoyed by Cypriot farmers, resulting in expensive products with low market competitiveness (Costas Petrides and Associates 2005). Apart from increasing fuel costs worldwide and the prolonged drought, the Agricultural Research Institute attributes the high production costs in Cyprus to the fragmented nature of the agricultural landscape, which does not allow mechanisation and the introduction of new technology (Markou & Kavazis 2006, Papadavid 2008).

Intensification of agriculture in Cyprus takes the form of irrigation, as much investment in the agriculture sector relates to water development (MANRE 2005b, Markou & Kavazis 2006). Intensive, irrigated crops, such as vegetables, citrus and other fruit trees are the most valuable, and irrigated olive trees and vineyards are proportionally increasing. Viticulture is a particularly interesting system, as it has shown the largest decline in its share of agricultural land area, as a result of government policy to combat over-production, eliminate abandoned vineyards and emphasise quality of product (Department of Agriculture 2004, Costas Petrides and Associates 2005, Markou & Kavazis 2006). Costas Petrides and Associates (2005) also state that many vineyards were lost to residential or tourism development. This is also cited as a reason for the loss of carob groves, along with use of carob trees for charcoal production, despite carob-specific government subsidies (Della 2000, Akkelidou *et al.* 2004).

These trends point to the loss of traditional elements (e.g. vines, carobs, non-intensive olives) on which much avian biodiversity depends. Land under agriculture is likely to continue declining in Cyprus, to a large extent lost to building development, with much of the remaining farmland dedicated to irrigated production of the more valuable crops. The effect of irrigation and other forms of intensification of within-field farming practices (biocide and fertiliser inputs) on the avian biodiversity was outside the scope of earlier chapters in this thesis. It is therefore difficult to evaluate the potential impact of the increasing irrigated proportion of agricultural land. However, both horticulture and citrus groves were found to be valuable for farmland birds (see Chapter 3), including priority species, particularly within a heterogeneous farmland matrix (see Chapter 4). Therefore, the apparent inertia of field parcel size may mitigate at least some of the adverse effects of intensification.

However, loss of marginal land-uses would certainly have (and probably has had) significant negative impacts on farmland biodiversity. The trends in area suggest that RDP payments for rotovation (replacing herbicide treatment) of traditional tree varieties (carobs and nut trees) do not appear to have had a positive impact on maintenance of these crops. Perhaps a more direct subsidy to carob and nut tree farmers, which like all CAP payments would require cross-compliance (meeting criteria for sustainable and environmentally-friendly agricultural practices), would be more effective.

In future, low-value low-intensity vines may continue to be replaced by irrigated marketable varieties, although there has been a positive response to the RDP measure for subsidisation of maintenance of traditional grape varieties (ΕΤΑΜ ΑΕ & ΛΚΝ ΑΝΑΛΥΣΙΣ ΕΠΕ 2008). Viticulture policy deserves further study, as contrasting RDP prescriptions are acting to subsidise grubbing up of vineyards on the one hand and their maintenance under integrated or organic management on the other, while the bulk of “less favoured area” payments in mountainous areas are made to viticulturists (Department of Agriculture 2010, ΛΚΝ ΑΝΑΛΥΣΙΣ ΕΠΕ & ΙΤΑΝΟΣ ΛΤΔ 2010). Interviews with key informants would allow clarification of intent, while analysis of more detailed data is necessary for understanding how the structure of the viticulture sector is changing. Vines have been shown to provide valuable habitat for the farmland bird community, including many priority species (Chapters 3 and 4) and it is therefore important to understand these changes in order to make specific recommendations for RDP prescriptions to limit further loss of area under viticulture and ensure remaining vineyards continue to support farmland biodiversity.

