Universitat de Lleida

Fallow lands as a tool for farmland biodiversity conservation

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http://hdl.handle.net/10803/398837

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Universitat de Lleida

Escola Tècnica Superior d´Enginyeria Agrària

Departament d´Hortofruticultura, Botànica i Jardineria

Fallow lands as a tool for farmland biodiversity conservation

Dissertation to obtain the degree of Doctor by

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This PhD has been carried out within the consolidated group of research "Weed Science and Plant Ecology" (2014SGC008) from the Universitat de Lleida. The author was funded by a PhD grant from Ministerio de Economía y Competitividad (BES-2011 047518). Study funded by Ministerio de Economía y Competitividad (Project AGL 2010-22084-C02-01).

Presentación

Esta tesis se ha llevado a cabo bajo la dirección del profesor Dr. Jordi Recasens Guinjuan dentro del grupo de investigación consolidado de Malherbología y Ecología Vegetal del Departament d´Hortofruticultura, Botànica i Jardineria de l´Escola Tècnica Superior d´Enginyeria Agrària (ETSEA) de la Universitat de Lleida. El presente trabajo se enmarca dentro del proyecto de investigación (AGL 2010-22084-C02-01) financiado por el Ministerio de Economía y Competitividad.

Una beca predoctoral FPI (BES-2011 047518) fue concedida por el Ministerio de Economía y Competitividad desde septiembre de 2011 a agosto de 2015.

Durante la realización de esta tesis se han llevado a cabo dos estancias en otros centros Eurpeos:

-**National Institute De La Recherche Agronomic (INRA)** de Dijon (Francia), con la Dra. Sandrine Petit (septiembre 2013-diciembre 2013).

-**Rothamsted Research** de Harpenden (Inglaterra), con el Dr. Jonathan Storkey (septiembre 2014-noviembre 2014).

A partir de los resultados obtenidos en el desarrollo de esta tesis se han elaborado dferentes artículos:

-**Artículo 1**: Using the response – effect trait framework to quantify the value of non-crop patches in agricultural landscapes to pollinators. Irene Robleño, Jonathan Storkey, Xavier O. Solé-Senan & Jordi Recasens. Enviado a la revista *Applied Vegetation Science* en abril de 2016.

-**Artículo 2**: Fallow management for steppe bird conservation: the impact of cultural practices on vegetation structure and food resources. Irene Robleño, Gerard Bota, David Giralt & Jordi Recasens. Enviado a la revista *Biodiversity and Conservation* a principios de febrero de 2016.

-**Artículo 3**: Steppe bird responses to different management practices in fallow lands: towards an enhancement of agri-environmental schemes efficiency. Irene Robleño, Gerard Bota, David Giralt, Francesc Sardà & Jordi Recasens. Este artículo se encuentra en preparación.

-**Artículo 4**: Spatial distribution of vegetation modifies the suitability of farmland birds' habitat in fallow lands. Irene Robleño, Manel Ribes-Dasi, Aritz Royo-Esnal, Joel Torra & Jordi Recasens. Enviado a la revista *Annals of Applied Biology* en mayo de 2016.

Además, han tenido lugar diversas difusiones de los resultados en congresos y grupos de trabajo de ámbito nacional e internacional:

Solé-Senan, X. & Robleño, I. The role of landscape heterogeneity on pollination services in cereal fields. Final Meeting Farmland Proyect. 2016, Camargue, (France).

Robleño, I., Solé-Senan, X., Royo-Esnal, A., Torra, J., Conesa, J.A. & Recasens, J. El manejo de barbechos como indicador de la eficiencia de medidas agroambientales. XIV Congreso Sociendad Española de Malherbología. 2013, Valencia (Spain).

Izquierdo, J., Robleño, I., Royo-Esnal, A., Torra, J., Baraibar, B., Conesa, J.A. & Recasens, R. Effect of soil management (no-tillage vs. tillage) on weed spatial distribution in cereals. 9th European Conference on Precision Agriculture. 2013, Lleida (Spain).

Robleño, I, Royo-Esnal, A., Torra, J. & Recasens, R. Weed management in fallow fields as indicator of the agri-environmental schemes in dryland areas. 16th European Weed Research Society Symposium. 2013, Samsun (Turkey).

A lo largo de este periodo también se ha colaborado en el proyecto europeo Farmland-Biodiversa en el que participan grupos de investigación de diversos países (Francia, Alemania, España, Inglaterra y Canadá), realizando muestreos de campo y participando en reuniones y grupos de trabajo. Entre los trabajos en preparación se encuentran los siguientes artículos:

-Enhancing biodiversity across taxa and regions by increasing multiple components of agricultural landscape heterogeneity. Clélia Sirami, Aliette Baillod, Colette Bertrand, Romain Carrié, Annika Hass, Laura Henckel, Paul Miguet, Carole Vuillot, Audrey Alignier, Jude Girard, Peter Batary, Yann Clough, Cyrille Violle, David Giralt, Gerard Bota, Isabelle Badenhauser, Gaetan Lefebvre, Nicolas Gross, Bertrand Gauffre, Aude Vialatte, François Calatayud, Assu Gil-Tena, Nora Quesada-Pizarro, Lutz Tischendorf, Scott Mitchell, Kathryn Lindsay, Romain Georges, Samuel Hilaire, Jordi Recasens, Irene Robleño, Xavier O. Sole-Senán, Jordi Bosch, Jose Antonio Barrientos, Antonio Ricarte, Mª Ángeles Marcos, Jesus Minano, Raphael Mathevet, Annick Gibon, Jacques Baudry, Gerard Balent, Brigitte Poulin, Françoise Burel, Teja Tscharntke, Vincent Bretagnolle, Gavin Siriwardena, Annie Ouin, Lluís Brotons, Jean-Louis Martin & Lenore Fahrig.

-How do landscape composition and configuration influence plant diversity at the field level? Audrey Alignier, Peter Batary, Xavier O. Solé-Senán, Irene Robleño, Barbara Baraibar, Nicolas Gross, Cyrille Violle & Clélia Sirami.

- The role of landscape heterogeneity on pollination services in cereal fields. Xavier O. Solé-Senán, Irene Robleño, Audrey Alignier, Peter Batary, Nicolas Gross, Cyrille Violle & Clélia Sirami.

Agradecimientos

Es prácticamente imposible resumir en poco más de un folio las miles de gracias que tengo que dar a tantas personas que, de una u otra forma, me han acompañado en esta "aventura" porque cada una de ellas ha aportado su granito de arena para que hoy sea como soy, esté aquí, y tú puedas estar leyendo este documento.

Gracias a mi director, Jordi Recasens, por darme la oportunidad de iniciar este camino, por confiar en mí y nunca ponerme barreras. Al grupo de Malherbología: Joel, Aritz, Bàrbara, Núria, J. Antoni, y a todos los ayudantes esporádicos por su gran dedicación en el trabajo de campo, sin vuestra ayuda todo hubiera sido muy difícil. Gracias también a Núria Llop por su atención siempre amable y eficiente.

A Jordi Caus, Jaume Messegué, J.M. Montull, Pere Vall y Pau Forns por dejarnos trabajar en sus fincas y por estar dispuestos a colaborar en todo momento.

A Gerard Bota y a David Giralt, gracias, gracias por creer en mi trabajo, por darle valor y por recibirme siempre tan bien a pesar de vuestras apretadas agendas. Vosotros también sois padres de esta tesis.

A Jonathan Storkey por su energía positiva, entusiasmo y profesionalidad que hicieron de mi estancia una gran e inspiradora experiencia que me llenó de motivación para continuar con fuerza.

Cariño, apoyo, risas, llantos, confianza, comprensión, porque todo esto es imprescindible y precioso, porque a veces la familia se escoge, y ellos son mi familia en Lleida. Alex, Xavi, os quiero mucho.

A mis floretes: Eva, Salo, Paula, Agnès y Diana. Por vuestro apoyo infinito, porque sois maravillosas y tengo mucha suerte de teneros al lado. Tenéis un trocito de mi corazón.

Y quién mejor para entenderte que alguien que vive tus mismas experiencias. Siempre a un toque de puerta con una sonrisa, Blanca bonita, eres un sol. Gracias por ser y estar.

A Lluís, Ana, Matilda, Tere, Carmen, Meri, César, Filipe, Jonathan, Fran, Tunica, Addy, Carles, Laura, Eva, Jordi, Héctor y Jorge. Porque la vida es mucho más divertida e inspiradora con vosotros en ella. Gracias por todos los buenos ratos que hacen olvidar los colores grises.

A mis hermanos Carlos y Titu, de los que a veces me separan miles de kilómetros pero de los que nunca me ha faltado su calor, una palabra de cariño, una risa en días difíciles o consejos para cualquier cosa. Sois únicos e insustituibles.

A los UAMers: Cristian, Eva, Miguel, Raúl, Javi, Alfredo y Bea, porque hemos crecido juntos en este mundo, porque nos entendemos y nos apoyamos. El tiempo no mata nuestro cariño.

A mis arancetanos: Nuri, Aurora, Rubo, Fer, David, Miguel, Sonia, Maca, Silvia, Bea, Sara, Kuko, Pilar y Marta, por hacerme sentir en casa cada vez que vuelvo a casa.

A C. Bernarda por estar siempre presente y porque, en definitiva, es responsable de que todo gire de una determinada manera.

A la música, las películas, los libros o los personajes que en algún momento de este viaje me han servido de apoyo e inspiración y me han aportado la tranquilidad y el equilibrio para seguir adelante.

A mi familia, que adoro. A mis abuelas Brígida e Isabel, porque siempre han sido y son un ejemplo de fuerza, valentía y buen corazón. A mi hermana Laura y a mis padres, Julián y Teresa, por darme siempre libertad sin que nunca me sintiera sola. Vuestro apoyo incondicional ha hecho posible todo lo que he conseguido en la vida. Os quiero.

A la belleza intrínseca de los secanos

Contents

Summary

Agri-environmental schemes (AES) have been designed to counteract the dramatic decline in farmland biodiversity across Europe driven by agricultural intensification. Despite protection efforts, many species of conservation concern are showing ongoing decline, opening the debate regarding the efficiency of current measures applied. This study aimed to shed light on these aspects for the specific case of fallow fields located in a semi-arid region of the north-eastern Iberian Peninsula. Farmers traditionally managed fallow lands with the aim to control diseases, pests or serious weeds that could affect the future crop. However, today the important role of these temporal semi-natural areas as suitable habitats for the enhancement of farmland biodiversity and ecosystem service development make it necessary to plan specific management regimes from a conservationist perspective. Knowledge of the vegetation assembly response (in terms of functionality) to the different agricultural management and landscape conditions improves understanding of their effect on higher trophic levels, and may potentially contribute to enhancing their viability. In this study, different management practices were experimentally tested to show their effects on the habitat suitability of two groups of species which represent farmland biodiversity and ecosystem services: steppe bird species insect pollinators, respectively. Moreover, the surrender area assemblage was also taken into account.

