MASTER THESIS PROJECT

RELATIONSHIP BETWEEN TRENDS IN ABUNDANCE, LAND USE CHANGES AND NEST PROTECTION: THE MONTAGU'S HARRIER IN SPAIN

Master's Degree in Biodiversity and Conservation Biology

Author: Castel López, Manuel [1]

Supervisor: Arroyo López, Beatriz [2]

1. manuelcastellopez@gmail.com

2. Instituto de Investigación en Recursos Cinegéticos (IREC), CSIC-UCLM-JCCM, Ronda de Toledo, s/n, E-13005 Ciudad Real, Spain; E-Mail: beatrizarroyo@uclm.es

ABSTRACT

Montagu's Harrier is a steppeland raptor, whose populations in Spain (a stronghold of the species in the EU) and elsewhere in Europe are affected by agricultural management modifications supported by CAP policies in the last decades. With lineal mixed models (including province nested within autonomous community as a random term) we try to relate the population changes between 2006 and 2017 at UTM cell level with modifications of area occupied by different farmland land uses, the extension of protection campaigns to protect nestlings at harvest time, and the levels of risk that harvest activities pose to harriers there (based on harvest dates).

Overall, we found a net loss of breeding pairs in the 410 UTM cells monitored both years, as well as a net loss of pastures/dehesas, and a net increase in woody crops. We did not find significant relationships with any explanatory variable on Montagu's Harrier population changes, but changes in woody permanent crops area approached significance (p=0.08), with more pairs being lost in areas where woody crops had increased the most. Also, and although differences were not significant, there was a trend for bigger population losses of this raptor in areas with no protection, which suggest that protection measurements may reduce the population drop, but its efficacy may be diminished under land use changes.

Keywords: Steppeland raptor, population change, land uses, protection campaigns and harvest problem.

INTRODUCTION

There are many studies about the damages that agricultural intensification and fragmentation of natural habitats are producing in European farm biodiversity in the last decades. Even so, there exist still scant information about how land use changes within farmland, specifically from annual crops like cereal to permanent woody crops (Bossard et al. 2000), are affecting farmland biodiversity.

The current Common Agricultural Policy (CAP) in the European Union (henceforth EU) is the result of a chain of policies and economic decisions which have been applied since the end of Second World War, and whose main aims are to increase production and yield (Stoate et al. 2009, WWF 2009). From the end of the 19th century, the aim to increase agricultural production led to the decline of natural grasslands and other natural vegetation areas (Ellemberg and Leuschner 1996), habitat of many steppeland species (Caballero et al. 2009). In addition, recent changes in management have also aimed to increase production per surface unit (intensification) (Figure 1).

From centuries, vast areas of the European continent have been used as agricultural farmlands; this historical anthropogenic modification of natural places has acted as an important factor of environment modulation (Donald et al. 2001, Caballero et al. 2009, Stoate et al. 2009, Santangeli et al. 2014), providing large areas of open-landscape with abundant grasses, and many ecosystem pieces and functions have tried to develop to adapt to it (Kleijn et al. 2009). But the recent changes in agricultural policies of the EU leading to intensification have induced a loss of this balance (Bota et al. 2005, Henle et al. 2008a). Agricultural landscapes present large differences between them. Due to their malleable character, based on varying ecological features of different locations and management factors such as type of crop, intensity and scale of use (Pain and

Pienkowski 1997), farmland landscapes may contain a mosaic of environmental conditions.

Regarding this information, and knowing that CAP measurements are similar across all EU area (Pain and Pienkowski 1997) and that many farmland species, particularly birds, maintain a narrow relation with agricultural activities, we can associate the biodiversity loss crisis with these political aims (Fuller et al. 1995, Donald et al. 2001, Hiron 2013). Thus, the main conservation issues in farmland areas within current EU are to offset the agricultural intensive management impairs, linked to the loss of traditional farming practices and drop of historical habitats within the farmland matrix like hay meadows, lowland wet grasslands, heathlands, chalk and dry grasslands, moorlands, and arable land (Henle et al. 2008b).

In the Mediterranean Basin, a main land use change in recent decades is the increase of permanent woody crops, specially to intensive management (Sokos et al. 2013). If we look upon Spain in particular, where next to 50% of the surface is agricultural lands (Carricondo et al. 2011), an intensive land use change has occurred since the 1990s, with 460000 ha of new olive plantations (Eurostat 2015) and a reduction of land surface dedicated to cereal cultivation of 800000 ha (Ministerio de Agricultura and Ministerio para la Transición Ecológica 2017). The expansion in olive groves has not only replaced arable land, new plantations have also substituted natural vegetation lands like pastures (Food and Agriculture Organization of the United Nations 2017), the habitat for many agricultural associated species (Beaufoy 2001, Heikkinen et al. 2004). The same situation is observed in relation with the wide expansion of vineyards in some autonomous communities, like Extremadura (Carrasco 2015).

There are many species of birds associated with agricultural landscapes (Donald et al. 2001, Newbold et al. 2015), whose association with farmland is variable and depends on biological and behavioural features (Atkinson et al. 2002, Hiron 2013). Arable land, because of its broad extension and open structure, supports many of this species. In western Europe, bird species known as specialist steppeland birds do the majority of their vital activities in this anthropogenic environment, including foraging and breeding. One of them is the Montagu's Harrier (*Circus pygargus*), whose survival is strongly sensitive to modifications of the intensity in agricultural management (Arroyo et al. 2002, Arroyo and García 2007).

The Montagu's Harrier is a semi-colonial ground-nesting raptor of medium size, present across all European continent during breading season with a patchy distribution (Arroyo 1995, International Union for Conservation of Nature and Natural Resources. 2004, Estrada and Arroyo 2012). West of Russia, the main population strongholds occur in Poland, France and the Iberian Peninsula (Santangeli et al. 2014), related with flat areas with wide extension of arable land (Arroyo and García 2007, Pinilla Torres 2015).

This steppeland raptor uses two main types of habitats for breeding, natural or semi-natural lands (marshes, meadows, grasslands, reedbeds, young conifer plantations, heaths and wastelands) and cultivated areas, commonly with winter cereal crops like wheat and barley (Arroyo 1995, Arroyo et al. 2002) . Because of its ground-nesting habits and habitat use, population sustainability of this species depends on protecting nestlings from dying at the time of harvest (Castaño and Díaz n.d., Arroyo et al. 2002), and many conservation programs exist at regional and national levels. Protection actions are known to significantly improve fledgling productivity (Conserjería de Medio Ambiente y Ordenación del Territorio 2013, Santangeli et al. 2014). However, it is not known whether they have positive impacts on population trends overall, particularly in areas where land use changes are taking place, modifying also habitat suitability for the species.

Recent modifications of CAP have favoured the abandonment or replacement of large extensions of cereal croplands by woody-permanent crops in important breeding areas of this raptor, like an increase of olive groves in Andalusia (Camarsa et al. 2010), or vineyards in Extremadura (Pinilla Torres 2015). Agricultural intensification has also led to the loss of natural shrubland in Northwest Spain to farmland (Oñate et al. 2007a, WWF 2009, Tapia et al. 2016). These situations may worsen survival possibilities of Montagu's Harrier throughout diminishing suitable breeding areas and impoverishing food supplies (Arroyo and Bretagnolle 2000, Arroyo et al. 2002), despite conservation efforts to save nests at harvest time.

We use data from the two national censuses for Montagu's Harrier (in 2006 and 2017) to assess population changes of this raptor. We hypothesized that local changes in abundance are related to local modifications in land use, mainly from cereal crops to permanent woody crops (which are unsuitable for breeding). Additionally, we hypothesize that these are also related to the existence of protection programs (which increase short-term productivity) or to the degree of overlap between the harvest season and the breeding cycle (which is an indication of the risk of harvest to productivity, therefore affects productivity).

Hence, the aims of this research are assessing populations change of Montagu's Harries between 2006 and 2017 and evaluate if this change keeps relation with land use changes, harvest time and intensity of protection measures in Spain.