Unfortunately, there is a lack of information and understanding about agricultural abandonment, which is not captured in government publications. Evidence suggests that farmland is converted to built development, amounting to habitat loss for many priority bird species. The push for change in legislation on housing development may limit further conversion (ETEK 2012), but incentives to maintain agricultural activity should also be strengthened. A review of the Cyprus 2004–2006 RDP suggested that low levels of uptake of subsidies for the most marginal farmers (those active in mountainous areas) indicate low willingness to continue agricultural practices in those regions (ΕΤΑΜ ΑΕ & ΛΚΝ ΑΝΑΛΥΣΙΣ ΕΠΕ 2008). According to ΕΤΑΜ ΑΕ and ΛΚΝ ΑΝΑΛΥΣΙΣ ΕΠΕ (2008) the two RDP measures concerned with addressing the ageing farming population (early retirement subsidy and payment for transfer of the holding to a younger relative, < 40 years of age) were not taken up in combination in mountain and hilly areas due to “difficulties in recruiting successors” (“αδυναμία εξεύρεσης διαδόχων”), in contrast to the higher level of combined uptake in the lowlands. Furthermore, RDP payments for “less favoured areas” were mainly taken up by holders in lowland areas, with lower uptake in mountainous areas where environmental limitations to agricultural activity are greater (ΕΤΑΜ ΑΕ & ΛΚΝ ΑΝΑΛΥΣΙΣ ΕΠΕ 2008). CAP reform proposals (European Commission 2011) seek to increase support for marginal and small-scale farming through new measures under Pillar I, the section of the CAP concerned with direct payments. However, emphasis on “active” farmers for these payments (European Commission 2011) may exclude a large proportion of farmers in Cyprus, as the main source of income for 59% of Cypriot farmers in 2007 was not agriculture, especially for those in marginal areas (Papadavid 2008).

In order to improve assessments of trends in agriculture and be able to make more specific recommendations for RDP prescriptions, a clear understanding of farmland abandonment is necessary. For this to be possible, long term information on unused agricultural land will be required, both for its accurate enumeration and to determine subsequent uses of abandoned land. Although the definitions used in Agricultural Census and Statistics publications vary, it should be possible to consistently extract historic area of abandoned farmland from pre-publication databases, assuming that data from older publications are kept and in an accessible form. However, it is not clear whether data are collected regarding the crop type that was abandoned and the land-use that succeeded it. This information is very important for assessing vulnerability of different types of agriculture to abandonment and hence to direct CAP payments to the most threatened land-uses. In addition, more detailed spatial analysis of agricultural data would be valuable to determine the most marginal regions, and the most marginal land-uses within them. Fortunately, the 2003 Agricultural Census provides village-specific data, and previous Censuses claim that such data are available, though not presented in published form. Finally, analysis of socio-economic data, which was beyond the scope of this study, would help elucidate the drivers behind the social and cultural changes observed in the agricultural community. This would also help identify the reasons for variable uptake of subsidies, with a view to optimise the Cyprus RDP.

World supply and demand, input and commodity prices, demographic trends, and physical limitations of the climate and landscape will be consistent in their effects on agriculture across the eastern Mediterranean region. However, agricultural subsidies and development policy, and farmers’ responses to these, will be region- and country-specific. Good quality agricultural data are necessary in order to understand the nature of change and its drivers, and thus identify priorities for biodiversity conservation effort.

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Chapter 6

Concluding Remarks

Heterogeneous farmland mosaic in Cyprus – Filousa village, Pafos

6.1 Key findings

Land-use change and associated habitat loss and species invasions are two of the greatest threats to global biodiversity. In Europe, where a large proportion of land is under agriculture, changes in farmland management practices, driven in part by the European Union (EU) Common Agricultural Policy (CAP), have caused dramatic declines in associated biodiversity (Donald *et al.* 2002, Robinson & Sutherland 2002, Stoate *et al.* 2009). This thesis studied avian land-use associations to understand the relative importance of different habitat and landscape elements to the farmland bird community, with particular emphasis on priority species for conservation, in Cyprus, a recently acceded EU Member State, as a case study for the eastern Mediterranean. Results provide the first evidence base to inform CAP agri-environment measures in the region.

Chapters 3 and 4, which considered responses by bird categories and species respectively, demonstrated the high value of heterogeneous farmland mosaics to breeding and wintering avian biodiversity in Cyprus. A wide range of habitats and land-uses were found to be positively associated with birds in both seasons, and local habitat diversity was of key value. More bird categories were positively associated with farmland than with semi-natural habitats, as also found in Greece (Kati & Sekercioglu 2006), but remnant scrub was also valuable to many priority species for conservation. Viticulture and groves were the most important land-uses, although no single land-use was found to be of disproportionate value.

Chapter 5 showed that the area of land under agriculture in Cyprus has substantially decreased, with much of this decline attributable to decreases in marginal low-intensity crop types (vines, carobs, non-irrigated olives) on which much avian biodiversity depends. Conversion to built-up and related land appears to be one important driver behind these trends, amounting to habitat loss for many priority bird species.