The presence of semi-natural habitats around fallow fields improves the diversity of flower features available for insect pollinators, and additionally, is related with a more active presence of steppe birds. However, a highly heterogeneous configurational landscape composed of irregular fields with many boundaries is

avoided by the majority of steppe bird species mainly because of the high predation risk associated with this type of environment. Also, the high disturbance pressure suffered in field border areas by the neighboring crops leads to a homogenization of the functional weed communities, represented by annual graminoids which are not at all attractive to pollinators. Within fallow fields, there is the need for field practices on account of the lack of suitability shown in non-managed fallows. Tillage management leads to weed colonization of ruderal species, which thereof promotes floral features related with generalist pollinators, but enhances plant material palatability and seed ground availability as a result of the open habitats created. This habitat type fits into the requirements of Pin-tailed sandgrouse (*Pterocles alchata*), Black-bellied sandgrouse (*Pterocles orientalis*), Short-toed lark (*Calandrella brachydactyla*) and Stone-curlew (*Burhinus oedicnemus*). Little bustard males (*Tetrax tetrax*) also prefer these conspicuous areas for their sexual display activity during breeding time. While alfalfa sowing was not a successful treatment, shredding and herbicide action encouraged a denser vegetation habitat structure related with a high invertebrate biomass. Little bustard females and Calandra lark (*Melanocorypha calandra*) respond positively to these habitat characteristics. The heterogeneous patchy habitat configuration resulting from the selective action of an early herbicide application (February) promotes the coexistence of diverse plant phenotypes which in turn allow for a longer period of forage availability for pollinators. Management effects, however, often follow a common trend leading to homogenization of vegetation cover over the years. Due to this, a maximum of three years under the same management is recommended to maintain habitat suitability.

This study aims to improve current conservation measures by providing valuable information about the different aptitudes of management strategies, according to the preferences of the target species studied. Moreover, an economic analysis was taken into account to merge effective conservation strategy goals with feasible budgets for farmers.

Resumen

El diseño de las medidas agroambientales tiene como principal objetivo frenar la importante pérdida de biodiversidad asociada a la intensificación agrícola que ha tenido lugar en Europa. A pesar de los esfuerzos, muchas de las especies de interés para la conservación continúan en descenso abriendo el debate sobre la eficacia de las actuales medidas aplicadas. Este estudio tiene como objetivo contribuir a incrementar dicho conocimiento para el caso específico de los barbechos en las zonas semi-áridas del noreste de la Península Ibérica. De forma tradicional, el manejo de los barbechos tenía como finalidad controlar plagas y malas hierbas perjudiciales para los cultivos posteriores. Sin embargo, estas áreas semi-naturales transitorias juegan un importante papel contribuyendo a mejorar el hábitat de numerosas especies y el desarrollo de servicios ecosistémicos, poniendo de manifiesto la necesidad de planificar gestiones específicas enfocadas a la conservación. Conocer las respuestas de la comunidad vegetal –en cuanto a variaciones en sus características funcionales- a diferentes manejos agrícolas y condiciones del paisaje permite una mejor comprensión de sus efectos sobre niveles tróficos superiores, pudiendo contribuir a mejorar su viabilidad. En el presente estudio fueron evaluadas de forma experimental diferentes prácticas agrícolas con el objetivo de determinar la idoneidad del hábitat de dos grupos de especies representantes de la biodiversidad en zonas agrícolas –aves esteparias- y servicios ecosistémicos –polinizadores- y la influencia del hábitat circundante.

La presencia de áreas semi-naturales en las proximidades de los campos en barbecho incrementa la disponibilidad de diversidad de formas florales, favoreciendo el hábitat para los insectos polinizadores. Además están relacionadas positivamente con la presencia de aves esteparias. Sin embargo,

paisajes de una alta heterogeneidad configuracional compuestos por campos irregulares y gran cantidad de bordes son evitados por éstas aves debido principalmente a riesgos de depredación. La continua e intensiva presión de perturbación de los campos aledaños en estas zonas de borde origina una homogeneización en la comunidad funcional de malas hierbas, representada por especies graminoides anuales, que no aportan ningún atractivo para los polinizadores. A nivel de campo, la falta de aptitud de los barbechos no manejados confirma la necesidad de su gestión mediante prácticas agrícolas. La acción del arado conforma hábitats abiertos que promueven la colonización de especies ruderales relacionadas con formas florales que atraen a polinizadores generalistas, mejoran la palatabilidad foliar además de la disponibilidad y accesibilidad de las semillas. Este tipo de hábitat se ajusta a los requisitos de la ganga (*Pterocles alchata*), la ortega (*Pterocles orientalis*), la terrera (*Calandrella brachydactyla*) y el alcaraván (*Burhinus oedicnemus*). Los machos de sisón (*Tetrax tetrax*) también muestran preferencia por estas zonas de alta visibilidad para realizar el *display* sexual durante la época de cría. La siembra de alfalfa no resultó ser un tratamiento exitoso, sin embargo el tratamiento con picadora y herbicida dió lugar a una estructura de vegetación densa relacionada con el incremento en la biomasa de invertebrados, asociada positivamente con las hembras de sisón y la calandria (*Melanocorypha calandra*). La acción selectiva del herbicida genera una configuración de hábitat heterogénea permitiendo la coexistencia de diversidad de fenologías vegetales, lo que ofrece una amplia disponibilidad de alimento para los polinizadores. Sin embargo el efecto de los manejos sobre la vegetación a lo largo del tiempo suele confluir en la homogeneización de su cobertura, por lo que para mantener unas condiciones de hábitat adecuadas es recomendable no realizar un mismo tipo de manejo más de tres años.

Este estudio proporciona información valiosa sobre la adecuación de los diferentes manejos agrícolas en barbechos de acuerdo a las preferencias de las especies de interés para la conservación y así contribuir en la mejora y efectividad de las medidas aplicadas en la actualidad. A su vez, la inclusión del análisis económico permite establecer el balance entre conservación y producción.

Resum

El disseny de mesures agroambientals en espais agrícoles té com a principal objectiu frenar l'important pèrdua de biodiversitat associada a la intensificació de l'agricultura que ha tingut lloc a Europa en els darrers decennis. Tot i els esforços, moltes de les espècies d'interès per a la conservació continuen encara en regressió, fet que planteja un debat sobre l'eficàcia d'aquestes mesures. El treball que aquí es presenta té com a objectiu aportar nou coneixement en aquest àmbit, en concret sobre la gestió dels guarets en les zones semi-àrides del nord-est de la Península Ibèrica. De forma tradicional, el maneig dels guarets ha tingut com a objectiu la prevenció de l'aparició de plagues i el control de les males herbes perjudicials per als cultius posteriors. No obstant això, aquestes àrees semi-naturals transitòries juguen un important paper contribuint a millorar l'hàbitat de nombroses espècies i en l'establiment de serveis ecosistèmics, ficant de manifest la necessitat de planificar gestions específiques enfocades a la conservació. Així, el coneixement de la resposta de la comunitat vegetal -pel que fa a variacions en les seves característiques funcionals- a diferents manejos agrícoles i a condicions del paisatge, ha de permetre una millor comprensió dels seus efectes sobre nivells tròfics superiors i contribuir a millorar la seva viabilitat. En aquest sentit, en el present estudi han estat avaluades, de forma experimental, diferents pràctiques agrícoles amb l'objectiu de determinar la idoneïtat de l'hàbitat per a dos grups d'organismes: d'una banda les aus estepàries, com a representants de la biodiversitat en aquestes zones agrícoles, i d'una altra, els pol·linitzadors, indicadors de l'eficiència dels serveis ecosistèmics. En aquest context, la configuració paisatgística de l'hàbitat de l´entorn ha estat també tinguda en compte.

La presència d'àrees semi-naturals en les proximitats dels camps en guaret incrementa la disponibilitat de diversitat de formes florals, afavorint l'hàbitat per als insectes pol·linitzadors. A més, aquestes àrees estan relacionades positivament amb la presència d'aus estepàries. Malgrat tot, els paisatges amb una configuració molt heterogènia i compostos per camps irregulars i amb gran quantitat de marges no són adequats per a aquestes aus pel seu risc de depredació. D'altra banda, la contínua i intensa pertorbació dels camps limítrofs origina una homogeneïtzació en la comunitat funcional de males herbes, representada per espècies graminoides anuals, que no aporten cap atractiu per als pol·linitzadors. A nivell de camp, la manca d'aptitud estructural dels guarets sense un maneig específic confirma la necessitat de la seva gestió mitjançant pràctiques agrícoles. L'acció de les labors del sòl conforma hàbitats oberts que promouen la colonització d'espècies ruderals relacionades amb formes florals que atrauen pol·linitzadors generalistes, milloren la palatabilitat foliar a més de afavorir la disponibilitat i accessibilitat de les llavors com a recurs tròfic. Aquest tipus d'hàbitat s'ajusta als requisits de la ganga (*Pterocles alchata*), la xurra (*Pterocles orientalis*), la terrerola (*Calandrella brachydactyla*) i el torlit (*Burhinus oedicnemus*). Els mascles de sisó (*Tetrax tetrax*) també mostren preferència per aquestes zones en afavorir una alta visibilitat per a poder realitzar el display sexual durant l'època de cria. La sembra d'alfals no ha esdevingut un tractament exitós, però el tractament amb picadora i herbicida ha donat lloc a una estructura de vegetació densa relacionada amb l'increment en la biomassa d'invertebrats, associada positivament amb els requisits d'hàbitat de les femelles de sisó i de la calàndria (*Melanocorypha calandra*). L'acció selectiva de l'herbicida genera una configuració d'hàbitat heterogènia i permet la coexistència de diversitat de fenologies vegetals, fet que ofereix una àmplia disponibilitat d'aliment per als pol·linitzadors. En qualsevol cas l'efecte dels manejos sobre la vegetació sol confluir al llarg del temps en l'homogeneïtzació de la seva cobertura, de manera que per mantenir unes condicions d'hàbitat adequades és recomanable no incidir en un mateix tipus de maneig durant més de tres anys seguits.

Aquest estudi proporciona informació acurada sobre l'adequació dels diferents manejos agrícoles als requisits i preferències de les espècies d'interès per a la seva conservació en aquests espais, i alhora aporta propostes de millora per assolir una major efectivitat de les mesures agroambientals fins ara implementades. L’estudi inclou, a més, una anàlisi econòmica que permet als agents involucrats (agricultors, assessors, gestors...) prendre decisions dins el crític balanç entre producció i conservació.

Chapter 1

General introduction

General introduction

Framework

Globally, agricultural lands cover approximately 38% of the planet's surface and about 60% of that of the EU (Gillings et al., 2010). Traditional agricultural systems based on low intensive farming and extensive grazing historically resulted in highly heterogeneous landscapes capable of supporting species-rich communities (Benton et al., 2002). As a result of thousands of years of agricultural expansion, a large number of wild species now rely on land dedicated to human food production and their preservation strongly depends on traditional low-intensity practices (Cardador et al., 2014; Moreno et al., 2010). The demands for food of an increasing population promoted the application of new farming technologies which became more noticiable since the so-called "Green Revolution" in the 1960´s allowing significant yield increases on roughly the same amount of land (Tilman et al. 2002). These technologies included new synthetic fertilizers, herbicides and pesticides, the development of high yielding cereal cultivars, improved methods of seed cleaning, among others. However, agricultural intensification to increase food production is one of the major drivers of ecosystem change leading to a global biodiversity loss and to the deterioration of valuable goods and services provide by the agroecosystems such as provision of resources for pollinators, soil fertility, regulation of climate conditions as well as biocontrol by natural predators of crop pests, among others (Balvanera et al., 2006; Díaz et al., 2006; Foley et al. 2011; Gabriel et al., 2013; Green et al. 2005). Consequently, farmland habitat in many industrialized countries is being profoundly altered, decreasing the ability of communities to respond to environmental change and disturbance.

Agriculture intensification is operating at different spatial scales, both landscape scale and field scale (Benton et al. 2003; Gámez-Virués et al. 2015; Tscharntke et al. 2005). The simplification process suffered at landscape scale is guided by the reduction in land cover types´ diversity and specialization in few (arable) crops (reducing compositional landscape heterogeneity) and also by increasing farm size, natural habitat fragmentation, disappearance of non-crop areas, such as fallow, or destroying edge habitats (reducing configurational landscape heterogeneity) (Fahring et al. 2011; Gámez-Virués et al. 2015; Tscharntke et al. 2005). Intensification at field scale is related with species loss and biotic homogenization due to the high intensity of field management by means of application of fertilizers, use of agro- chemicals (herbicides and pesticides), intensive mechanization or plantation of monocultures, among others (Gámez-Virués et al. 2015).