MATERIAL AND METHODS

1. Study species

The Montagu's Harrier in Spain breeds generally in cereal croplands and has to face deep and fast agricultural management changes (WWF 2009, Carrasco 2015). This raptor makes its nest on the ground, hidden in the cereal fields (Arroyo et al. 2002, Hardey et al. 2009). Its nesting cycle lasts approximately 70-75 days, from egg laying (early May) until first flights of chicks (mid-July) (Seo BirdLife 2008, Hardey et al. 2009). With these biological and behavioural characteristics Montagu's Harriers tackles a difficult conservation panorama. In many areas 60-100% of the nestlings would die due to mechanical harvest in the absence of nest protection measures (Castaño and Díaz n.d., Arroyo et al. 2002).

Breeding protection campaigns, based on saving nestlings from harvest activities at local or regional level, occur in many areas (Arroyo et al. 2002, Santangeli et al. 2014, Cardador et al. 2015). Montagu's Harriers present wide dispersive movements (Limiñana et al. 2012), which means that areas can be quickly abandoned or colonized. Knowledge of the relationship between land uses changes and population changes may allow to improve implementation of conservation programs beyond protection from harvest.

2. Montagu's Harrier abundance data:

In general, the census methodology consisted in performing a minimum of three visits to each UTM cell, each lasting a minimum of three hours (Arroyo & Garcia 2007). Visits were meant to occur between early May and mid-July. In reality, there was variation in the number of visits carried out to each cell (from one to more than 20), both in 2006 and 2017. During each visit, it was noted the number of harriers observed, and their behaviour, in order to estimate the number of certain breeding pairs (those observed in a food pass, copulating or entering a nest), probable breeding pairs (when both male and female had been observed in adequate habitats doing territorial behaviours) and possible breeding pairs (when males or females were observed in a suitable habitat during breeding season) (Arroyo and García 2007). From this information, a minimum and a maximum number of pairs in each cell was estimated, the minimum being the sum of certain and probable breeding pairs, the maximum being the sum of certain, probable and possible.

In 2006, a total of 1245 UTM cells were visited (Figure 2). In 2017, due to budget and time limitations, a minimum number of priority cells was identified in each province (aiming to cover some UTM quadrats which had been monitored in 2006, as well as others unmonitored in the previous census). 2017 survey cells not visited in previous census (although they are not comparable) provide important data about species with big mobility and in this agricultural intensification and land use changes panorama, processes which that can modify the location of occupied breeding places. In this second national Montagu's Harrier survey, a total of 601 cells were prospected by volunteers and environmental agents. The sample effort represents 52% less than in

2006 census and only 25% of cells with detected presence of Montagu's Harrier in the 2003 Atlas of Breeding Birds of Spain. 2017 census did not cover the Aragon and Navarra autonomous communities and provinces of Vizcaya and Gipuzkoa (Basque Country); and, A Coruña and Pontevedra in Galicia. Of these 601 cells censused in 2017, 410 had also been monitored in 2006 census, and are useful for analyses of population changes (Figure 2).

The main strong point of these comparable data is that quadrats were broadly distributed across all Montagu's Harrier breeding area (Figure 2), the field methodology was the same (Arroyo & García, 2007), and that quadrats were in areas with different land use and variation in the intensity of regional protection programs of this species.

For calculating abundance data from these raw census data, it is necessary to take into account possible census mistake sources:

Each observer had different precision and capacity to find Montagu's Harrier and identify pairs and their behaviours. This fact could modulate the capacity to detect pairs in a given quadrats (Santangeli and Arroyo 2017). We cannot assess the value and influence of this variable in this study.

On the other hand, the most important bias is probably related to the different sampling effort between collaborators and grids. In particular, breeding pairs may be underestimated in grids with small sampling effort. The estimates for cells with less than three visits were corrected by the same mathematical operator than in Arroyo & García (2007), which related the number of pairs estimated at the end of the breeding season for those cells with more than 3 visits to the estimate in the first visit, the total number of visits, the time of the first visit within the breeding cycle, and a geographical component associated to average harrier density. The most parsimonious model explaining final estimate included first estimation, number of visits, geographical area and the interaction between first estimation and geographical area (Arroyo and García 2007). For cells with less than three visits, we used this model to forecast pairs estimated at the third visit, in order to obtain comparable data among cells. These corrections were done in 122 of the analysed cells for data from 2017, and 168 of the analysed cells for data in 2006.

3. Collecting land uses data:

From the census geographical data, it was necessary to convert the identity of grids to the CORINE (Coordination of Information on the Environment) framework. CORINE offers a big base of European land uses (Centro Nacional de Información Geográfica (CNIG) 2018). Our first step was to select the most common habitats observed in the distribution areas for Montagu's Harrier in Spain among the list of CORINE land uses (Bossard et al. 2000). Montagu’s Harrier breeding habitats include those with vegetation of a height of 50-100 cm, and therefore habitats like woody crops, agroforestry areas and pastures are not suitable for breeding. Even so, these land uses could be used to hunting, but their quality as food providers is probably related to the intensity of management. For this reason, we grouped all land uses in three categories, depending on kind of habitat, farming management measurements, and how Montagu’s Harrier use them: i) suitable habitats for breeding (*Suitable*), including arable lands (usually occupied by cereals), moors and heathlands (shrubland used for nesting outside farmland areas); ii) pastures and agroforestry areas (dehesas), which are land uses unsuitable for breeding but where there is usually a grass layer, management is less intensive and thus can be used for foraging (*Pasture-Dehesa*),; and iii) *Woodycrops*, including woody permanent crops, inadequate for breeding, and where management is usually more intensive (including frequently elimination of the grass layer under trees or vines), thus potentially less adequate for foraging (Table 1).

In this research we worked with land use data of years 2006 and the most recent actualization of CORINE, 2012. In this situation it was necessary to accept that land use distribution in the latter year was similar in 2017.

To calculate the land use proportion in each censused UTM cell we used the shape files of CORINE and we overlapped them with the grid of UTM quadrats surveyed in both censuses. The proportion of selected land uses within UTM quadrats was obtained dividing each land use surface in each UTM cell by the area of that cell.

From these data, we calculated *Land use changes* for each cell for the three land use categories as % area covered in 2012 minus % area covered in 2006.

4. Harvest date estimates and intensity of protection programs:

We obtained average harvest dates in each province from Santangeli et al. 2014, or else asking people and institutions in that area. We classified provinces in four degrees of harvest problem, depending on the relation between harvest date and breeding phenology in the area: *Early harvest* (harvest from May to early June, coinciding with harrier incubation), *Intermediate* (June, during development of nestlings), *Late* (harvest from end of June to July, coinciding with fledging) and *No*, areas where harvest is not a problem because harriers nest in natural vegetation; see Table 2. This variable gave information about the degree of risk of harvest to nestlings, as if harvest occurs during incubation or when there are small chicks at the nest, there are bigger chances that they could be killed in the absence of protection actions, but also higher time post-harvest and until fledging, which is known to also increase the risk of failure even when protection occurs (Santangeli et al. 2014)

Protection intensity was obtained from information in the publications of Grupo Ibérico de Aguiluchos, and regional protection campaign reports. We classified *Protection plans* in four levels related with effort and continuation of fieldwork: *Yes* (robust and not interrupted protection measures in last years, covering a large part of the breeding population), *Partial* (protection work only localized in space, or not continuous in time) , *No* (no actions have been done to protect nests at harvest time) and *Unnecessary* (no actions because there was no risk related with harvest activities; this was the case for populations nesting in natural vegetation).This information was available per provinces (Table 2).

5. Data treatment:

We reviewed the datasets of both censuses, and unified all information in only one database, where each line corresponded to a UTM cell censused both years. All fieldwork was contextualised in UTM quadrats, whereby we grouped all information in a data frame with 410 UTM cells' location (overlapping in both censuses), where we inputted population data (*Maximum* and *Minimum breeding pairs* observed in both years), as well as elements of risk (*Harvesting problem* and *Protection plans intensity*), percentage of pre-selected land uses in each census quadrat, and land use changes (percentage in 2012 minus percentage of land use in 2006).