Chapter 2 showed that there was no evidence that Sardinian Warbler *Sylvia melanocephala*, a recently established breeder in Cyprus, is competitively displacing the endemic Cyprus Warbler *S. melanothorax*. The changes observed in the distributions of these species are more likely mediated by changing land-use patterns. Grazing intensity of semi-natural scrub could not be quantified in the snap-shot sampling of birds and habitats across the survey localities obtained during the fieldwork. Similarly, changes in patterns of pastoralism are not captured within the government agricultural statistics, which indicate no overall decline in livestock but do not distinguish between penned animals and any that may still be herded in the traditional free-range manner (C. Triantafyllidou *in litt.* 2011). However, the loss of extensive grazing of scrub by goats (Christodoulou 1959) and abandonment of farmland will together have resulted in tall and diffuse scrub structures that provide habitat more suitable for Sardinian Warbler than its endemic congener, the Cyprus Warbler.

6.2 Landscape-scale land-cover and utility of CLC data

Habitat and land-use associations of bird categories and species were in general stronger for local than landscape-scale land-cover variables (Chapters 3 and 4) and local, patch-scale extent of habitat has often been shown to have more important effects on incidence or abundance than landscape extent (Andrén 1994, Trzcinski *et al.* 1999, Fahrig 2003, Bennett *et al.* 2006, but see Vergara & Armesto 2009). Multiple local habitat variables in this study were found to be better predictors than a single landscape-scale land-cover variable relating to landscape complexity, as no bird categories, with the exception of woodland bird abundance, showed associations with landscape-scale extent of 'complex agriculture' land-cover (Chapter 3). This aggregate land-cover type indicates the resolution limitation of the variables used in this thesis.

Landscape composition was extracted from the CORINE (Coordination of Information for the Environment) Land Cover (CLC) map of Cyprus for 2006 (MANRE 2009). CORINE is a European Environment Agency programme that provides Europe-wide biophysical land-cover data derived from satellite imagery. CLC data have a minimum mapping unit of 25 ha and are classified in 44 CLC classes. As part of the satellite image interpretation process, small land-cover features are not classified, but are either attributed to the neighbouring dominant class or may be shown as mixed classes where complex mosaics occur (Bossard *et al.* 2000 e.g. CLC class 243: 'Land principally occupied by agriculture, with significant areas of natural vegetation'). Validation of the EU CLC map for 2000 showed a high degree of classification accuracy (87%: European Environment Agency 2006), estimated to be similar for the 2006 map (Büttner *et al.* 2012); however, mismatches between land-cover maps and the real landscape introduce uncertainty in utilization of maps and databases like CLC (Fang *et al.* 2006). The dominant land-cover can be overestimated in CLC and other land-cover maps (e.g. Ellis *et al.* 2000, Fassnacht *et al.* 2006, Schmit *et al.* 2006, Nol *et al.* 2008), a limitation that arises from aggregating elements in complex landscapes at coarse resolutions.

The qualitative assessment of CORINE misclassification of urban land-cover, presented in Chapter 5, suggests that mixed land-cover classes may introduce substantial uncertainty over land-cover changes. CLC resolution may be too coarse for Cyprus, while EU land-cover databases consider the island as a single unit, even at the finest grain classification (NUTS3: Eurostat 2011). More detailed assessment of avian associations with landscape-scale extent of habitat and of land-cover change in Cyprus will therefore benefit from development of maps at a finer grain, more appropriate to the patchy mosaic nature of the landscape.

6.3 Value of species-specific land-use associations

Multivariate analysis of the overall farmland bird community composition (Chapter 4) emphasised the difference between steppe species, which were positively associated with arable land-uses and land-cover, and forest species, which were positively associated with extent of forest habitat and land-cover. All other species categories showed a high degree of overlap and much variation within categories. Nevertheless, different habitats and land-uses as well as habitat heterogeneity itself had significant and distinct effects on the incidence and abundance of each category (Chapter 3). The variability among species within categories probably stemmed from the use of habitat structure as a basis for classification of species into categories, which, although accurate (Tucker & Evans 1997, Snow & Perrins 1998), did not account for functional trait differences and thus pooled species with differing ecological niches (e.g. diet) in the same category.