Because of the rising demand for food from a growing global population, agricultural production is set to double again by 2050 (Green et al., 2005). Within this context, new sustainable agricultural practices are required to limit the decline of farmland biodiversity and portions of the world’s species that are threatened with extinction, in order to preserve the ecosystem services they are capable of providing (Butler et al., 2007; Tscharntke et al., 2007).

Within Mediterranean Europe, vast regions of the Iberian Peninsula are covered by agricultural landscapes known as pseudo-steppes, characterized by a mosaic of land cover including cereal crops, dry legumes, ploughed fields, and grasslands (pastures and fallows) (Moreira et al., 2012). Compared with the other European regions that have an average cereal yield of 6000 kg ha^{-1}, these areas represent low productivity systems, with a yield of only 2500 kg ha^{-1} (Oñate et al., 2007). Thus, managing the effects of these agricultural changes requires the development of frameworks that allow for the quantification of their potential threats and opportunities, while working towards a suitable and multi-functional agricultural system whereby the needs of agricultural production are reconciled with objectives for environmental protection, including biodiversity conservation. To guide this process, appropriate biodiversity conservation targets must be identified (Butler et al., 2009; Cardador et al., 2014). Following this idea, we have selected three important groups within agroecosystems as biodiversity indicators for this study: arable weeds, steppe birds and insect pollinators.

Arable weeds

Although arable weed have traditionally been considered as harmful species for agronomic and socio-economic processes, they are in fact key primary producers and of central importance to the arable system food web (Hyvonen and Huusela-Veistola 2008; Moretti et al., 2013). They belong to the group of species with high ecosystemic relevance, whose losses lead to major changes in the system (Pocock et al., 2012). Furthermore, they play an important role in supporting biodiversity, on account of their multiple interactions within and among trophic levels in agroecosystems, serving as immediate food sources by providing nectar, pollen, seeds and vegetative organs, and by providing shelter and suitable reproduction sites (Marshall et al., 2003). Such species inhabiting arable fields have, however, suffered a reduction of their richness, abundance and diversity because they are directly affected by intensification processes (Chamorro et al., 2016). High sensitivity to arable practices, together with a strong relationship to other organism groups make arable weeds a suitable indicator for evaluating management effects on wildlife diversity in arable fields (Albrecht, 2003; Gerowitt et al., 2003). Also, surrounding habitats are known to influence the plant community in a given habitat. A complex landscape, formed by a high proportion of semi-natural habitats may enhance dispersal-diversity relationships and therefore survival of populations (Ma et al., 2002; Myers et al., 2009; Tscharntke et al., 2005). Species pool of these areas can also provide environmental benefits and maximize important ecosystem services such as pollination and biological pest control and furthermore, provide forage and shelter for fauna (Batary et al., 2011; Ma et al., 2002).

Biotic and abiotic factors influence and change the structure and composition of weed communities, selecting species according to certain characteristics related to shifts in ecosystem function (Fried et al., 2012; Lavorel et al., 2013). The linkages between a disturbance factor, via vegetation, and certain ecosystem functions or processes, appear to be strongly controlled by plant traits (Pakeman and Stockan, 2013; Sebastià et al., 2011). A trait can be defined as a morphological, physiological or phenological characteristic of a species (that is measurable in an individual), referring to a function and indirectly affecting the phenotypic fitness (Violle et al., 2007; Wood et al., 2015).

Many recent studies have shown that plant functional traits can be used to predict the response of plant assemblages to management or other environmental changes and the effect on upper trophic levels, leading to a greater understanding of the impacts of biodiversity in ecosystems (Lavorel et al., 2013;

Verheyen et al., 2003). Focusing entirely on species identity is problematic in that it results in a loss of generality regarding patterns and processes across geographical areas (Fukami et al., 2005). In contrast, the trait-based methodology enables us to identify more general patterns of species response between regions with different environmental conditions, allowing for the prediction of vegetation changes in response to future variation (Kahmen 2005; Pakeman 2013; Sandel et al., 2010). Thus, the application of functional approaches to understanding ecosystem processes is highlighted (Wood et al., 2015).

Pollinators

Pollinators are key-species in ecosystem functioning, as they ensure the provision of vital ecosystem services both in wild habitats and in major crop yields, so are responsible for producing enormous economic benefits to food production (Firbank et al., 2013; Rands 2014). It has been reported that 84% of the species cultivated in Europe depend on pollinator insects (Ricou et al., 2014). The positive relationship between floral abundance or diversity and pollinators means that spatial and temporal changes in abundance, diversity, or distribution of flowering plants may strongly affect the pollinator populations that depend on them, and vice versa (Kohler et al., 2007; Tadey 2015).

The transformation of agriculture has caused the widespread decline of native insect pollinators (Nicholls et al., 2012). The loss of suitable habitat and the removal of weeds that provide forage are the major contributing factors to pollinator decline within agroecosystems, which is directly related to the loss of functional plant–pollinator interactions (Steffan-Dewenter et al., 2005). The negative impact of changes in pollinator abundance on the reproductive success of flowering and plant production is because not all insect species are equally efficient as pollinators (Fontaine et al., 2006; Tadey 2015). Diverse floral and insect phenotype adaptations reflect specialization, resulting in better pollination services. However, the loss of species diversity often results in the loss of trait diversity, which is responsible for complementary pollination services, thus having likely consequences for communityfunctioning with its loss (Fenster et al., 2004; Forrest et al., 2015; Whelan et al., 2008). Since specialists are often more vulnerable to environmental changes than generalist species, this pattern of change and loss could lead to considerable decline in pollinator efficiency as a result of genetic impoverishment of plant species (Díaz et al., 2006; Potts et al., 2010).

The conservation of pollinator diversity represents an important issue because of their contribution to maintaining rich floral diversity (Ricou et al., 2014). The loss of pollination services not only affects the survival of viable populations of pollinators and wild plant diversity but also of beneficial entomofauna which act as natural enemies against pests, leading to substantial decreases in the quantity and quality of seeds produced; an early step in the demographic collapse of plant populations (Ashworth et al., 2004; Kohler et al., 2007; Potts et al., 2010).

Steppe-birds

Steppe birds comprise a highly heterogeneous community of species (De Juana 2005) and are thought to be good indicators of overall farmland biodiversity (Gil-Tena et al., 2015; Tryjanowski et al., 2011) since they are easily monitored, located high in the food web and have many key ecological functions. The decline of farmland birds across Europe is well documented in many studies (Bracken and Bolger 2006; Devictor and Jiguet 2007; Donal et al., 2001; Whittingham et al., 2006). Their populations have almost halved since 1970 and are at present the most threatened bird group in Europe with 83% of the species possessing unfavourable status (Benítez-López et al., 2013). It is widely accepted that these declines have been driven by agricultural intensification based on the knowledge that a large number of such species are not supported by any other habitat on account of their highly specialized requirements (Butler et al., 2007; Wretenberg et al., 2010). Butler et al. (2007), distinguishing them in their degree of specialization over farmland bird species. According to this definition, steppe birds may be within the group of specialists, with narrower niche requirements, making them highly vulnerable to the effects of agricultural change. The Iberian Peninsula holds the most important breeding populations of several species classified as endangered at the European level (Ponce et al., 2014) and hence, stands as an indicator of bird biodiversity health in farmland areas. Evaluating the status of the most threatened bird species populations and understanding their response to widely accepted farming practices is necessary to enhance their population viability in an area. Steppe bird habitat selection is based on a trade-off between energy gain and predation risk that maximizes their fitness (Sanza et al., 2012). Vegetation structure can influence in both and therefore strongly determines habitat selection (Whittingham et al., 2006). High breeding success is also associated with the availability of key supplies, such as alternative plant or invertebrate food, highlighting the necessity of considering the quantity and quality of the resources in determining habitat suitability (Butler et al., 2013; Cardador et al., 2014).

Due to the nature of the birds' preferred habitat, productive and economic interests are in permanent conflict. It is therefore necessary to allocate special effort not only towards maintain agricultural landscapes for the conservation of biological diversity, but also to generate benefits for productive agriculture (Morgado et al., 2010).

Agri-environmental schemes and Fallow lands

The semi-permanent habitat patches of fallow land have always been recognized as having the potential as opportunities to provide environmental benefits and reverse biodiversity decline (Boatman et al., 2011; Toivonen et al., 2013). In contrast to other agri-environmental measures which have been specifically designed with biodiversity goals in mind, fallow/set-aside land was first introduced by the European Common Agricultural Policy (CAP) as a voluntary measure to reduce surpluses of arable crops. With the aim to improve the competitiveness of European agriculture, this measure became obligatory after the MacSharry reform in 1992 and led to the widespread implementation of agri-environmental measures under the CAP (Burton et al., 2008; Hodge et al., 2006; Institute for European Environmental Policy, IEEP 2008). As a result of these reforms, farmers were compensated for their projected income losses via the introduction of direct payments (Gillings et al., 2010; Salonen and Hyvönen 2006).

Since then, agri-environment schemes (AES) have become a key policy instrument that is broadly implemented by European governments to counteract the detrimental effects of modern agriculture and to conserve and enhance the quality of the environment (Kleijn et al., 2006). The “greening” measure proposed by the European Commission in the 2013 CAP reform promotes the incorporation of non-crop strips within fields in order to achieve a win-win situation, generating benefits both for biodiversity conservation and for productive agriculture (EIP-Agri, 2016). Despite this investment, nowadays there has been considerable debate as to whether these schemes actually deliver the expected biodiversity benefits, suggesting that more elaborate and efficient measures than the ones currently applied are required (Batáry et al., 2015; Mccracken et al., 2015).

In AES programs, there are several options offered to farmers for managed fallow fields. Within semi-arid north-eastern Spain, fallow lands included in AES programs that also fall within the Natura 2000 network must be managed by shredding, sowing with a competitive grass, ploughing, grazing or by spraying out with herbicide (BirdLife International 2008). All these practices must be conducted outside of the restriction period, which coincides with the farmland bird breeding time (from the 15th of April to the 1st of September).

Management modifies habitat features to discriminate against the use of the patches by the different species (Whittingham et al., 2006). Arable weeds are primary producers and the base of foodchains in agroecosystems. Their importance in supporting biodiversity at higher trophic levels has been demostrated (Hyvonnen et al., 2008; Marshall et al., 2003). Plant traits determine how primary producers response to different environmental factors and so the evolution of a community assembly that affect other trophic levels and influence ecosystem processes and services (Kattge et al., 2011).

Vegetation structure and the availability of high quality food reservoirs are key elements strongly influencing habitat choice of steppe birds (Sanza et al., 2012). However, and because of the birds' different optimal habitat requirements, the same management action can produce opposite effects, so it is often more effective for conservationists and managers to implement strategies for individual species at the local level (Mcmahon et al., 2010; Moreira et al., 2005).

The presence of semi-natural habitats is also outstanding as a key factor for achieving pollination sustainability, however, there is little information as to the impact of AES on pollination and especially on pollinator food resources (i.e. insect-pollinated plants) (Kohler et al., 2007; Ricou et al., 2014). The potential to utilize weed vegetation management as a tool to encourage pollinator diversity and abundance may prove to be a cost- effective means of maximizing crop yield. Therefore, an interesting task would be to define a habitat management strategy in which weed manipulation enhances pollinator resources, especially since there is a gap in knowledge in terms of this issue (Nicholls et al., 2012).

Objectives

In this study, we investigated how vegetation assembly on fallow lands responds to different abiotic factors such as management practices and surrounding habitats, and analyzed the effect of the resulting plant community on higher trophic levels. Thereby, the particular objectives addressed in this thesis are:

1- Investigate the effect of abiotic filters on plant features that modify the attractiveness for pollinator insects through a functional trait framework.