Land use variables were standardised prior to analyses, by calculating its value minus the mean divided by the standard deviation.

We calculated change in population size at UTM level as minimum population size of each UTM cell in 2017 minus minimum population size of that quadrat in 2006.

6. Statistical analyses

Analysis of data began with descriptive statistics, looking up the most predictable relations of population change with modifications of land uses, different protection intensities and harvest problem, and assessment of how strong (in relative value) these had been and analysed correlation between explanatory variables.

Subsequently, we used Linear Mixed Models (with the package *lme4* of R 3.5.1 (Bates et al. 2015)) to test the possible relationships between detected changes in population size of Montagu's Harrier and our explanatory variables. The response variable fitted a normal distribution. These models tried to explain the difference in breeding numbers in each cell between both national censuses. We included province nested within autonomous community as a random effect, to account for the non-independence of data from the same provinces and autonomous communities (as they were related to similar protection policies, harvest dates and environments features).

We considered 5 different explanatory variables; *Protection intensity*, four levels depending on the robust of Montagu's Harrier protection campaigns; *Harvesting problem*, four levels derived of overlapping degree between harvest season and Montagu's Harrier nestling developing; and finally, the three *Land uses changes*.

We constructed a full model including all explanatory variables. We compared AIC values of the full model and those excluding individual variables, using the function *drop1* in R.

RESULTS

In 137 (33.40%) of UTM censused quadrats we have registered a population increase, mainly in the provinces of Huelva, Segovia, Valladolid, Albacete and Lleida. In some of these provinces, the increase reached 20 pairs of Montagu's Harrier in a given quadrat. In 66 (16.10%) UTM cells, population estimates did not change; in approximately 50% of these cells Montagu's Harriers were not present in any census. Finally, we found a population drop in 207 UTM cells (50.50%). Quadrats in Galicia and Extremadura experienced the biggest decreases, but decreases were observed in all but three autonomous communities (Figure 3).

The number of UTM quadrats in which the three designed groups of land uses increased or decreased during our study period varied (Figure 4), but the global net effect was a stability of suitable habitats for breeding (on average, change was 0.5 ± 11.2%), as well as a small loss of pastures-dehesas (-0.07 ± 6.2%) and an increase of woody crops (3.03 ± 8.8%). We did not find significant correlation between changes in land uses at the quadrat level.

In 56% of studied quadrats protection actions occurred, mainly in Southwestern areas (Andalusia and Extremadura). In 33% of monitored cells no protection programs occurred, despite a potential need because of harvest activities. In the remaining 11% of monitored quadrats, protection for harvest was not necessary (areas of Galicia, Asturias, Cantabria, East of Catalonia and South of Valencian Community) because of Montagu´s harriers nesting in natural vegetation.

The LMM model showed no significant effects of any of the explanatory variables on Montagu´s harrier population change ($p > 0.05$) (Table 3).

Number of breeding pairs in 2017 decreased more on average on quadrats where there were no conservation plans and where harvest posed no problem for the harriers (because they breed in natural vegetation). However, differences among groups were very far from being significant (Table 3, Figure 5 and 6).

On the other hand, variation in abundance of woody permanent crops had a nearly significant effect on populations change ($p = 0.08$, Table 3), with higher Montagu´s harrier losses in quadrats where woody crops had increased more (Figure 7).

DISCUSSION

In our 401 UTM monitored quadrats we detected an overall loss of at least 271 pairs between 2006 and 2017 (representing 15% of those counted in 2006 in the same quadrats). Despite the mobility of the species, the trend observed in these quadrats points to a general decline in the Spanish Montagu´s harrier population at large (Seo/BirdLife 2018).

However, this reduction was not homogenous in all monitored quadrats. The 410 UTM quadrats used in this study are broadly distributed in Spain, and they include different land uses, and distinct harvest times and protection intensity, so it was possible to see if variations in breeding numbers were associated to those variables.

The LMM results did not show significant effects of the intensity of protection actions in population maintenance, but we detected a weak trend in population change from areas with protection plans and areas without them, the latter suffering a bigger decrease of this steppeland raptor. Previous studies (Arroyo and Bretagnolle 2000, Arroyo et al. 2002, Castaño 2009) have defended the importance of protection plans against nest loss during harvest as the main factor in Montagu's Harrier conservation, at least in areas with early and intensive mechanised harvest. The efficacy of protection depends to a large degree on harvest time and its overlapping with nestlings development (Santangeli et al. 2014). Harvested crops expose the specific location of nests, increasing the risk of predation, and this is the principal known cause of nestling mortality in protected nest in Andalusia (Pita et al. 2009, Miguel and Gema 2018). At broad spatial and temporal scales, the effect of protection on Montagu's Harriers might depend on distribution of resources, and whether these are prioritized to create population sources connected with others through juvenile dispersal (Arroyo et al. 2002, Estrada and Arroyo 2012).

We may conclude that Montagu's Harrier is in a conservation trap, described by Cardador et al. (2015). In this situation, despite costly conservation actions to protect this raptor in environments occupied by human agroecosystems, the protection programs will not save this raptor in a future without conservation measurements and the Montagu's Harriers would return to a risk situation if we do not change the agricultural management policies.

We did not find a relationship between population change and the level of risk that harvest poses. This may be because areas with earliest harvest season also had the most intensive protection programs (Figure 8), and in these zones the populations of Montagu's Harrier decrease less than in the rest, although protection does not seem to stop the population decline completely. We found the real gap of protection in areas under intermediate harvest time, where 41% of studied quadrats do not present any protection measurement, and nestlings are thus entirely exposed to agricultural machinery. On the other hand, in quadrats where harvest is not a problem, because the Montagu's Harriers construct the nests in natural vegetation, Montagu's Harrier populations had suffered the biggest declines. It is possible that in these areas there are additional undetected problems, such as destruction of natural vegetation to be transformed in corn, as happens in Galicia (Tapia et al. 2017).

Future research would be necessary to widen the protection concept not only for direct protection actions, considering the implication of protected areas like Special Protection Area (SPA), which are under a specific agroenvironmental legislation.

From the point of view of land use changes, we observed a general stability of cereal crops in our monitored quadrats, a decrease in pastures and an increase of woody permanent plantations (Sainz Ollero and Van Staalduinen 2012, Estrada and Arroyo 2012, Pinilla Torres 2015). At the quadrat level we did not find defined tendency of changes in the land use, with no significant correlations among changes in land uses, which indicates that in the same UTM quadrat there may be simultaneously increases in woody permanent crops and arable land.

We did not detect a significant effect of change in suitable land uses for breeding on changes in Montagu's Harrier populations. However variations in the area occupied by woody permanent crops seems to affect this steppeland raptor: the broad increase of olive and fruit groves and vineyard, together with the proliferation of other less abundant crops as almond cultivation in the Peninsular Southwest (Romero Díaz et al. 2012), or pistachio trees in Castile la Mancha (Rabadán et al. 2017, Brunat 2018) produces near significant negative effect in the number of breeding birds of Montagu's Harriers at local (quadrat) level.

The almost significant effect of changes in woody crops area on Montagu's Harrier population change also indicates that this factor could be negative for population maintenance of this vulnerable species (Pinilla Torres 2015, Arenas et al. 2018).

The CAP supports the increase of permanent woody crops (Romero Díaz et al. 2012, Pinilla Torres 2015, Arenas et al. 2018) and, in these there are developing an intensive and aggressive management that replace other extensively land uses and impairs the steppeland biodiversity (Chamberlain et al. 2000, Donald et al. 2001), damaging one of the ecosystem most biodiverse and specialised in the European continent.

CONCLUSION

In Spain, as in the rest of Europe, the PAC are supporting a generalised land use change toward the increase of woody permanent crops under a very intensive farming management. Montagu's Harrier and also many other steppeland bird populations are suffering a seriously decrease from last decades because of intensification of farming systems and, also land use changes could have a relevant impact, but we need to study hem more. These land use changes may be hampering the positive effect of protection measures for the species. We need to promote a less aggressive farming model, more integrated in the natural environment.