For this reason, the species-specific approach employed in Chapter 4 provided potentially more meaningful results. In particular, the value of semi-natural scrub to priority species for conservation was highlighted only when considering species-specific habitat associations. However, the key findings were consistent whether bird categories or individual species were studied: not one single, but multiple habitats and land-uses were important; grove and viticulture habitats and local habitat diversity were of key value and land-use heterogeneity was important.

6.4 Utility of modelling framework for predicting future bird species abundance

The habitat association models presented in Chapter 4 provide evidence of direction and significance of effects of land-use and habitat features on the abundance of priority bird species for conservation. However, this in itself is not sufficient to quantify the impacts of agricultural change on avian populations in the eastern Mediterranean. Such complex multivariate models, including a range of both positive and negative habitat-specific regression coefficients, cannot be readily interpreted to predict the consequences of land-use change and as such do not provide the most useful evidence from which to prioritise the development of agri-environment measures. To quantify the potential effect size of likely trajectories of agricultural change on species abundance, it is necessary to integrate socio-economic drivers, resulting land-use change, and consequences for biodiversity (Mattison & Norris 2005, Sutherland & Freckleton 2012).

One way of tackling this would be to link scenarios of likely future agricultural landscapes to predictive models of species abundance and compare predicted abundance to the baseline current species abundance predicted by the habitat-association models (e.g. Swetnam *et al.* 2005). Scenarios are useful in exploring the consequences or available options for conservation under uncertainty in a complex changing environment (Peterson *et al.* 2003, Sutherland 2006). Scenarios of agricultural land-use change have been constructed for the EU (EURURALIS), investigating consequences of socio-economic change along two axes: (1) from global to regional markets and economies, and (2) from low government regulation and market-driven change to high governance to ensure economic, social and environmental objectives (Westhoek *et al.* 2006). There has been some investigation of the potential impacts on biodiversity under these scenarios, using a biodiversity indicator, though Cyprus was poorly represented due to lack of data (Reidsma *et al.* 2006). In addition, the EURURALIS scenarios are likely to be of limited use for Cyprus, as the whole island was considered as one spatial unit in scenario construction (NUTS2 spatial resolution: Westhoek *et al.* 2006) and thus potential differences in land-use change in different parts of Cyprus were not considered.

Like CLC (see Section 6.2), the EURURALIS scenarios are not at a spatial scale that is meaningful for the fine-grain farmland mosaics of rural Cyprus (though Verburg *et al.* [2010] demonstrate these scenarios could be translated to higher spatial resolution using dynamic simulation models). In order to develop useful scenarios of land-use change for the island, it is necessary to first understand the socio-economic drivers of agricultural change and any regional variation (see Sections 5.4.5 and 6.5). Furthermore, scenario development would greatly benefit from consultation with stakeholders, land planners and decision makers, as this would ensure they are relevant and useful for policymaking (Peterson *et al.* 2003, Coreau *et al.* 2009).

The bird species abundance models presented in this thesis take a multi-scale approach. Therefore, in order for scenarios of future agricultural change to be useful in the context of predictive models of bird abundance, they must incorporate an understanding of the relationship between local land-use and landscape-scale land-cover. As shown in Chapter 5 and discussed in Section 6.2, the relationship between land-use on the ground and CLC is not straightforward due to the poor spatial resolution of CORINE. It would be impossible given the current data structure to translate changes in area of different crop types to changes in proportion of land-cover categories, particularly the mixed 'complex mosaic' land-cover class. One option would be to exclude the land-cover variables from the models used for prediction. As discussed in Section 6.2, local habitat variables were more strongly supported than landscape-scale variables and multiple individual habitat variables were better predictors than the single 'complex mosaic' land-cover variable.

The sampling method used to collect the local habitat data imposes further limitations. Habitat data were collected in the form of frequencies, constituting the sum of survey points along each transect where each land-use or habitat feature was present, ranging from zero to 21. This means that frequencies have a strongly non-linear response to areal extent, with an upper limit to the frequency of any land-use or habitat feature that may be reached before that land-use or habitat type becomes the dominant component of land-cover. Thus, it may not be possible to realise large increases in crop extent, such as those that may be projected for olive cultivation, under a possible scenario for the future. Localised crop types (see Figs. 2.2 and 5.6), e.g. citrus, would be particularly problematic. It would not be appropriate to add the crop to transects other than those where it was already present, as this could result in implausible landscapes and juxtapositions of crop types and habitats, e.g. horticulture on shallow soils and in scrubland, or citrus cultivation on non-irrigable land or within forest.