2- Predict the habitat suitability in terms of structure and food availability for steppe birds according different management practices.

3- Evaluate the economic cost of the implemented management practices on fallow lands.

4- Assess the response of steppe birds to contrasting fallow habitats with the aim to validate the previous predictions.

5- Explore the preferred landscape characteristics for steppe birds´ establishment, differentiating between configurational and compositional habitat heterogeneity.

6- Estimate changes in the spatial and temporal distribution of vegetation structure and food resources among different management practices.

7- Quantify the suitability habitat available for steppe birds along fallow habitat changes.

These particular objectives are addressed in different chapters of this thesis in the form of several scientific papers (i.e., with the corresponding sections: introduction, methods, results, discussion and references), allowing readers to understand each one independently from the others. Finally, and to address the main goal of the thesis, results from the different chapters are integrated and jointly discussed, leading to the main conclusions.

Methodology

All the field experiments of this research were conducted in Catalonia (NE Iberian Peninsula) during spring time (May) between the years 2011-2015, always coinciding with the breeding period of the bird species. This dry-land cereal area of the Ebro basin is a flat to slightly undulated terrain, characterized by low annual rainfall (mean of 350 mm) that is mainly concentrated in spring and autumn (Servei Meteorològic de Catalunya). All of the area surveyed was included in Special Protection Areas (SPA); sites established under the 2009/147/EC Birds Directive and included in the Natura 2000 network (the European network of protected natural areas) and presented a homogeneous landscape.

To accomplish objectives 1, 2 and 3, three cultural practices which highlight as the most commonly applied were arranged in a randomized complete-block design (200 m^2 per each experimental plot) with three replications and were experimentally tested in four fallow fields during three agronomic seasons (Figure 1, Chapters 2 and 3). The practices carried out in each experimental plot were: chisel plough -a minimum tillage down of ten cm-; shredding -cutting and removal off the biomass-; herbicide spray -glyphosate at a 1.5 l ha^{-1} dosage-; alfalfa sowing -*Aragon* seed variety at 30 kg ha^{-1} dose-. The applications were administered at different times according to common practices: “early dates” (February) for chisel and herbicide, and “late dates” (April) for chisel, herbicide and shredding. Alfalfa was sown once in October of the first season. In addition, some plots were untreated (control), giving a total of seven treatments in each study area. This field experiment was conducted from 2012 to 2014 agronomic season (Figure 2).

Figure 1. The four study sites selected to place the experimental design (Chapeters 2 and 3): Mas de Melons, Balaguer, Ballobar and Montcortés.

Figure 2. Scheme of the randomized complete-block design carried out in Chapters 2 and 3. Each management technique was applied in a 10 x 20m plot, with three replicates each. In each plot, five 50 x 50cm quadrants were established as sampling points.

Changes in plant characteristics caused by the different management regimens, age of fallow and surrender habitats structure and their influence on pollinator insect attractiveness was explored by a response-effect framework by identifying specific plant traits and discussed in Chapter 2. Carry out a proper management of the high number of field practices tested in the experimental design makes impossible to establish a landscape gradient that would entail increasing the sampling points and reducing the number of practices tested. The four sites are placed within a homogeneous landscape, however, the effect of the surrounding elements over the vegetacion assembly in untreated plots has been assessed. Unlike the managed plots, where the vegetation composition is strongly influenced by the impact of the agricultural practice, in the untreated ones we are able to study the effect of other abiotic factors, such as age of fallow or surrounding elements. As an approach to the surrounding area characteristics, the percentage of semi-natural habitat and total field edge length were assessed within a 500 m radius of each experimental design unit (Figure 3). To assess the functional approach, Rao's quadratic entropy of functional diversity (FD (Rao), which takes into account intraspecific trait variability) (Lepš et al., 2006) and the community-weighted mean (CWM, which reflects the average trait value of the most dominant species in a community) (Garnier et al., 2004) were used.

Figure 3. Orthophotomaps of the 500 m buffer around each experimental design to measure the percentage of semi-natural habitats and total border lengths as a surrounding area approach, taken into account in Chapter 2 (pictures of Mas de Melons on the left and Balaguer on the right).

Furthermore, as a plant species characterization complementarity, two taxonomic metrics were calculated: species richness (S) and the Shannon entropy index (H), presented as the exponential of Shannon-Weaver index (H') to allow comparison with species richness (Jost, 2006).

In Chapter 3, we predict the habitat suitability for six of the most threatened steppe bird species -Little Bustard (*Tetrax tetrax*), Stone-curlew (*Burhinus oedicnemus*), Calandra Lark (*Melanocorypha calandra*), Short-toed lark (*Calandrella brachydactyla*), Black-bellied sandgrouse (*Pterocles orientalis*) and Pin-tailed sandgrouse (*Pterocles alchata*)- by comparing variations in vegetation structure (coverage and height) and food supply with their suitable habitat range according to bibliographic data. Availability of seeds and green material as trophic resources were estimated by creating indexes using both field data and functional traits information from databases. Moreover, a cost-evaluation of the field practices was two-fold in that it was carried out in order to create ideal fallow habitat scenarios and also devise plans for less costly field work.

To meet objectives 4 and 5, a total of 241 fallow fields from six regions (included in protected bird areas, IBAs) were selected in the year 2015. These regions were: Mas de Melons-Alfés (7618.63 ha), Belianes-Preixana (6521.12 ha), Bellmunt-Almenara (4039.48 ha), Granja d'Escarp (1800 ha), Plans de Sió (10382.69 ha) and Segria-Utxesa (7727.27 ha), where most of the steppe bird species of conservation concern are coexisting. The surrounding habitat heterogeneity, which is the compositional and configurational approach of taking a 200 m radius around each fallow field, along with bird censuses and vegetation surveys (structure and trophic availability) were used to develop models for assessing bird responses to different habitats (Chapter 4). The bird species selected in this study were: the Little bustard (*Tetrax tetrax)*, Stone-curlew (*Burhinus oedicnemus)* and Calandra lark (*Melanocorypha calandra)*. We measured plant coverage and height as vegetation structure and the availability of seeds and green material were estimated following the indexes developed in Chapter 3. Also, as an important food resource for chick survival, invertebrate supplies were estimated by recording the presence of grasshoppers, creating an insect biomass index. Proper knowledge of the effects of applied management allows for the construction of ties between bird preferences and certain practices.

To achieve objective 6 and 7, two adjacent plots measuring 50 x 150 m were established in one fallow field located in Conill. Each plot was managed using a different method: shredding or herbicide application for three consecutive agronomic seasons (from 2012 to 2014). Samples were taken every 10 m (with a total of 150 units per plot) georeferencing each point following a grid pattern (Figure 4). Spatial and temporal variation of the vegetation structure and food resources (seeds and green material, in accordance with the indexes developed in Chapter 3) was analyzed using semivariograms. Maps achieved by kriging technics were used as visual representation to study the spatial and temporal changes of the variables analized. A vegetation threshold (in terms of structure: cover and height) was fixed to calculate the suitable habitat available for steppe birds in each stage and per treatment. Pitfall traps were used to estimate the abundance of terrestrial invertebrates (Chapter 5).

Figure 4. Scheme of the 50 x 150 m grid design implemented in Chapter 5 to compare the effect of two management treatments in the locality of Conill. Sampling was conducted every 10 m in each 50 x 50 cm quadrant (a total of 150 sample points per grid).

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Chapter 2

Using the response – effect trait framework to quantify the value of non-crop patches in agricultural landscapes to pollinators

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This chapter has been submitted to Applied Vegetation Science

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Summary

Pollination services contribute to the production of valuable goods for humans but recently pollinator abundance and diversity has declined because of habitat destruction and land use intensification. Achieving the sustainability of this important service will not only depend on implementing management practices that alter local habitat conditions, but also understanding the importance of landscape structure. Fallowing is a well-recognized agro-environmental scheme to preserve biodiversity within the agro-system, however the potential for enhancing these areas for greater provisioning of ecosystem services has been poorly explored. In our study, we tested if plant functional traits can be related to fallow management to develop a response-and-effect trait approach to link plants and insects for the enhancement of pollination attractiveness in the non-crop areas of two semiarid Mediterranean agricultural regions. The linkages between the selected plant traits were analyzed using community-weighted mean-RDA (CWM-RDA) using region, landscape complexity, fallow field age and management practices as explanatory variables - capturing different spatial scales that interact with each other affecting pollination communities. The presence of semi-natural areas is shown to enhance the value of non-crop patches for pollinators, providing a source of diverse flower forms. We found that field edges act as a poor reservoir for flowering plant species in these areas. Land-use practices must focus on promoting mid-successional plant communities that combine the coexistence of diverse life forms which overlap flowering periods and have a range of flower morphologies supporting a diverse pollinator community An early-herbicide application (February) join with a shredding are expected to be the best fallow-practices for enhancing plant-pollinator interactions. The construction of this framework helps policy makers to identify key factors that most benefit plant configuration to pollination attractiveness in fallows.

Keywords: Fallow lands; Agri-environment schemes; Functional traits; Ecosystem services; Pollinator attractiveness; Environmental filters.

1. Introduction

Agricultural intensification is one of the main factors driving ecosystem change and global biodiversity loss as a consequence of the specific drivers of land conversion, habitat fragmentation and agro-chemical application (Tscharntke et al., 2005). The resulting loss of farmland biodiversity threatens the sustainability of ecosystem goods and services delivered within agricultural landscapes, apart from provisioning of food (Zhang et al.,2007) such as pollination, biological pest control and climate regulation among others (Marshall et al., 2006).

In recognition of the unintended environmental consequences of the drive for increased productivity of agricultural land, the European Union's Agri-Environmental Regulation Initiative has promoted various Agri-Environmental Schemes (AES) to enhance levels of biodiversity on farmland (Whittingham 2011). Fallowing is one of the most promising approaches to support and enhance biodiversity in the agro-ecosystems (Toivonen et al., 2013; Ma and Herzon 2014). As opposed to perennial field margins, fallows presents the opportunity to manage larger areas of ruderal habitat in field centres that provides a habitat for species adapted to frequently disturbed environments. Although AESs design has tended not to be explicitly linked with ecosystem services, these non-crop habitats are important landscape elements which may provide key ecosystem services such as provision of resources for pollinators and there is now a drive to optimize the multi-functionality of AES habitats (Huusela-Veistola et al., 2011; Kuussaari et al., 2011; Toivonen et al., 2013).

Characteristic arable plant species, adapted to the disturbed habitat of crop fields, differ from the other generalist species that tent to be found in the boundary features of arable landscapes in being more sensitive to perturbations but also in having high intrinsic values as component of biodiversity that provide a distinct resources and functions in agroecosystems (Rotchés-Ribalta et al., 2015). As a consequence, the value of the above-ground flora on fallow lands will be influenced by the historical management pressure imposed on the field crop and on the specific conditions generated by the standing management on the fallow. A poor seed bank resulting from an intensively managed land will require seeds from outside the field to increase plant diversity, therefore the surrounding landscape may also play a key role, acting as a reservoir for propagules (Kohler et al., 2008). A complex landscape, with a high percentage of natural and semi-natural habitats, is likely to act as a refuge for weed species that are most sensitive to intensive agriculture and supply pollinator sources (Smart et al., 2002; Gaba et al., 2010; Solé-Senan et al., 2014).