(Ministerio de Agricultura and Ministerio para la Transición Ecológica 2017)
(R Core Team 2018)
(European Environment Agency 1995)
(Seoane 2014)
(Heikkinen et al. 2004)
(Oñate et al. 2007b)
(Marini and del Moral 2003)
(Tapia et al. 2016)
(Arroyo and García 2004)

BIBLIOGRAPHY

Arenas, R., B. Arroyo, E. Ballesteros, J. M. Barea-Azcón, G. Blanco, A. Cabello, A. Carricondo, M. de las Heras, J. A. Hódar, F. Casas, F. J. Contreras, M. C. García, E. González, J. L. González, M. Guerrero, J. E. Gutiérrez, P. Laiolo, A. Leiva, J. Manrique, F. Martin, J. L. Molina, M. Morales, G. Moreno, F. B. Navarro, I. Parrillo, J. Pérez, M. Pérez, J. Pinilla, F. Pulpillo, B. Ramos, A. B. Robles, J. Salcedo, F. Sánchez-Piñero, D. Serrano, J. L. Tella, J. Traba, F. Valera, and M. Yanes. 2018. Manifiesto por la Conservación de las Aves Esteparias en Andalucía. Granada.

Arroyo, B. 1995. Breeding ecology and nest dispersion of Montagu’s Harrier Circus pygargus in central Spain. University of Oxford.

Arroyo, B., and V. Bretagnolle. 2000. Evaluating the long-term effectiveness of conservation practices in Montagu’s Harrier Circus pygargus.pdf. Pages 403–408*in* P. Press, editor.Raptors at Risk. Cornwall.

Arroyo, B., and J. García. 2007. El aguilucho cenizo y el aguilucho pálido en España Población en 2006 y método de censo. Page (SEO/BirdLife, Ed.). Madrid.

Arroyo, B., and J. T. García. 2004. Aguilucho Cenizo Circus pygargus. Pages 138–141*in* A. Madroño, C. González, and J. C. Atienza, editors.Libro Rojo de las Aves de

España. Dirección General para la Biodidversidad-SEO/BirdLife, Madrid.

Arroyo, B., J. T. García, and V. Bretagnolle. 2002. Conservation of the Montagu's harrier (Circus pygargus) in agricultural areas. Animal Conservation 5:283–290.

Atkinson, P. W., R. J. Fuller, and J. A. Vickery. 2002. Large-Scale Patterns of Summer and Winter Bird Distribution in Relation to Farmland Type in England and Wales. Ecography 25:466–480.

Bates, D., M. Maechler, B. Bolker, and S. Walker. 2015. Fitting Linear Mixed-Effects Models Using lme4. Journal of Statistical Software 67:1–48.

Beaufoy, G. 2001. EU policies for olive farming Unsustainable on all counts. First edition.

Bossard, M., J. Feranec, J. Otahel, and C. Steenmans. 2000. CORINE land cover technical guide-Addendum 2000. Copenhagen.

Bota, G., M. B. Morales, S. Mañosa, and J. Camprodon. 2005. Ecology and Conservation of Steppe-Land Birds. Page (L. E. & C. T. F. de Catalunya, Ed.) Ecology and Conservation of Steppe-Land Birds. Fundación Biodiversidad, Barcelona.

Brunat, D. 2018, June 28. El boom del pistacho: un oasis en el desierto que promete salvar la España vacía. El Confidencial.

Caballero, R., F. Fernández-gonzález, R. P. Badia, G. Molle, P. P. Roggero, S. Bagella, P. D. Ottavio, V. P. Papanastasis, G. Fotiadis, A. Sidiropoulou, and I. Ispikoudis. 2009. Grazing Systems and Biodiversity in Mediterranean Áreas : Spain , Italy and Greece. Pastos 39:9–152.

Camarsa, G., S. Gardner, W. Jones, J. Eldridge, T. Hudson, E. Thorpe, and E. O'Hara. 2010. LIFE among the olives Good practice in improving environmental performance in the olive oil sector. Page (Office for Official Publiations of the European Union, Ed.). Luxembourg.

Cardador, L., L. Brotons, F. Ois Mougeot, D. Giralt, G. Bota, M. Pomarol, B. Arroyo, and A. Vespucio. 2015. Conservation Traps and Long-Term Species Persistence in Human-Dominated Systems. Conservation Letters 8:456–462.

Carrasco, M. C. 2015. XIII CONGRESO del Grupo Aguiluchos. Pages 29–33*in* GREFA and AMUS, editors.Estado de la Población y Medidas de Conservación de los Aguiluchos en Extremadura. San Ildefonso.

Carricondo, A., C. Martín, Y. Cortés, and P. Martínez. 2011. Estudio y análisis de los esquemas agroambientales para aves esteparias en España. Madrid.

Castaño, J. P. 2009. LOS AGUILUCHOS CENIZO Circus pygargus Y PÁLIDO Circus cyaneus EN TOLEDO . EVALUACIÓN DE DIEZ AÑOS DE CAMPAÑAS DE CONSERVACIÓN REALIZADAS POR ESPARVEL. Page Anuario Ornitologico de Toldeo. 2002-2007. Toledo.

Castaño, J. P., and G. A. Díaz. (n.d.). Estado de conservación y dinámica poblacional del Aguilucho cenizo Circus pygargus y del Aguilucho pálido Circus cyaneus en las comarcas de la Sagra y Torrijos. Toledo.

Centro Nacional de Información Geográfica (CNIG). 2018. CORINE Land Cover. http://centrodedescargas.cnig.es/CentroDescargas/index.jsp#.

Chamberlain, D. E., R. J. Fuller, R. G. H. Bunce, J. C. Duckworth, and M. Shrubb. 2000.

Changes in the abundance of farmland birds in relation to the timing of agricultural intensification in England and Wales. Journal of Applied Ecology 37:771–788.

Conserjería de Medio Ambiente y Ordenación del Territorio. 2013. Programa de actuaciones para la conservación del Aguilucho cenizo (Circus pygargus) en Andalucía.

Donald, P. F., R. E. Green, and M. F. Heath. 2001. Agricultural intensification and the collapse of Europe’s farmland bird populations. The Royal Society 268:25–29.

Ellemberg, H., and C. Leuschner. 1996. Vegetation Mitteleuropas mit den Alpen: in ökologischer, dynamischer und historischer Sicht. Sixth edition. UTB, Stuttgart.

Estrada, A., and B. Arroyo. 2012. Occurrence vs abundance models: Differences between species with varying aggregation patterns. Biological Conservation 152:37–45.

European Environment Agency. 1995. CORINE Land Cover.

Eurostat. 2015. Olive plantations: number of farms and areas by size of farm (UAA) and size of olive plantation area. http://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do.

Food and Agriculture Organization of the United Nations. 2017. Land Use. http://www.fao.org/faostat/en/#data/EL/visualize.

Fuller, R. J., R. D. Gregory, D. W. Gibbons, J. H. Marchant, J. D. Wilson, S. R. Baillie, and N. Carter. 1995. Population Declines and Range Contractions Among Lowland Farmland Birds in Britain. Conservation Biology 9:1425–1441.

Hardey, J., H. Crick, H. Riley, B. Etheridge, D. Thompson, Scottish Raptor Monitoring Group, and Scottish Natural Heritage. 2009. Montagu's Harrier (Circus pygargus). Pages 110–116*in* Scottish Natural Heritage, editor.Raptors: a field guide to surbey and monitoring. 2nd edition. The Stationery Office Limited, Edinburgh.

Heikkinen, R. K., M. Luoto, R. Virkkala, and K. Rainio. 2004. Effects of Habitat Cover, Landscape Structure and Spatial Variables on the Abundance of Birds in an Agricultural-Forest Mosaic. Journal of Applied Ecology 41:824–835.

Henle, K., D. Alard, J. Clitherow, P. Cobb, L. Firbank, T. Kull, D. Mccracken, R. F. A. Moritz, J. Niemelä, M. Rebane, D. Wascher, A. Watt, and J. Young. 2008a. Identifying and managing the conflicts between agriculture and biodiversity conservation in Europe-A review. Agriculture, Ecosystems and Environment 124:60–71.