In the fieldwork conducted for this thesis, it was not practicable to quantify areal extent of proportionate cover of land-uses in the local area around transects. The complex structure of the landscape, particularly on terraced slopes, often obscured nearby areas. For the purpose that data were collected, to explore bird–habitat associations, frequency data were appropriate. However, model predictors in units of area would be more appropriate for use with scenarios of agricultural change. These should relate to the total area available for habitats to occupy, so that it is not exceeded under scenario projections, although special consideration will be necessary for understorey vegetation and soil (e.g. tilled or left fallow), which will result in more than 100% coverage. Scenarios could also be spatially explicit, to ensure plausible potential future landscapes. Habitat mapping could be used to provide suitable predictor data structure. This would also allow exploration of the effect of configuration of habitat patches (the spatial pattern of individual patches: Fahrig *et al.* 2011) as well as composition (the variety of habitat types: Fahrig *et al.* 2011) and extent of different habitat types. The scale at which mapping would be carried out would greatly affect how well the resulting models of bird abundance perform. Landscape context has been recognised as having an important effect on bird species incidence and abundance (Dolman 2012). Therefore, excluding landscape-scale land-cover from predictive models, as described above, would result in poor models for those species for which land-cover has an important effect. At the opposite extreme, models incorporating finer scale within-habitat structure variables as predictors would be more appropriate for some species. For example, Cyprus and Sardinian Warbler models that incorporated scrub structure were more informative than those that considered scrub as a single predictor (Chapter 2).

Scale dependence is a common issue in ecology (Wiens 1989, Levin 1992) that has important implications for management, where mis-matches may occur when management is applied at the wrong scale (Pelosi *et al.* 2010). For agri-environment measures to be effective, they must be applied at a scale that is relevant to the ecological processes driving biodiversity distribution and abundance. Farmland birds have been shown to respond not only to characteristics of the local patch, but also to the context of the patch in the surrounding landscape mosaic at multiple scales (Vickery & Arlettaz 2012). Bennett *et al.* (2006) suggest that in complex agricultural landscapes, the unit of replication should be the whole mosaic. This approach could be very useful in Cyprus, as the fine-scale mosaic of farmland made patch-scale survey of birds and habitat impossible in the present study, necessitating the use of line transects that traversed different habitat types.

6.5 Management and policy recommendations

The results presented in this thesis suggest that homogenisation of the agricultural landscape would have negative effects on priority species and avian biodiversity in general, as elsewhere in Europe (Donald *et al.* 2002, Stoate *et al.* 2009). Therefore, a 'land-sparing' approach (Green *et al.* 2005), which would result in regionally specialised agriculture, offset initially by scrub and ultimately forest encroachment outside farmland, may not be appropriate. The complex Mediterranean farmland mosaic has been created by traditional farming practices that are usually economically marginal (European Environment Agency 2004). Therefore, agri-environment mechanisms to support this heterogeneity in a 'land-sharing' framework are necessary for effective conservation of priority species and bird biodiversity in the eastern Mediterranean.

Although farmland decline in Cyprus will probably continue, and remaining agriculture is likely to consist of intensive irrigated production of more valuable crops, the small field parcel size that characterises many agricultural holdings may to some extent mitigate negative effects of intensification on biodiversity, by maintaining the complex landscape. However, small and fragmented holdings may be less economically viable and thus at greater risk of being abandoned (Donald *et al.* 2002). Agricultural abandonment opens up land to development (Symes 2006, Chapter 5) and a land-sharing approach that maintains farmland as habitat for biodiversity would be preferable to land-sparing, which may result in a net loss of habitat through agricultural intensification and building development on abandoned land. To maintain the range of land-uses and habitat heterogeneity that support avian biodiversity, agri-environment measures that directly support marginal agriculture and that subsidise maintenance of the farmland mosaic are necessary. There are, however, no such provisions in the current Cyprus Rural Development Plan (RDP) and measures that indirectly support traditional crop types do not appear to have been effective (see Chapter 5), while there appears to be low uptake of payments in the most marginal regions (ΕΤΑΜ ΑΕ & ΛΚΝ ΑΝΑΛΥΣΙΣ ΕΠΕ 2008). Furthermore, there are no provisions for retention of non-crop scrub boundary features (Department of Agriculture 2010), despite their importance to many priority bird species. In addition, mechanisms to support extensive grazing would be beneficial for the endemic Cyprus Warbler, but government policy has limited free-range grazing and encouraged penning of animals (Economides 1997, C. Triantafyllidou *in litt.* 2011).