It has been long noted that weeds have a positive role in enhancing beneficial insect survival, and their removal from the landscape through herbicide use, along with habitat destruction and the decrease in crop diversity, has been identified as a driver of both pollinator declines and losses of pollination services (Steffan-Dewenter and Westphal 2008; Nicholls and Altieri 2012). Greater plant biodiversity on farmland through the provision of areas of land managed specifically for is likely to increase the provision of a range of ecosystem services, however it is difficult to successfully quantify the enhancement of pollinator habitat (Whittingham 2011; Wratten et al., 2012). All plant species do not contribute equally to varied ecosystem processes and delivery of services, and thus the sustainability and resilience of these processes depend on aspects of diversity beyond the number of species present in a community (Stuart-Smith et al., 2013). Different pollinators promote selection for diverse floral forms that produce an array of "pollination syndromes”, defined as a suite of floral traits that function as an advertisement and reward for pollinators (Fenster et al., 2004; Poveda et al., 2005). Changes in floral characters such as morphology, colour and odor or food quality can influence pollinator visits (Wratten et al., 2012; Ricou et al., 2014). Developing models for quantifying the relative value of different habitats in the context of these floral traits is a clear research need for assessing contrasting habitats and management recommendations. The most often used management techniques to enhance pollinator habitat on farmland consist of field margin manipulation, including non-crop buffer strips which can provide nesting sites and encourage forage plant growth and the restoration of native plants in adjacent natural areas, among others (Wratten et al., 2012). However the role of fallow land as a temporary patch habitat in dryland Mediterranean systems has been seldom explored in studies. A proper habitat management within this non-crop system can provide resources needed for pollinators´ conservation, therefore, progress in research is required.

The use of functional traits has been an important conceptual advance in linking biodiversity with ecosystem processes and associated services (Ma and Herzon

2014). A trait can be defined as a morphological, physiological or phenological characteristic of a species, measurable in an individual, referring to a function and indirectly affecting the phenotypic fitness (Violle et al., 2007). A conceptual framework following the idea of Lavorel et al., (2002 and 2013) has been developed differentiating traits associated with response to environmental and management filters –response traits- from those that determine the effect of that change on ecosystem services -predicted by effect traits-. The overlaps or correlation between relevant response and effect traits determined the trait pool of plant communities responsible for the different dynamics that influence the relation with higher trophic levels and provision of ecosystem services. This framework has recently been extended to systems where services are delivered by higher trophic groups.

Various studies have also highlighted the importance of the surrounding landscape on the effectiveness of AESs due to both habitat fragmentation and land use intensification, affect pollinator communities at different spatial scales that interact with each other (Steffan-Dewenter and Westphal 2008; Whittingham 2011). Arable landscape composition together with management at field scale act as filters selecting between a diversity of ecological strategies (Raevel et al., 2012; Duflot et al., 2014). Determining the variation on biological communities, therefore, requires linking these multiple scales.

The goal of this study was to populate a framework based on plant species abundance and traits to identify the effects of landscape, age of fallow and field management as a series of filters acting on pollination service following the model described by Lavorel et al., (2013). By selecting target traits and based on our knowledge, this study set out to 1) examine the response of plant vegetation traits to abiotic factors; 2) explore the impact on traits driving the response of higher trophic levels; and 3) evaluate their interaction to predict the impact on pollinator attractiveness.

2. Material and methods

2. 1 Study area and experimental design

Trials were located in the Catalan part of the Ebro basin (north-eastern Iberian Peninsula), an area with a flat or slightly undulating topography, Mediterranean continental climate and average annual rainfall of 350 mm. A total of four separate fallow lands with different ages were selected as study areas: Montcortes (41°42'35.22''N; 1°13'52.33''E) and Ballobar (41°32'55.37''N; 0°5'59.06''E), were new fallows following a crop rotation and Balaguer (41°44'38.92''N; 0°45'21.63''E) and Mas de Melons (41°30'14.26''N; 0°42'40.18''E), have remained as fallow for five and four years respectively. All the study sites were selected because they were located in areas dominated by dry cereal crops and are also included in a special protection area of the Natura 2000 network, a key policy instrument for continental wide biodiversity protection in Europe.

We conducted a three-year field experiment (from 2012 to 2014 agronomic season) to examine the succession of vegetation communities on fallow lands and the impact of contrasting management. The different starting points of the fallow fields in terms of the successional stage of vegetation allowed the effect of management treatments to be tested in the context of the natural plant succession from more ruderal to more competitive communities (from one, in case of the first year of fallow field, to seven, the oldest ones). In each of the four study sites, one fallow field was divided into 21 plots of 200 m^2 as a randomized complete block design with three replicates for each of the treatments which reproduce some of the most common cultural practices. The following treatments were applied: 1) chisel plough -a minimum tillage resulting in soil disturbance down to ten cm-, 2) shredding –cutting and removal of the biomass-, 3) herbicide spray –glyphosate at 1.5 l ha^{-1} dose- and 4) alfalfa sowing. The treatments had different timings: “early dates” –February-, for chisel and herbicide, “late dates” –April-: again for chisel, herbicide and shredding, and October for alfalfa sowing). Additionally, some plots were untreated (control), giving a total of seven treatments repeated three times in each study area: early chisel (EChi), late chisel (LChi), early herbicide (EHer), late herbicide (LHer), late shredding (Shre), early alfalfa (Alf) and untreat/control (Cnt). At the end of each agronomic season

(October), the vegetation of all experimental plots was cut in order to remove an excess of organic matter while maintaining the cumulative effect of the previous treatments.

2. 2 Vegetation sampling

Plant data were collected from five quadrats of 0.25 m^2 located on each experimental plot in May, 15-20 days after the last management was done and when AES restrictionscame into force. Coverage of each species was visually estimated as a percentage of the area of the entire quadrat. Vegetation richness was recorded as the number of plant species identified in each quadrat.

2. 3 Surrounding area information

According to numerous evidences, landscape patterns influence over the vegetation assembly at field scale (Albrecht, 2003; Concepción et al. 2008; Duflot et al., 2014; Gabriel et al. 2006). However, the effect of local processes can only be detected at appropriately small local scales where often converge under similar physical conditions and so, plant composition is strongly shaped by the in-field management (Petit et al. 2012). For this reason, and although the selected experimental areas shared a homogeneous landscape, the effect over vegetation assembly in the untreated plots can be inferred by characterizing the surrounding area of each of the four fallow fields to identify either structural or compositional differences between them. From an aerial orthophoto SIGPAC (MARM [Sistema de Información Geográfica de Parcelas Agrícolas] 2006) and measured within circles 500 m radius around the centre of each experimental field, identified as the appropriate scale at which weeds are most strongly associated with landscape structure (Gaba et al., 2010; Marshall et al., 2006). Two variables were calculated: percentage of semi-natural habitats (compositional) and length of field edges (configurational), which previous studies have shown are relevant to plant diversity and weed community composition in the study region, providing quantified information regarding the surrounding area (Solé-Senan et al., 2014). Semi-natural habitats were identified as all non-cropped land uses and edge length was calculated by summing all the boundaries of the fields in that area (Table 1).

Table 1. Summary of the site characteristics.

Location	Semi-natural habitats* (ha)	Length of field edges (m)	Age of fallow		
			2012	2013	2014
Mas de Melons	20.12	8981.26	4	5	6
Montcortes	1.77	8575.42	1	2	3
Balaguer	4.52	8322.89	5	6	7
Ballobar	5.23	9588.63	1	2	3

*500 m buffer = 78.54 ha (100%)

2. 4 Plant traits selection

According to the model proposed by Lavorel et al. (2013), we first identified the plant traits that are expected to respond directly to the environmental drivers described (response traits) (Table 2). Growth forms together with flowering onset were included as they have been associated with persistence in disturbed habitats (Mcintyre et al., 1995; Cornelissen et al., 2003; Gunton et al., 2011) and have been related to management practices, specifically the intensity of tillage (Fried et al., 2012). Seed dispersal plays an important role as it affects plant colonization, related with landscape structure and disturbance level, therefore modulating community assembly in space and time (Mcintyre et al., 1995; Critchley et al., 2004). Plant height is expected to respond directly to management practices (Lavorel et al., 2013) as well as specific leaf area (SLA, the ratio of leaf surface to leaf dry mass), associated with faster resource-use strategies sensu Westoby (1998). SLA is also related to plant competition, which will vary with the succession stage.

Secondly, we classified the plant traits that can influence interactions with pollinator communities (effect traits/trophic response traits) (Table 3). It has long been noted that changes in floral features are highly linked with this function (Wratten et al., 2012; Ricou et al., 2014). So-called by Fenster et al. (2004), "pollination syndromes", such as corolla morphology and colour were selected as traits that promote pollination interaction. Discrimination between different corolla shapes are associated with accessibility (Gomez et al., 2008), distinguishing among generalists (pollinated by several to many animal species from different taxa) and specialist (pollinated by one or a few taxonomically similar animal species) flowers (Ashworth et al., 2004). This is likely to be correlated with morphometric parameters of pollinators (body size and mouthparts length) (Fenster et al., 2004). Flower colour is also under selection by pollinators. It is related to UV reflection and the ability of perception, thus it is associated with visual attractiveness (Menzel and Shmida 1993; Ricou et al., 2014). Flowering duration also influences pollination visitation, determining reward (nectar and/or pollen) availability period (Bosch et al., 1997).

Trait values for each of the species were obtained from the literature and from open access databases (summarized in Tables 2 and 3).

Plant community characterization was calculated based on taxonomic and functional indexes. Two taxonomic metrics were selected: the total species richness (S) and the Shannon entropy index (H), presented as the exponential of Shannon-Weaver index (H'). With this transformation, species are weighted in proportion to their frequency in the sampled community and thus it can be interpreted as the number of equally-common species in the community and eases the interpretation and comparison of diversity among communities (Jost, 2006). To assess the functional approach we used the community-weighted mean (CWM) trait value (Garnier et al., 2004), which expresses the mean trait value in the community weighted by the relative abundance of the species. CWM reflects the average trait value of the most dominant species in a community, being the ones which exert the greatest effect on ecosystem functions (Díaz et al., 2007). Furthermore, we quantified the degree to which trait values differ in a community by the Rao’s quadratic entropy of functional diversity, FD (Rao), defined as the sum of the dissimilarities in the trait space among all possible pairs of species weighted by the product of relative species abundances (Botta-Dukát, 2005). FD (Rao) is associated with the complementary resource use hypothesis and, unlike CWM which is calculated per each trait separately, FD is based on the combining of multiple traits (Leps et al. 2006; Moretti et al., 2013).

Table 2. Summary of plant response traits used in the analysis.

Response Traits	Categories	Source*
Growth form	Annual forbs Perennial forbs Annual graminoids Perennial graminoids Legumes Shrubs	a
Seed dispersal	Anemochory Autochory Zoochory Unassisted	b
Average height (cm)	continuous	a
SLA (mm^2 mg^{-1})	continuous	c
Flowering onset (month)	1-12	a

*(a) de Bolòs and Vigo (1984–2001); (b) LEDA (Kleyer et al., 2008); (c) TRY Database (Kattge et al., 2011).

Table 3. Summary of plant effect traits used in the analysis.

Effect Traits	Categories	Source*
Flower shape	Anemophilous corolla Open entomophilous Tubular Zygomorphic	a
Flower colour	Purple Blue Yellow White Other colour (greenish-brownish)	a
Flowering duration (month)	1-12	a

*(a) de Bolòs and Vigo (1984–2001)

2. 5 Statistical analysis

Firstly, variation partitioning using partial redundancy analysis (RDA) was used to evaluate the effects of landscape (semi-natural areas and length of field edges), age since fallow and field treatments on the species composition. The partitioning result was represented by a Venn diagram, as has previously been done in other studies (Vincent et al., 2006).

Species richness, H and FD (Rao) indexes were used to describe changes in plant communities among the different habitats. We performed General Linear Modelling (GLM) with Poisson error distribution to investigate the relationship with landscape features and fallow-age taking into account only data from control plots. The effect of field treatments on diversity and species richness were tested by ANOVA using all data.