Henle, K., D. Alard, J. Clitherow, P. Cobb, L. Firbank, T. Kull, D. McCracken, R. F. A. Moritz, J. Niemelä, M. Rebane, D. Wascher, A. Watt, and J. Young. 2008b. Identifying and managing the conflicts between agriculture and biodiversity conservation in Europe–A review. Agriculture, Ecosystems & Environment 124:60–71.

Hiron, M. 2013. From Fields to Landscapes: Effects of Agricultural Land Use and Landscape Heterogeneity on Farmland Birds. Faculty of Natural Resources and Agricultural Science.

International Union for Conservation of Nature and Natural Resources. 2004. The IUCN red list of threatened species.

Kleijn, D., F. Kohler, A. Báldi, P. Batáry, E. D. Concepción, Y. Clough, M. Díaz, D. Gabriel, A. Holzschuh, E. Knop, A. Kovács, E. J. P. Marshall, T. Tscharntke, and J. Verhulst. 2009. On the relationship between farmland biodiversity and land-use intensity in Europe. Proceedings. Biological sciences 276:903–9.

Kosztra György Büttner, B., and G. Hazeu Stephan Arnold. 2017. Updated CLC illustrated nomenclature guidelines European Topic Centre on Urban, land and soil systems. Wien.

Limiñana, R., J. T. García, J. Miguel González, Á. Guerrero, J. Lavedán, J. Damián Moreno, A. Román-Muñoz, L. E. Palomares, A. Pinilla, G. Ros, C. Serrano, M. Surroca, J. Tena, and B. Arroyo. 2012. Philopatry and natal dispersal of Montagu's harriers (Circus pygargus) breeding in Spain: a review of existing data. European Journal of Wildlife Research 58:549–555.

Marini, M. A., and J. C. del Moral. 2003. Atlas de las aves reproductoras de España. Page (Dirección General de Conservación de la Naturaleza-Sociedad Española de Ornitología, Ed.). Dirección General de Conservación de la Naturaleza-Sociedad Española de Ornitología, Madrid.

Miguel, M. G., and R. J. Gema. 2018. Vigilancia y Protección del Aguilucho Cenizo. Programa de actuación del Plan de recuperación y conservación de aves esteparias de Andalucía.

Ministerio de Agricultura, P. y A., and Ministerio para la Transición Ecológica. 2017. Superficies y producciones anuales de cultivos. http://www.mapama.gob.es/es/estadistica/temas/estadisticas-agrarias/agricultura/superficies-producciones-anuales-cultivos/.

Newbold, T., L. N. Hudson, S. L. L. Hill, S. Contu, I. Lysenko, R. A. Senior, L. Börger, D. J. Bennett, A. Choimes, B. Collen, J. Day, A. De Palma, S. Díaz, S. Echeverria-Londoño, M. J. Edgar, A. Feldman, M. Garon, M. L. K. Harrison, T. Alhusseini, D. J. Ingram, Y. Itescu, J. Kattge, V. Kemp, L. Kirkpatrick, M. Kleyer, D. Laginha, P. Correia, C. D. Martin, S. Meiri, M. Novosolov, Y. Pan, H. R. P. Phillips, D. W. Purves, A. Robinson, J. Simpson, S. L. Tuck, E. Weiher, H. J. White, R. M. Ewers, G. M. Mace, and J. P. W. Scharlemann. 2015. Global effects of land use on local terrestrial biodiversity. Nature 520:45–50.

Oñate, J. J., I. Atance, I. Bardají, and D. Llusia. 2007a. Modelling the effects of alternative CAP policies for the Spanish high-nature value cereal-steppe farming systems. Agricultural Systems 94:247–260.

Oñate, J. J., I. Atance, I. Bardají, and D. Llusia. 2007b. Modelling the effects of alternative CAP policies for the Spanish high-nature value cereal-steppe farming systems. Agricultural Systems 94:247–260.

Pain, D. J., and M. W. Pienkowski. 1997. Farming and birds in Europe : the common agricultural policy and its implications for bird conservation. Academic Press, San Diego.

Pinilla Torres, A. J. 2015. XIII CONGRESO del Grupo Aguiluchos. Pages 64–69*in* GREFA and AMUS, editors.Repercusiones de la transformación de un paisaje agrario: El caso del Aguilucho cenizo en Tierra de Barros. San Ildefonso.

Pita, R., A. Nio Mira, F. Moreira, R. Morgado, and P. Beja. 2009. Influence of landscape characteristics on carnivore diversity and abundance in Mediterranean farmland. Agriculture, Ecosystems and Environment2 132:57–65.

Rabadán, A., M. Álvarez-Ortí, J. E. Pardo, R. Gómez, A. Pardo-Giménez, and M. Olmeda. 2017. A comprehensive approach to pistachio oil production. British Food Journal 119:921–933.

R Core Team. 2018. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Romero Díaz, A., C. Martínez Hernández, and F. Belmonte Serrato. 2012. Cambios de usos del suelo en la Región de Murcia. El almendro como cultivo de referencia y su relación con los procesos de erosión. Nimbus 29–30:607–626.

Sainz Ollero, H., and M. Van Staalduinen. 2012. IBERIAN STEPPES. Page 568*in* M. Werger and M. Van Staalduinen, editors.Eurasian Steppes. Ecological Problems and Livelihoods in a Changing World. First edition. Springer Netherlands, Netherlands.

Santangeli, A., and B. Arroyo. 2017. The Montagu ' s Harrier Circus pygargus in Spain : Population status and trend , nesting habitat , nest protection measures and conservation solutions. Vogelwet 137:1–6.

Santangeli, A., E. Di Minin, and B. Arroyo. 2014. Bridging the research implementation gap - Identifying cost-effective protection measures for Montagu's harrier nests in Spanish farmlands. Biological Conservation 177:126–133.

Seo/BirdLife. 2018. Descienden las poblaciones de aguilucho cenizo y aguilucho pálido en España en los últimos 10 años. https://www.seo.org/2018/07/06/descienden-las-poblaciones-de-aguilucho-cenizo-y-aguilucho-palido-en-espana-en-los-ultimos-10-anos/.

Seo BirdLife. 2008. Aguilucho cenizo - SEO/BirdLife. https://www.seo.org/ave/aguilucho-cenizo/.

Seoane, J. 2014. Temas actuales de Etología ¿Modelos mixtos (lineales)? Una introducción para el usuario temeroso. Page ETOLOGUÍA. Madrid.

Sokos, C. K., A. P. Mamolos, K. L. Kalburtji, and P. K. Birtsas. 2013. Farming and wildlife in Mediterranean agroecosystems. Journal for Nature Conservation 21:81–92.

Stoate, C., A. Bá Ldi, P. Beja, N. D. Boatman, I. Herzon, A. Van Doorn, G. R. De Snoo, L. Rakosy, and C. Ramwell. 2009. Ecological impacts of early 21st century agricultural change in Europe – A review. Journal of Environmental Management 91:22–46.

Tapia, L., A. Gil-Carrera, A. Regos, and J. Domínguez. 2016. Collapse of Montagu’s harrier (Circus pygargus) population in Galicia (NW Spain) associated to land use changes. Page IX Congresso de Ornitologia de SPEA y VI Congreso Ibérico de Ornitología. Universidade de Trás-os-Montes e Alto Douro (Vila Real).

Tapia, L., & A. Regos, A. Gil-Carrera, and & J. Domínguez. 2017. Unravelling the response of diurnal raptors to land use change in a highly dynamic landscape in northwestern Spain: an approach based on satellite earth observation data. European Journal of Wildlife Research 63:40–55.

WWF. 2009. Agriculture in the EU.

Table 1. Codes and type of habitats selected as suitable and non-suitable habitats for breeding for Montagu's Harrier. (Kosztra György Büttner and Hazeu Stephan Arnold 2017).