Unfortunately, the inadequate measurement of agricultural abandonment by government Agricultural Census and Statistics publications hinders development of effective incentives to maintain agricultural activity. A clear understanding of abandonment, including regional variation and the fate of abandoned farmland, is required in order for the Cyprus RDP to be optimised and targeted. It is encouraging that the proposals for CAP reform promote further support for marginal and small-scale farming, but the requirement that farmers be 'active' in order to qualify for CAP subsidies (European Commission 2011) may exclude a large proportion of farmers in Cyprus, whose main income does not derive from agriculture (Papadavid 2008). Therefore care will be needed when the reformed CAP comes into effect in 2014.

6.6 Further enquiry

6.6.1 Grazing

Management of grazing livestock, mainly sheep and goats, in Cyprus has changed dramatically. Free-ranging mixed flocks of sheep and goats were traditionally grazed on semi-natural scrubland that is otherwise agriculturally unproductive, and used to be grazed on cereal stubbles and in state-owned forest (Christodoulou 1959). Shepherds, animal numbers, and the distribution of free-range flocks have been regulated by law since 1935 to control grazing damage to crops and browsing damage to forest regeneration. This drove a decline in goat numbers, as well as a shift in husbandry towards penning of animals (Christodoulou 1959). The proportion of free-range goats declined from 80% to 57% between 1946 and 1958 (Christodoulou 1959) and remains low to this day (Economides 1997), while the area of grazing land declined by 62% from 3,200 ha in 1975 to 1,232 ha in 2010 (Chapter 5). Secondary succession following grazing abandonment has been shown to affect the bird community and other biodiversity, causing the decline of scrub and open habitat species, which in the Mediterranean are usually the species of highest conservation interest (Preiss *et al.* 1997, Sirami *et al.* 2007, Zamora *et al.* 2007).

The probable expansion of taller scrub vegetation following declines in grazing intensity in Cyprus could be an important driver for the expansion of Sardinian Warbler, and of the perceived decline of Cyprus Warbler in the same areas. The impact of grazing regime on avian biodiversity merits further study, as the changes in livestock management in the last century are likely to have dramatically changed the structure of semi-natural vegetation in Cyprus. However, grazing history will to a degree determine current floristic composition (Peco *et al.* 2006, Díaz *et al.* 2007), owing to differing responses or degrees of tolerance to grazing of different plant species and functional groups (Papanikolaou *et al.* 2011, Peco *et al.* 2012). The ability to relate avian composition to long-term relaxation of grazing could be confounded by more ephemeral changes of scrub structure caused by contemporary grazing activity. Research seeking to investigate the biodiversity conservation value of structurally different semi-natural scrub would therefore require careful investigation of both current and past history of grazing. As government agricultural statistics from 1960 do not distinguish between penned and free-range animals, it would be necessary to carry out interviews to obtain information on changes in the nature of pastoralism. Changes in land-cover and structure of scrublands over time could be investigated using remote sensing techniques (aerial photography and satellite imagery are available for Cyprus from the early 1970s: Hadjimitsis *et al.* 2003, E. Ridder *in litt.* 2010), as has been carried out for parts of Crete by Papanastasis and Kazaklis (1998).

6.6.2 Viticulture

Viticulture was shown to be important for open-woodland and scrub birds, and for many priority species for conservation. Vines are cultivated in terraced fields with large amounts of semi-natural scrub vegetation that persist in field margins and along terrace boundaries. This remnant scrub and the open structure and bare ground available within vineyards are beneficial for many species. However, viticulture is often overlooked in terms of value to biodiversity, although there exists a body of research on vineyard management with a view to improving invertebrate biodiversity for biological pest control (Nicholls *et al.* 2001, Altieri & Nicholls 2002, Bruggisser *et al.* 2010, Rochard *et al.* 2011). Work regarding the importance of viticulture to farmland birds is limited (e.g. Verhulst *et al.* 2004, Schaub *et al.* 2010, Arlettaz *et al.* 2012, Tagmann-Ioset *et al.* 2012), but corroborates evidence from this study, which indicates that the heterogeneity of viticulture landscapes in the eastern Mediterranean supports both priority species and wider avian biodiversity. More detailed species-specific work is necessary to identify at a finer grain which parts of vineyards are used by birds and how this is affected by management (e.g. scrub, tree or drystone wall terrace boundary features, timing for rotovation or suppression of weed seed resources by herbicide use). Ultimately, this can be better translated into targeted recommendations for agri-environment measures.