To quantify the innate correspondence between response-effect traits values in the study species pool, a Principal Components Analysis (PCA) was carried out to characterize the patterns of correlations among them. Variance in trait values between species were standardized to zero mean and unit standard deviation to give them all equal weight in the analysis before performing the PCA. To assess how the variability of individual traits changes along the environmental gradients we performed a CWM-RDA analysis following Kleyer et al., 2012. This technique uses multiple linear regressions (ordinary least squares) among response variables (traits) and predictors (environmental data). Because *Medicago sativa* cover was manipulated, this species was excluded from the analysis in alfalfa´s plots, therefore only testing the indirect effect of the cultivation and additional competition on the background flora.

T-value biplots were used to identify the functional traits that can, on their own, explain a significant amount of variation using the environmental factors. These ordination diagrams are based on reduced-rank regression, combining multiple regressions between species traits and a particular site factor, and the model defined by the RDA. The interpretation of reduced-rank regression biplots is facilitated by so-called Van Dobben circles, which enclose the traits arrows of those traits with a strong relation to the environmental variables tested, as indicated by t-value biplots (*t*-value<|2|).

Statistical analyses were performed with the R program, 3.0.2 (R Foundation for Statistical Computing, Vienna, AT) with the package *vegan* (R Core Development Team, R Foundation for Statistical Computing, Vienna, AT) and with CANOCO 5.0 for Windows (Microcomputer Power, Ithaca, NY, US).

3. Results

According to the Venn diagram (Fig. 1), 7.1% of the variation in plant species composition was explained by a pure effect of landscape features, 1.6% by a pure age effect, and 7.5% by a pure field treatment effect. About 83% of the variation remains unexplained.

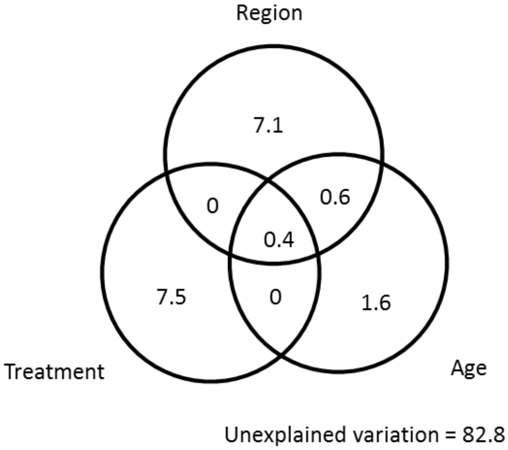

Figure 1. Venn diagram representing the partition of the variation of species composition among region, age since fallow and field treatment.

An increase in Shannon entropy index (H), species richness and FD (Rao) was observed when the percentage of semi-natural habitat in the area increased (F= 5.441***; F= 8.241***; F= 4.958*) and on older fallows (F= 4.487***; F= 3.634***; F= 15.35**) while the total length of field edges had no effect (Table 4). ANOVA analysis did not find significant differences either for the taxonomical indices (Shannon entropy index and species richness) or for the functional diversity index (FD Rao) between different treatments (data not shown). However the late management interventions (chisel and herbicide) resulted in lower values of H and richness (around 5±1.3 and 15±3 respectively). In constrast, shredding and early herbicide were the treatments with highest values (7.8±2 for H and 21±4 for richness), more similar to those of the control. As regarding FD (Rao), the highest values were related to early-herbicide and late-chisel treatments (2.08 ± 0.14 and 1.99 ± 0.14 respectively) (Table 5).

Table 4. General linear modelling (GLM) of the changes in species richness, Shannon entropy index (H) and Rao's quadratic entropy of functional diversity, FD (Rao) in relation to landscape features (percentage of semi-natural habitat and length of field edges) and age since fallow using Poison error distribution.

Environmental factors	Indexes	F
Semi-natural habitat	Richness	8.24***
	H	5.44***
	FD (Rao)	4.96*
Edges lenght	Richness	0.71
	H	-0.62
	FD (Rao)	3.67
Age since fallow	Richness	3.63***
	H	4.49***
	FD (Rao)	15.35**

* P <0.05; ** P <0.01; ***P <0.001

Table 5. Summary of the mean species richness, Shannon entropy index (H) and Rao's quadratic entropy of functional diversity, FD (Rao) (±S.E.) per field treatment.

Management	Richness	H	FD (Rao)
Alfalfa	19 ± 4	5.304 ± 1.361	1.73 ± 0.19
Early chisel	21 ± 4	6.483 ± 1.39	1.89 ± 0.18
Late chisel	14 ± 3	5.349 ± 1.176	1.99 ± 0.14
Early herbicide	22 ± 4	7.879 ± 1.841	2.08 ± 0.14
Late herbicide	16 ± 2	5.293 ± 1.641	1.94 ± 0.18
Shredding	21 ± 5	7.86 ± 2.946	1.95 ± 0.18
Control	21 ± 4	7.316 ± 2.107	1.96 ± 0.18

Not significant differences in ANOVA test

The first PCA axis identified the trade-off between plant response traits related by a ruderal strategy and more competitive ones also reflecting a successional gradient from annuals to perennials. This axis was also indicative of a contrast in plant effect traits that determine the preference of generalist vs. more specialists pollinator insects (Fig. 2). Contrast between, on the one hand: species with high SLA, early flowering or annual cycle of life,common characters in disturbed habitats (ruderal communities), and graminoids forms, white-greenish-brownish flower colours with anemophilous and open entomophilous shapes, characters that are have poor pollination attractiveness and the option to be pollinated by a larger spectrum of insects (generalistists). Polycarphy (capacity to produce several seed set per life time) is also a character related with ruderal species which can explain their long flowering duration. On the other hand: zygomorphic and tubular corollas, that restrict insect accessibility, and yellow and blue flower colours are characteristics more related with specialists pollinators. Perennial life form, late flowering time, tall stature and autochory seed dispersal are indicative of competitive plant communities.

Trait relationships from Van Dobben circles results have been summarized in Table 6, for those plant traits which response to the environmental factors (response traits), and in Table 7 for the traits underpinning interactions between plants and pollinators (effect traits/trophic response traits). Traits positively related are represented by a +, and the ones with a negative relation by a –.

3.1a Surrounding area and age since fallow

Fallow lands within an area with a high percentage of semi-natural habitats had a community with a higher proportion of legumes, autochory seed dispersal and later flowering species, characters correlated with zygomorphic corolla and blue flower colour. Whilst a greater length of field edges promoted a community dominated by annual graminoid species and an anemochory and unassisted seed dispersal, related positively with characteristics as white-greenish-brownish flower colours and negative with purple and yellow corolla ones and long flowering duration. The successional pattern of the vegetation became clear as the age since fallow increased, leading to plant communities dominated by perennial forbs, as hemicryptophytes and geophytes, and autochory seed dispersal, in turn positively correlated with tubular corollas, yellow flower colour and negatively correlated with open entomophilous corolla and purple flowers.

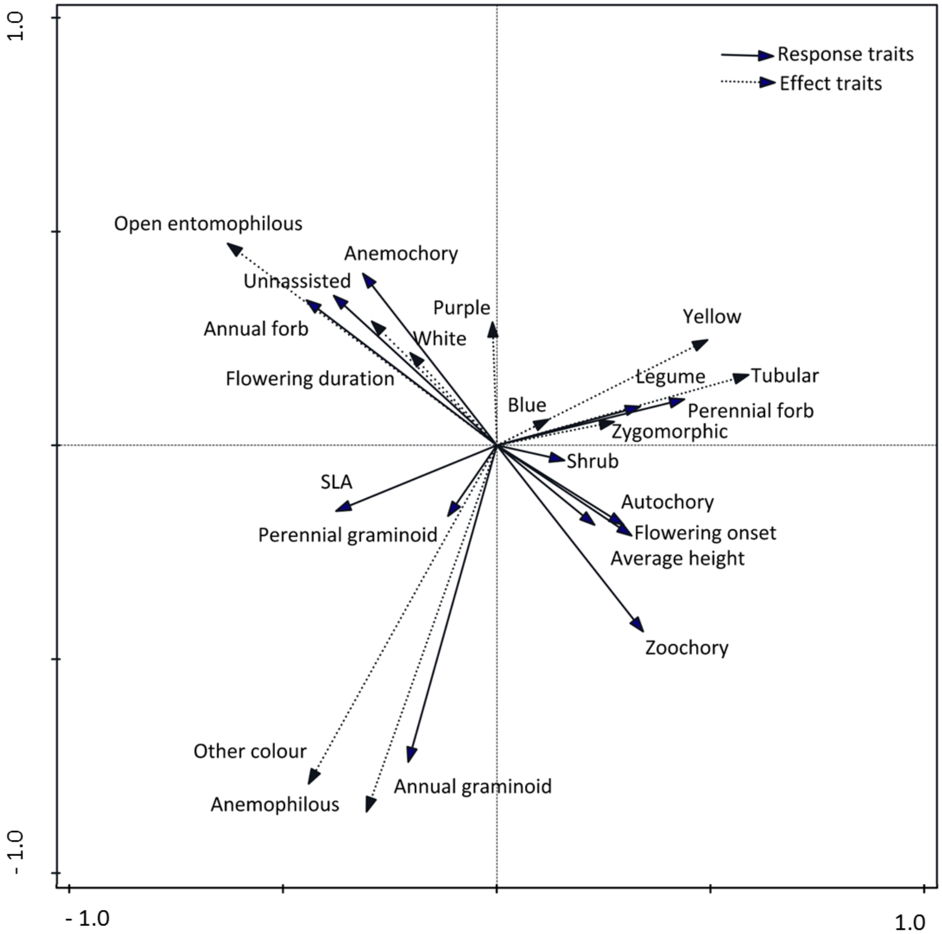

Figure 2. Correlation among plant functional traits represented by a Principal Components Analysis. Percentage variance accounted for first two axes = 36.3%. Primary axis for the response traits represents trade-off between ruderal traits (fast cycle of life, high specific leaf area, annuality) and competitive traits (late flowering time, perennial life-forms, tall stature) and for the effect traits is associated with the complexity of floral structures, traits related with generalists pollinators (white-greenish-brownish flower colours, anemophilous and open entomophilous corollas) and traits linked with more specialists insects (yellow and blue flower colours, zygomorphic and tubular corollas).

3.1b Field management practices

Among field management treatments, a promotion of annual plants by early interventions was observed together with the presence of shrubs on early-herbicide treatment. Late herbicide and shredding increased the presence of perennial forms (mainly hemicryptophytes). Graminoids forms were more prevalent on early-chisel and alfalfa treatments than forbs. A late flowering onset was observed on the early-herbicide practices while in late herbicide treatments, a positive relation with taller plants and early flowering time was observed. The characteristics of plant communities resulting from the different field treatments were correlated with traits which are likely to determine pollinator interaction such as anemophilous corollas, positive related with alfalfa, chisel and shredding practices. Early-herbicide and shredding treatments were positively correlated with open entomophilous corollas and negatively with tubular ones, as was observed in alfalfa and early-chisel treatments. Yellow flowers showed a positive correlation to late-herbicide and other flower colours (such as greenish and brownish) were positive correlated with alfalfa, chisel treatments and shredding. Finally, a longer period of flowering was related to late chisel and early herbicide treatment.

Table 6. Summary of Van Dobben circles results for response plant traits, representing the positive (+) or negative (-) relation to the abiotic variables.

		Abiotic filters								
		Landscape features		Age of fallow	Field managements					
		Semi-natural habitats	Length of field edges		Alfalfa	Early chisel	Late chisel	Early herbicide	Late herbicide	Shredding
Growth form	Annual forbs							+	-	
	Perennial forbs		-	+	-	-			+	+
	Annual graminoids		+	-	+	+				
	Perennial graminoids						+			
	Legumes	+								
	Shrubs							+		
Seed dispersal	Anemochory		+	-						
	Autochory	+		+						
	Zoochory									
	Unassisted		+							
	Average height								+	
	SLA			-						
	Flowering onset	+						+	-	

Table 7. Summary of Van Dobben circles results for effect plant traits, representing the positive (+) or negative (-) relation to the abiotic variables.