CODE	**LABEL LEVEL 1**	**LABEL LEVEL 2**	**LABEL LEVEL 3**	**ASSESSMENT OF HABITAT FOR FORAGING AND BREEDING[1]**
211	Agricultural areas	Arable land	Non-irrigated arable land	S
212	Agricultural areas	Arable land	Permanently irrigated land	S
221	Agricultural areas	Permanent crops	Vineyards	Ns
222	Agricultural areas	Permanent crops	Fruit trees and berry plantations	Ns
223	Agricultural areas	Permanent crops	Olive groves	Ns
231	Agricultural areas	Pastures	Pastures	Sf
243	Agricultural areas	Heterogeneous agricultural areas	Land principally occupied by agriculture, with significant areas of natural vegetation	S
244	Agricultural areas	Heterogeneous agricultural areas	Agro-forestry areas	Sf*
322	Forest and semi natural areas	Scrub and/or herbaceous vegetation associations	Moors and heathland	S

[1] *S* indicate suitable habitat for both breeding and foraging. *Sf* adequate habitat only for foraging, but not for breeding. *Ns* represents Unsuitable areas for breeding and foraging. * this is at least the case if there is cereal under the trees.

Table 2. Harvesting time (in relation to breeding of Montagu´s harriers) and occurrence of protection programs in each Province of the census.

AUTONOMOUS COMMUNITY	PROVINCE	PROTECTION INTENSITY[1]	HARVEST PROBLEM[2]
Andalusia	Cadiz	Yes	Early
	Cordoba	Yes	Early
	Granada	Yes	Early
	Huelva	Yes	Early
	Jaen	Yes	Early
	Málaga	Yes	Early
	Sevilla	Yes	Early
Asturias	Asturias	Unnecessary	No
Basque Country	Alava	No	Late
Cantabria	Cantabria	Unnecessary	No
Castile and Leon	Avila	No	Late
	Burgos	No	Late
	Leon	No	Late
	Palencia	No	Late
	Salamanca	Partial	Late
	Segovia	Partial	Late
	Soria	No	Late
	Valladolid	No	Late
	Zamora	No	Late
Castile la Mancha	Albacete	Partial	Intermediate
	Ciudad Real	No	Intermediate
	Cuenca	No	Intermediate
	Guadalajara	No	Intermediate
	Toledo	Partial	Intermediate
Catalonia	Girona	Unnecessary	No
	Lleida	Yes	Early
	Tarragona	Unnecessary	No
Extremadura	Badajoz	Yes	Intermediate
	Caceres	Partial	Intermediate
Galicia	Lugo	Unnecessary	No
	Ourense	Unnecessary	No
La Rioja	La Rioja	Yes	Late
Madrid	Madrid	Partial	Late
Murcia	Murcia	No	Intermediate
Valencian Community	Alicante	Unnecessary	No
	Castellon de la Plana	No	No

1) *Yes* (robust and not interrupted protection measures in last years, covering a large part of the breeding population), *Partial* (protection work only localized in space, or not continuous in time) , *No* (no actions have been done to protect nests at harvest time) and *Unnecessary* (no actions because there is no risk related with harvest activities; this was the case for populations nesting in natural vegetation).

2) *Early harvest* (harvest from May to early June, coinciding with harrier incubation), *Intermediate* (June, during development of nestlings), *Late* (harvest from end of June to July, coinciding with fledging) and *No*, areas without harvest activities

Table 3. LMM global results.

	DF	AIC	LRT	Pr(Chi)
None		2573.8		
Protection	2	2570.4	0.559	0.756
Harvesting date problem	2	2571.4	1.565	0.457
Suitable areas change	1	2572.2	0.392	0.531
Woody permanent crops area change	1	2574.9	3.024	0.082
Pasture-Dehesa areas change	1	2573.2	1.312	0.252

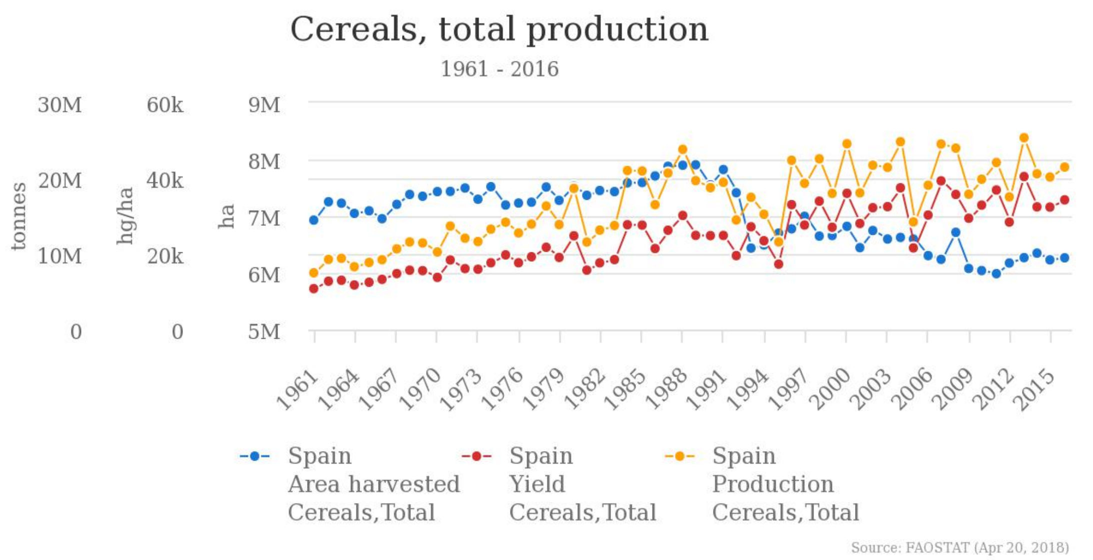

Figure 1. Spanish cereal crops surface, their yield and production per year since 1961 to 2015 (Food and Agriculture Organization of the United Nations 2017)

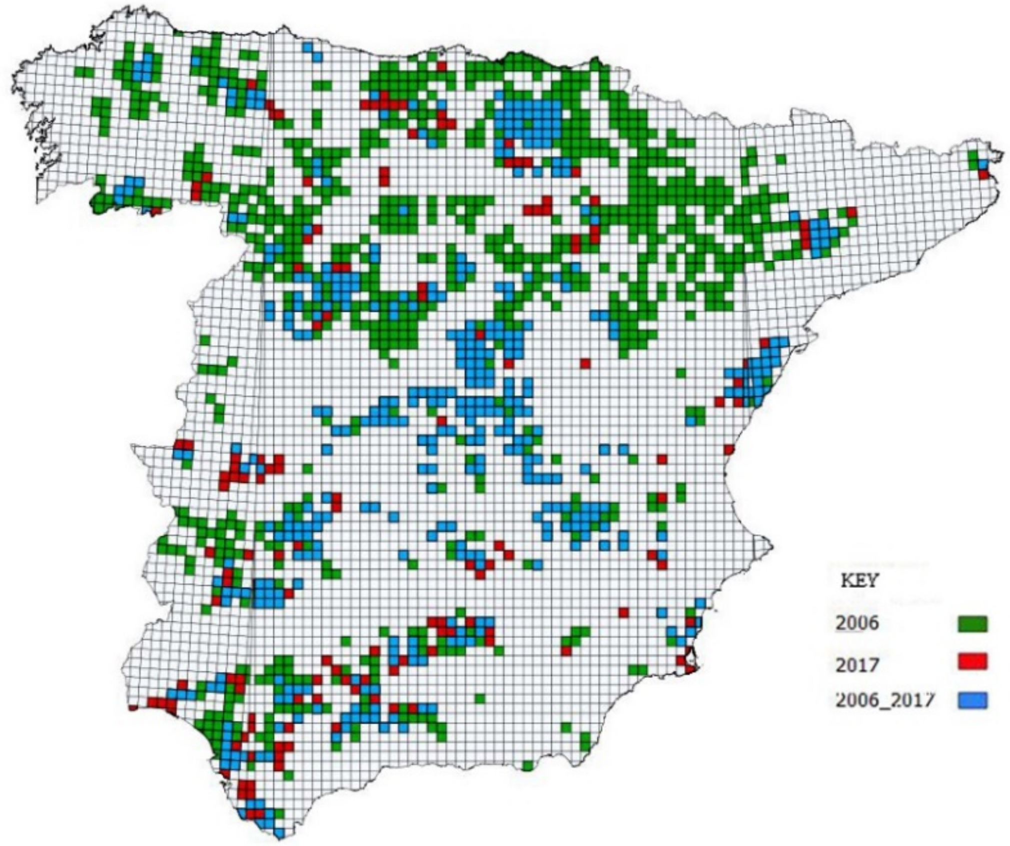

Figure 2. Spanish UTM grid of Montagu's Harrier census cells distribution.