In Cyprus, the viticulture sector has been radically restructured since accession to the EU (Papadavid 2008) and has had the largest decline of any crop type in its proportional share of farmland, with further loss of low-intensity vineyards suggested by the proportionate increase in irrigated high-intensity management systems (Chapter 5). Current government viticulture policy focuses on combating over-production (previously encouraged by pre-CAP subsidies), incentivises quality over quantity and seeks to eliminate abandoned vineyards (Department of Agriculture 2004, Costas Petrides and Associates 2005, Markou & Kavazis 2006). Different RDP measures are not consistent and some prescriptions promote permanent removal of vines, while others support integrated and organically managed vineyards. More detailed information is necessary in order to understand the changes in the viticulture sector and to evaluate government and farmer attitudes towards it, before policy recommendations can be made for ensuring that this valuable habitat is preserved.

6.6.3 Drivers of land-use change and effective agri-environment measures

Land-use change is driven by factors that operate at a variety of scales, with world supply and demand, commodity and input prices and international agreements operating at a global scale and socio-economic and cultural drivers that affect the activities and the decisions made at the country, regional, local and individual farmer level. Policy recommendations made on the basis of ecological findings alone will not be effective if applied without consideration to these drivers, including stakeholders' values and behaviours (Young *et al.* 2010).

For example, opportunity costs will be of major importance as to whether agricultural land, particularly of economically marginal land-use, remains in production or is converted to housing or tourism development, as suggested in Chapter 5. In the Greek islands, for example, much agricultural land has been converted to tourism development (Ioannides *et al.* 2001). In many developed countries, rural depopulation and an ageing farming population, particularly in areas where agriculture is economically marginal, have resulted from the pursuit of more profitable activities and higher standards of living in urban areas (OECD 2006, Kizos *et al.* 2011). The low uptake of agri-environment measures designed to mitigate the ageing rural population in Cyprus is attributed by ΕΤΑΜ ΑΕ and ΛΚΝ ΑΝΑΛΥΣΙΣ ΕΠΕ (2008) to difficulties in recruiting younger successors for agricultural holdings, particularly in marginal areas. A large proportion of agricultural land holders in Cyprus cite non-agricultural employment as their main source of income (Papadavid 2008), perhaps suggesting that cultural factors help maintain farming activity, or conversely that farming is no longer an economic mainstay and is thus vulnerable to rapid abandonment (e.g. Gellrich & Zimmermann 2007, Kizos *et al.* 2010a). In the Greek island of Lesvos, it was found that "hobby" farmers were more likely to take up agri-environment measures for terrace maintenance as an opportunity to boost the profitability of their land, than professional farmers who "probably regard terrace maintenance as a financial burden" (Kizos *et al.* 2010b).

The above example highlights a potential conflict between modern agricultural practices and the aspects of the traditional landscape that RDP subsidies seek to maintain, but that are no longer functional. Agri-environment measures have been adopted by the EU as the main mechanism to deliver multi-functionality in the agriculture sector, but simply providing financial incentives without establishing or reinforcing functional links is unlikely to be successful in meeting the EU Biodiversity Strategy objective of halting biodiversity loss and restoring ecosystem services (Fischer *et al.* 2012). The challenge will be in developing mechanisms that form sustainable connections between land-use and the environment, such as rural (eco-)tourism (or 'agrotourism' as it is known in Cyprus) or markets for traditional local produce, in a local participatory framework (Norris 2008, Fischer *et al.* 2012). Given the on-going Eurozone crisis and the projected significant decline in CAP funding (Mattison & Norris 2005, Sutherland & Freckleton 2012), such mechanisms must be economically viable and it will be imperative that agri-environment measures deliver biodiversity and environmental objectives.

This thesis has demonstrated the value of the heterogeneous farmland mosaic to avian biodiversity and priority species for conservation in the eastern Mediterranean. This suggests that a land-sharing approach to farmland biodiversity conservation is appropriate, and agri-environment measures that support the maintenance of the complex agricultural matrix are necessary. A detailed understanding of the drivers of land-use change will enable optimization and targeting of prescriptions, especially to economically marginal regions and crop types, which provide the habitat elements that support avian biodiversity.

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