		Abiotic filters								
		Landscape features		Age of fallow	Field managements					
		Semi-natural habitats	Length of field edges		Alfalfa	Early chisel	Late chisel	Early herbicide	Late herbicide	Shredding
Corolla shape	Anemophilous		+		+	+	+			+
	Open entomophilous			-				+		+
	Tubular			+	-	-		-		
	Zygomorphic	+								
Flower colour	Purple		-	-						
	Blue	+								
	Yellow		-	+					+	
	White		+							
	Other colour		+		+	+	+			+
	Flowering duration		-				+	+		

4. Discussion

The aim of this study was to understand the relationship between environmental variability and human-associated disturbances with the provision of resources for pollinators through plant trait information. Several analyses were used to quantify how altering the ecological scenario can influence the functional trait composition of the vegetation. From the shifts in response and effect traits we predicted the change in the attractiveness for pollinators. Following the response-effect framework, we now discuss each step described by the model (Fig. 3).

As shown by our results, linking multiple scales is required to understand the processes determining the variation in biological communities in habitats managed as part of agri-environment schemes. Both management strategies and landscape characteristics are playing an important role by benefiting certain plant species. Despite the lack sampling on both field edges and semi-natural habitats, the homogeneity conditions (land use and climate conditions) between the field experiments (Cardador et al. 2014; McMahon et al. 2010) make us to suggest that the changes in the plant composition of the untreated plots, can be inferred by the landscape variables calculated. To reinforce these preliminary results it would be necessary to plan a landscape study by increasing the sample points and determining a complexity gradient (from complex to simple landscape). However, the high number of field practices tested in this study did not permit the establishment of an elevated number of sampling sites.

Increasing the diversity of weeds would be expected to result in an increase in diversity pollinators (Carvalheiro et al., 2011), nevertheless it is related to functional characteristics since changes in the diversity would lead to the substitution of many specialist species by generalists, inducing a functional homogenization of the communities which may also lead to competition among pollinators for resources (Clavel et al., 2010; Tadey 2015). According to our results, an increase of semi-natural areas around fallow-fields would led to greater species diversity and richness, also reflected in an increase of functional differentiation (FD (Rao)) among species (Steffan-Dewenter and Westphal 2008). However, an opposite trend would be observed with the presence of field edges in the landscape context. In our study system, field edges were not managed for biodiversity and only provided a narrow range of plant habitats that contributed little to enhancing the resource value of fallow land to pollinators. Successional studies highlight the idea that old communities tends to be more competitive, leading to uniform landscapes which provide fewer niches for weeds or insects (Lososova et al., 2006; Huusela-Veistola et al., 2011; Kuussaari et al., 2011). Nevertheless, our results show a contrasting trend, where a coexistence of species with dissimilar functionality was observed. Low disturbances rate, the chance to develop different resource acquisition strategies or the unpredictable natural regeneration mainly dependence on the seed bank, may be the causes of high valuable flower species persistence (Wratten et al., 2012). It may also be that as the fallows age further, the dominance of a few, more competitive species may increase.

4. 1 Response of plant community to abiotic features (Figure 3A)

To explore landscape effects on plant community assembly, other studies take a buffer from 1000 to 200 m (Gabriel et al., 2005), but recent work suggest that weed flora should be influenced by landscape context within a circle of radius of 500 m or smaller (Gaba et al., 2010; Marshall et al., 2006). A complex agricultural landscape generally results from extensive field margins and a high proportion of non-crop habitat (Gaba et al., 2010; Gabriel et al., 2005). These areas represent the least disturbed habitat within arable systems, acting as a sink which provide shelter and refugia for weed species which are unable to persist in the harsh conditions of intensely cultivated habitats (Fried et al., 2009) and as a source, allow immigration fluxes of plant species either to crop fields or new uncultivated patches as fallow lands (Gabriel et al., 2005; Tscharntke et al., 2005; Kleijn et al., 2011). Semi-natural habitats are areas of poorly mineral fertilizer likely to harbor legumes forms, a plant morphology which is increased under these conditions (van Elsen 2000) represented by *Coronilla*, *Medicago* or *Retama* genera, among others. It is the type of growth form that is suggested to be favored on the fallow fields studied, together with other specific characteristic linked with stable plant communities such as late time of first flowering (Pinke and Gunton 2014) or autochory seed dispersal. Autochory is a short-distance dispersal mechanism and the low colonizing capacity over space suggests that species are in an optimal area. Field edges are also more susceptible to be colonized by external propagules and act as a reservoir of species (Fried et al., 2009), however the repeated

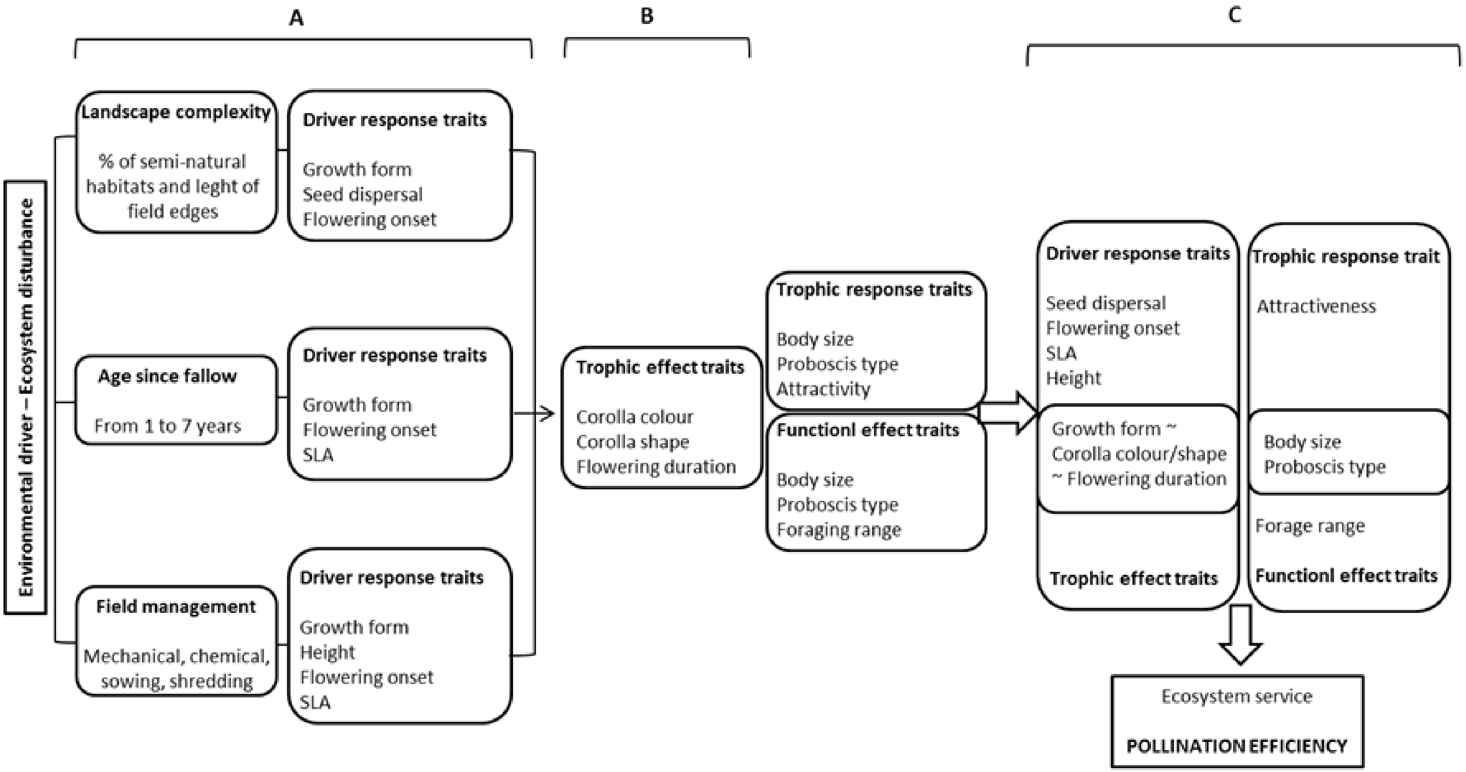

Figure 3. The response–effect trait framework based on Lavorel et al. (2013). A) identifies the response of plant traits to the environmental driver of interest; B) identifies the trophic effect plant traits which affect to pollination; C) linkages among the different response and effect traits across trophic levels.

disturbances here compromises the high potential of this habitat. Extremely narrow boundaries have no capacity to buffer negative effects from neighboring areas due to the high intensity of agricultural practices resulting in a homogenization of the flora (Aavik and Liira 2010; Ma et al., 2002). According to our results, regular disturbance in these arable habitats would lead to a community composed mainly of graminoid forms with annual character.

Succession along fallow age also reveals a gradient of plant strategies (Garnier et al., 2004). Early fallow stages, coming from previous agricultural disturbances, show a community dominated by opportunistic ruderal species highlighting traits associated with fast growth: annual cycle of life and high SLA. Anemochory seed dispersal is related most strongly to distance that increase the ability of a species to colonize new patches (Dupre and Ehrlen 2002; Kohler et al., 2008). Hemicryptophytes and geophytes appear as the dominant life forms on late successional fallow stages mainly represented by Asterceae family (genus as: *Crepis*, *Silybum* or *Carduus*) and autochory seed dispersal.

Among the management regimens tested in this study, early herbicide application is the one that led to a habitat occupied by both annual and woody plants diversifying vegetation structures and so, ecological strategies. Glyphosate is a non-selective contact herbicide that can affects a wide range of weeds. However, phanerophytes, chamaephytes and most of the hemicryptophytes are the less harmed, leading to a more heterogeneous habitat. The role of these biological forms against annuals allows a sparse and patchy habitat with a lower density of vegetation. Blooming is shown to be adapted to the intensity and frequency of soil disturbances in herbicide treatments (Gaba et al., 2013).

Tillage promoted a pioneer annual plants with fast life cycles (Sojneková and Chytrý 2015). It is also noteworthy that the annual graminoid dominance on alfalfa and early- chisel, both related to an early soil disturbance, while late-chisel managements are characterized with a predominance of perennial rhizomatous/stoloniferous graminoids such as *Cynodon dactylon* which permit an effective colonization of bare ground sites (Kahmen et al., 2002). Although we have shown that the effect of herbicides can be interpreted in the context of a disturbance regime and so related to plant traits, it is also the case that herbicide selectivity will play as well a major part in the structuring of communities in agricultural landscapes. These effects may ultimately have to be modelled at the level of individual species.

4.2 Response-and-effect traits interaction (Figure 3B)

Identifying key plant traits which influence the interaction with pollinators will be useful to understand the effect of the different environmental changes to the pollination service. Pollinators were not directly measured in this study, however, well established published relationships between flowering traits and attractiveness to pollinators allowed us to predict the impact of the landscape and treatments on the value for different plant communities to pollinators. Floral traits are associated with the attraction of pollinators and the differentially selective pressure on vegetation may be expected to impact their abundance and diversity (Fenster et al., 2004). Specific families´ growth forms are promoting the existence of different floral morphology and colours, traits that affect insect choice (Ibanez 2012). As well, flower duration would be increasing insect-foraging time as is strongly related with the plant life form. Perennial plants provide greater continuity and predictability of foraging resources overlapping flowering periods (Isaacs et al., 2009) while the value of annuals will depend on their limited flowering in the context of their short life cycle. Both growth and life form are linked with abiotic factors (response traits) and in turn are contributing to change the scenario of suitability for pollinators.