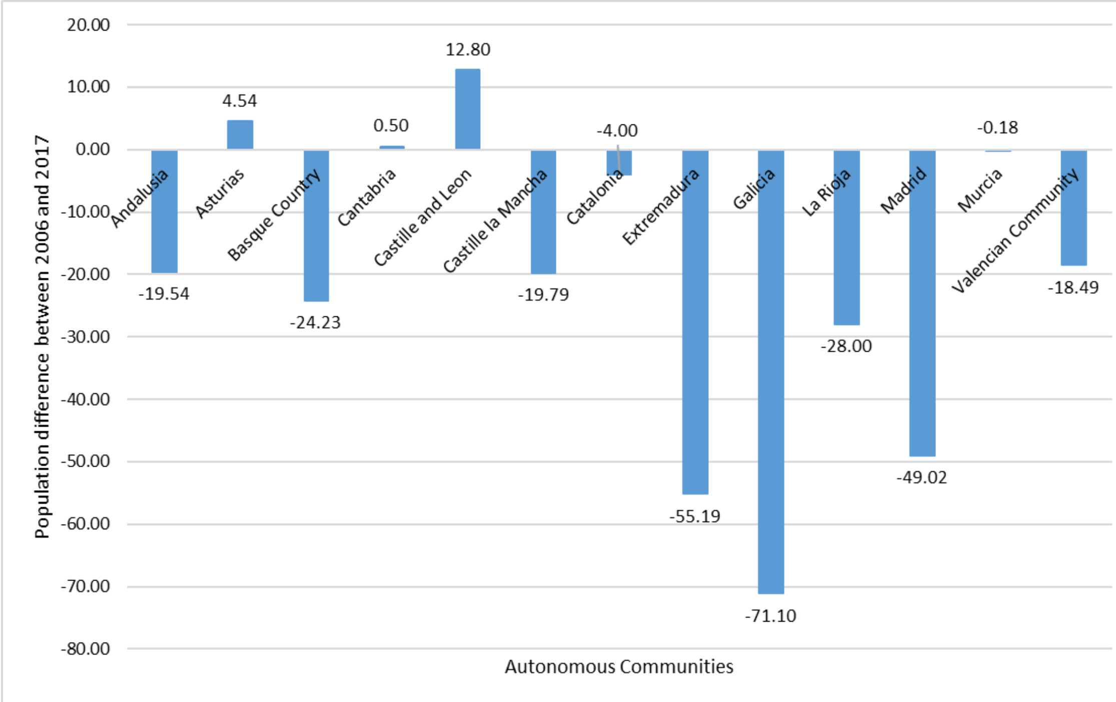

Figure 3. Difference in Montagu's Harrier minimum pairs number between 2006 and 2017 censuses in each autonomous community.

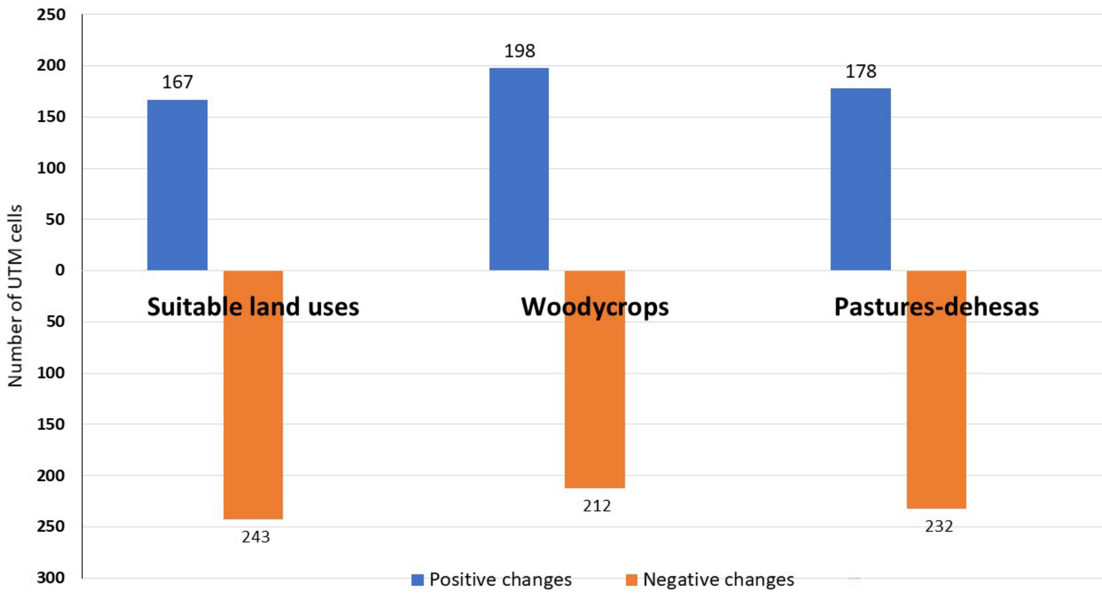

Figure 4. Number of monitored UTM quadrats with positive and negative changes in the extension of suitable land uses for breeding, woody permanent crops and Pastures-Dehesas areas.

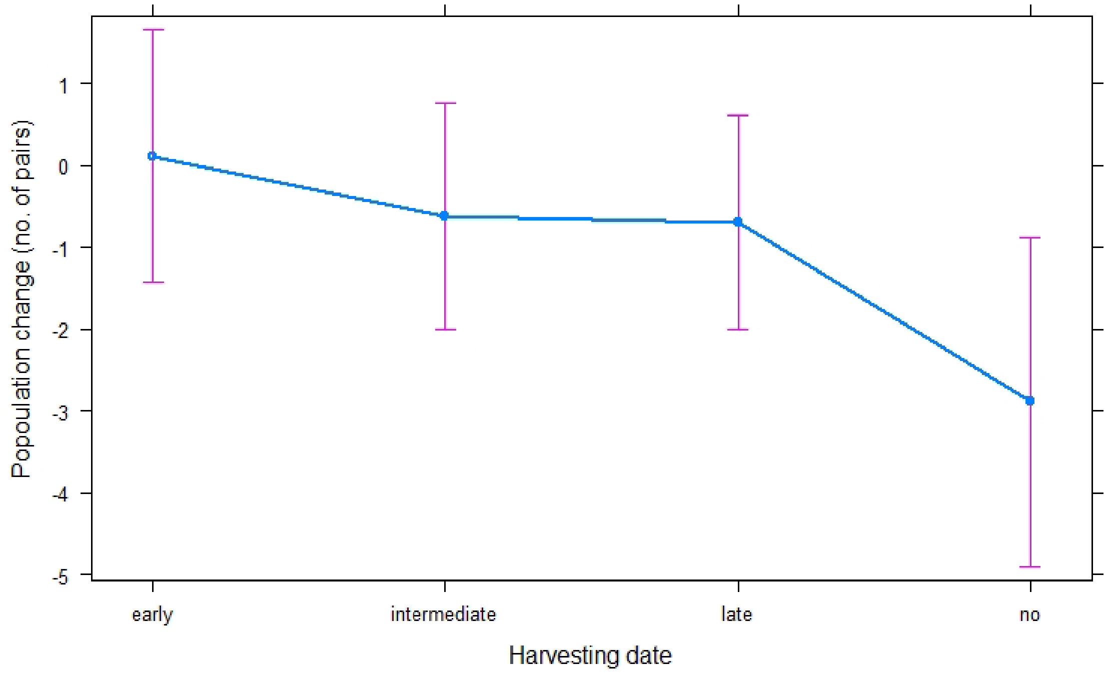

Figure 5. Partial effect of harvest date on Montagu's Harrier population change.

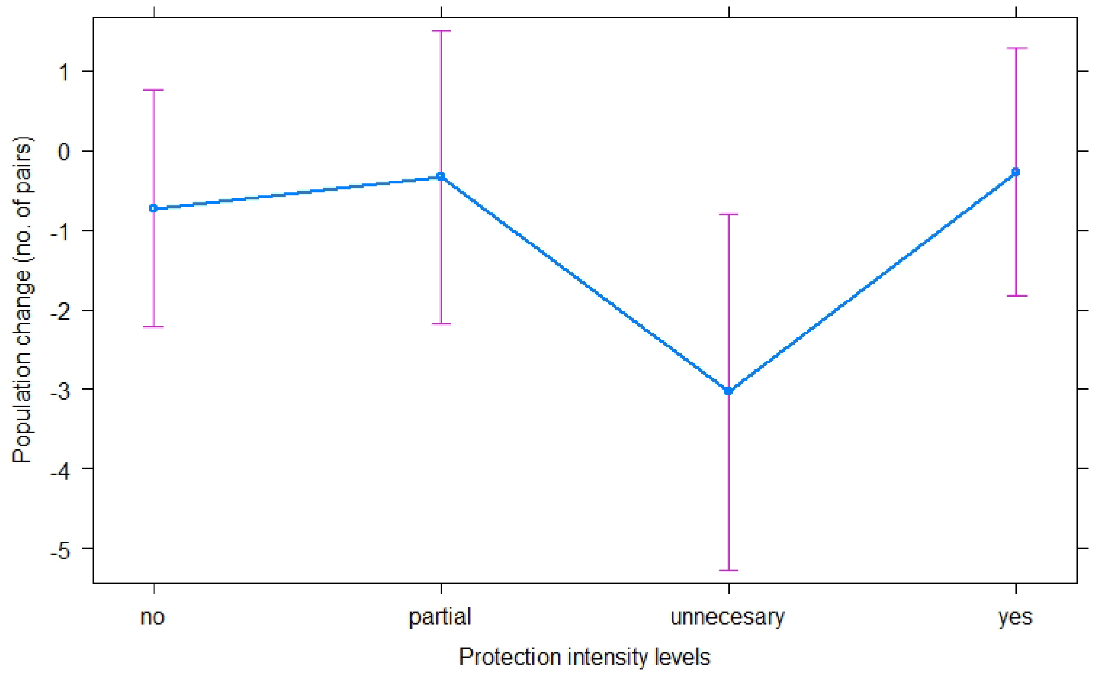

Figure 6. Effect of protection intensity levels about Montagu's Harrier population change.

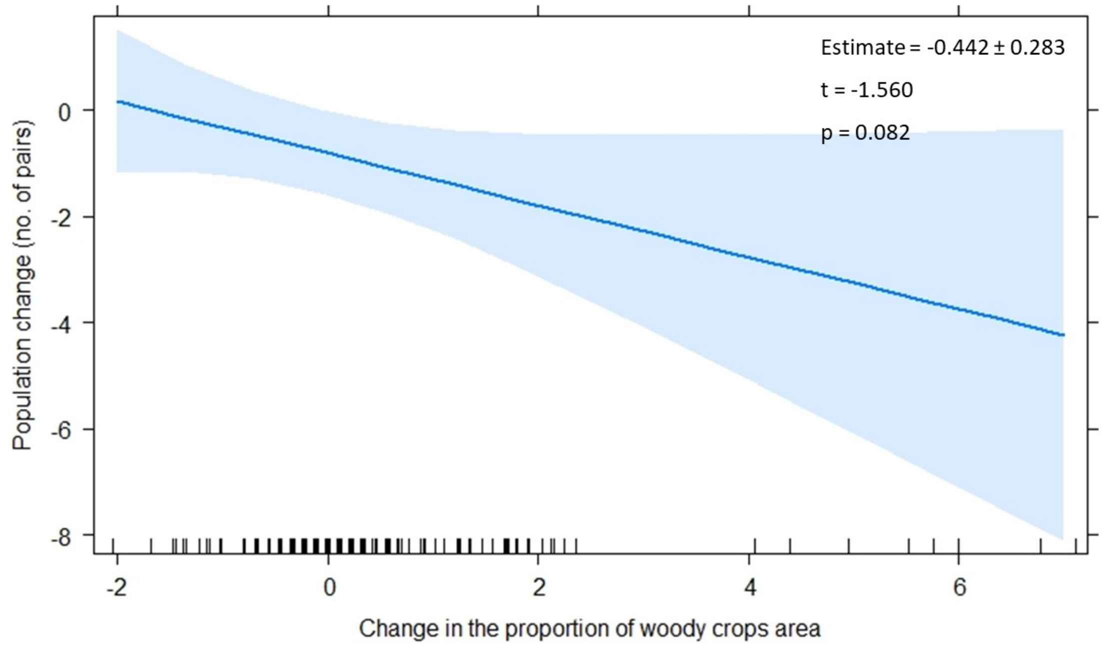

Figure 7. Partial effect of changes in area of woody permanent crops on Montagu's Harrier population change.

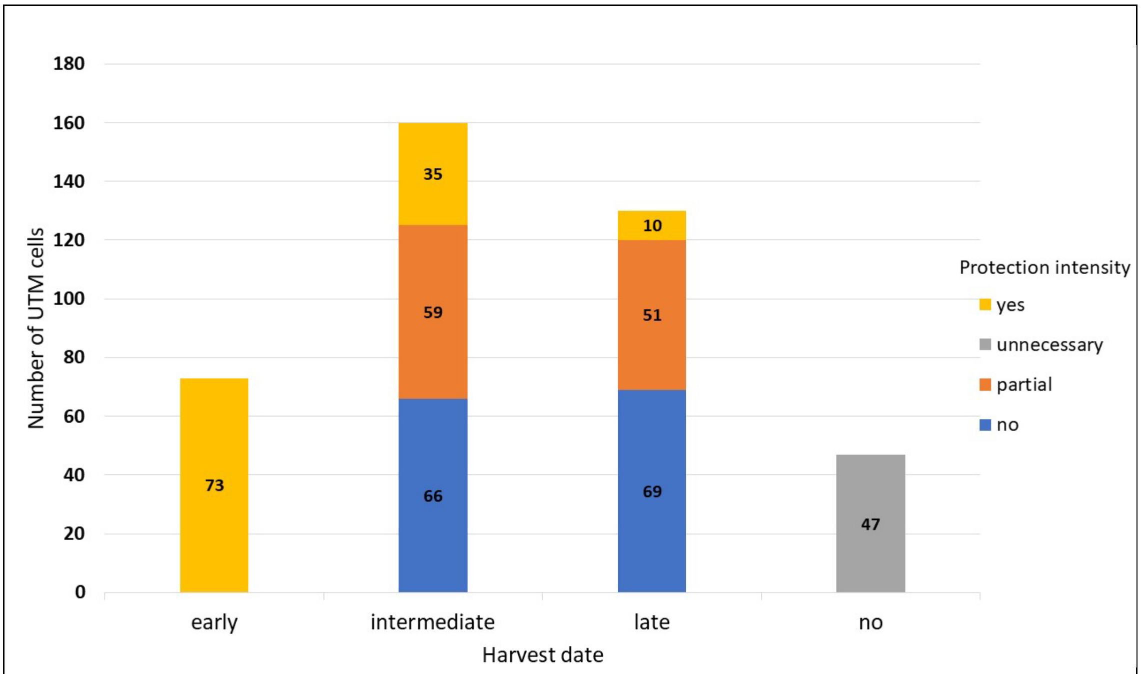

Figure 8. Protection intensity in relation to harvest date in the area.