4.3 Response-and-effect framework as a tool for enhance pollination service (Figure 3C)

Corolla shape is a flower characteristic related to insect-body size and proboscis type, insect-pollination syndromes which in turn predict a convergent selection pressures on floral traits, excluding one type of pollinator in favor to another (Fenster et al., 2004; Gomez et al., 2008). Flower colour and blooming duration are also linked to attractiveness. Highly visible colours which contrast to the background and other flowers can encourage interaction with the pollinator (Menzel and Shmida 1993). However is known that response to color depends on their taxa (Ibanez 2012). The suggested proliferation of legumes forms in response to seminatural habitats was linked with zygomorphic corolla and blue flower colour in our data, well-known syndromes of complex flowers that reflect selection by narrower functional group associated with pollination by long-tongued bees (Corbet 1995; Fenster et al., 2004). However, the high functional divergence showed in the results may indicate that, although pollinators specializing in zygomorphic flowers are promoted to a greater extent, there are also plants which provide resources to generalist pollinators. So, the presence of these patches of relatively high-contrast habitat types, commonly conceived as ecotones, are enhancing the fallow flora for pollinators. But, not all the so-called ecotones´ elements are acting in the same way. The high level of disturbance generated by the farm practices would be leading into a decrement erosion of the habitat value of field edges, acting as a source of undesirable kind of species such as graminoids. Poaceae family is considered to be inaccessible and so less frequently visited by pollinators (Ricou et al., 2014), leading to a reduction of flower features which promote pollinator-plant interaction (Fenster et al., 2004).

Along the age-gradient succession, the dominance of more generalist flower features in early stages such as open entomophilous corollas is notable and suggests that all pollinator fauna are functionally equivalent (Fenster et al., 2004). As other studies underline, ruderal communities harbor proportionally more invertebrates than later successional communities (Storkey et al., 2013) and so, a broad taxonomic diversity of pollinator visitors. On the other hand, late stages are mainly dominated by flowers with tubular corollas, promoting interaction with specialist pollinators. The source-sink function of the surrounding semi-natural habitats may be the origin of this flower traits and the reason of their stabilization on fallows with late successional stages.

As expected, different habitat stages are not functionally equivalent and one approach to management would be to design interventions that aim to maintain communities in the successional stage that delivers the most value to pollinators. Maintaining mid-successional communities would be ideal to host a wide range of pollinator. To achieve this type of habitat, intermediate levels of disturbance may be required (Wratten et al., 2012). Early-herbicide treatments, because they promote a heterogeneous habitat structure allow a high coexistence of life forms phenotypes and so an overlapping of flowering periods, allowing a high foraging availability during the year. The presence of flowers with open enthomophilous corollas as opposed to anemophilous ones, represented by the other management treatments, is an important component of the potential attractiveness to pollinators of this community. However, the use of pesticides in agriculture as causing pollinator declines is well documented, especially where spraying time coincides with flowering time (Nicholls and Altieri 2012). Here the application was made in early February, out of the flowering peaks of most of the species.

Open entomophilous and anemohilous corollas were promoted by shredding management, while anemophilous ones dominated in chisel and alfalfa treatments, offering a poor habitat quality in terms of attractiveness for pollination. Alfalfa is generally considered as a temporary pollinator-friendly cover crop (Wratten et al., 2012) because of it beneficial flower features. Nevertheless, this area presents a low productivity index (Oñate et al., 2007) and alfalfa crop without an irrigation supply, is often not very successful. At the same time, the early soil removal caused by the alfalfa sowing is favoring the germination of *Poaceae*´s species, the less attractive family for insects.

Previous studies suggest that agri-environmental management is more effective in simple landscapes than in complex ones (Tscharntke et al., 2012). Here we induce that a higher amount of semi-natural habitats provides new plant features to the system that would not been achieved with fallow field managements by itself, enhancing the habitat attractiveness for pollinators. Moreover, semi-natural habitats are the place to nest and hibernate for the major pollinator groups (Batáry et al., 2011) making them and essential element in the landscape to make effective the insect-plant interaction.

As a next step to further assess ways to enhance pollinator habitats in fallow lands, a validation of the results of the study would be desirable to determine the relationships between our predictions and information on insect species´ distribution. Furthermore, increasing the number of sampling points as well as considering new landscape metrics such as field shape, may help to understand the interface between semi-natural patches and fallow lands. Also, here we have tested the field practices which are most commonly developed in these non-crop habitats; however other practices could also be applied. Hence, if sowing is an option, and important issue to take into account for enhance its efficiency is to have a good knowledge about the abundance and diversity of groups of pollinator in the region before choosing plant species (Pywell et al., 2011). This would need to be combined with the appropriate management to maintain the sown community in the desired proportions.

4. 4 Conservation implications

A landscape perspective is needed to achieve conservation goals on fallow lands. The effect of local management can only be detected appropriately at small local scales where converge under similar physical conditions. However, it is dependent upon regional scales that aggregate environmental heterogeneity and allow to quantify the ecosystem services delivered by the system.

Our results suggest the importance of splitting between the landscape elements must be made. Focussing the attention on improving field edges areas would be necessary to promote their contribution to enhance pollinator habitat. On the other hand, the preservation of semi-natural is suggested to be an essential component of the landscape to harbor pollination rich plant communities, acting as a source-sink of important traits for farmland habitats. Planning priority managements that promote the persistence of mid-successional communities which include perennial species together with less competitive plant communities (ruderal species) would allow the presence of high value flowers traits that enhance pollinator services. An early herbicide application (February) and shredding on fallow lands are, among the treatments tested in our study, the ones that leads to this specific rich-habitat.

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Chapter 3

Fallow management for steppe bird conservation: the impact of cultural practices on vegetation structure and food resources

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This chapter has been submitted to Biodiversity and Conservation

Fallow management for steppe bird conservation: the impact of cultural practices on vegetation structure and food resources

Summary

The potential of fallow lands to favor farmland bird conservation is widely recognized. Since fallows provide key resources for birds within the agricultural matrix, such as nesting sites, shelter and forage, complete understanding of the effect of field-management strategies on vegetation structure and food is essential to fulfill bird requirements and improve habitat management. In this study we experimentally compare the most common field practices (ploughing, shredding, herbicide application and cover cropping) on fallow lands by assessing the resources they provide for birds in terms of vegetation structure and food resources (leaf and seed availability), as well as the economic costs of their implementation. Fallow management treatments are ranked for six target species in a lowland area of the north-eastern Iberian Peninsula, according to the available information on their requirements. The different agronomic practices offer various quantities and types of resources, highlighting the importance of fallow management in bird conservation. Shredding and early herbicide application (February) are estimated to be good practices for Little Bustard (*Tetrax tetrax*) and Calandra Lark (*Melanocorypha calandra*), providing both favorable habitat and foraging conditions, while being economical. Meanwhile, superficial tillage in spring is found to be optimum for the rest of the species tested, despite being among the poorest food providers. Alternating patches of the best treatments would improve the effectiveness of agri-environmental schemes by maximizing the harboring habitat for the endangered species.

Keywords: Non-cropped land; Habitat suitability; Farmland birds conservation; Field practices; Agri-environmental schemes.

1. Introduction

Thousands of years of agricultural expansion have led to the reliance of wild species on land dedicated to human food production. Thus, their preservation strongly depends on traditional low-intensity practices (Tscharntke et al., 2005). Throughout Europe, the effects of farm management on breeding birds are well documented, and intensified practices as well as the simplification of agricultural landscapes have been identified as the main causes of the decline of farmland bird populations (Benton et al., 2003; Donald et al., 2001). In order to slow and eventually halt this decline, farmland biodiversity has been the focus of important conservation efforts in Europe in recent decades, including various common policy tools and agri-environment schemes (AES) devoting great amounts of money to the process (Kleijn et al., 2006). Despite these efforts, the negative effects of agricultural intensification on European farmland biodiversity persist (Donald et al., 2006), and it is still unknown how the extensive European agri-environmental budget for conservation on farmland contributes to the policy objectives aimed at stopping biodiversity decline (Guerrero et al., 2014; Kleijn et al., 2011; Vickery et al., 2004) . Kleijn et al. (2006) found that the European schemes had limited usefulness for the conservation of endangered farmland species and, therefore, suggested that the measures currently applied would require elaboration as well as designs more tailored to the needs of these species. Furthermore, appropriate biodiversity conservation targets and measures must also be identified, and modulated according to the landscape characteristics of each region (Concepción et al., 2008; Butler et al., 2009; Cardador et al., 2014).

Cereal pseudo-steppes of the Iberian Peninsula are distinctive agricultural landscapes characterized by open areas with flat or slightly undulated topography, dominated by winter cereal crops and a Mediterranean continental climate (Suárez et al., 1997). These areas also represent a low yield farming system due to climatic and soil limitations, with an average cereal supply of 2500 kg ha^{-1}; compared with the 6000 kg ha^{-1} represented by the European Union (EU) as a whole (Delgado and Moreira 2000; Oñate et al., 2007). Steppe birds that inhabit this landscape are thought to be good indicators of overall farmland diversity due to their narrow niche requirements, strongly linked with these habitats (Butler et al., 2007; Stoate et al., 2001). Their populations have been reduced by almost half since 1970 and are at present the most threatened bird group in Europe; 83% of the species has unfavourable status since it is highly vulnerable to the effects of agricultural change (Benítez-López et al., 2013; Burdfield 2005). In this context, the Iberian Peninsula is home to the most important populations of these endangered species within Europe (Santos and Suárez 2005).

Establishment of temporary habitat patches such as fallow land is one of the most promising approaches to compensate for the loss of semi-natural habitat and mitigate the negative effects of agricultural intensification (Huusela-Veistola et al., 2011). Fallow land is an essential substrata during breeding and winter seasons for a variety of steppe land bird species (McMahon et al., 2010; Vickery et al., 2004). Hence, leaving a different proportion of arable land fallow is one of the most common commitments when creating AES (Oñate et al., 2007). Although many of these species can live in similar habitats, differences in microhabitat selection between species or even between different sexes of the same species may explain coexistence in steppe bird communities (Morales et al., 2008; Traba et al., 2015). Therefore, the maintenance and provision of microhabitat structure according to different species' needs should be considered a priority in the management of agricultural environments (Traba et al., 2015).

Fallow habitat is extremely variable in terms of structure and composition, thus allowing for the existence of different microhabitats within the same habitat type. Agronomic practices applied on fallow land are key factors in understanding that variability, and determining its value for birds since they strongly affect the vegetation development, microhabitat characteristics, and food availability. Management practices act as a filter, changing the composition and structure of weed communities which species select based on certain characteristics (Fried et al., 2012). Shredding, sowing with a competitive grass, ploughing, grazing or spraying out with herbicide are among the preferred options for farmers, who mainly aim to control weeds and prevent diseases. Regulating the timing and frequency of agricultural labors can also modify the vegetation response. Yet there is a lack of information regarding the most appropriate type of fallow management required to foster a suitable habitat for farmland bird conservation, and particularly in steppe-land bird species (Hyvönen and Huusela-Veistola 2011; Morgado et al., 2010). Research emphasizes that the availability of the nesting site, diet, foraging habitat, as well as easy access to food and shelter from predators are the most important resources that explain habitat selection (Cardador et al., 2014; Delgado et al., 2009; Green et al., 2000; Toivonen et al., 2013; Traba et al., 2015). Thus, if habitat associations are largely dictated by the availability of key resources, it is crucial to consider the habitat suitability (both the quantity and quality of the resources provided), rather than the habitat per se (Butler and Norris 2013; Ponce et al., 2014).

While previous studies are mostly based on correlating bird presence with habitat or land-use availability, here we utilized an experimental approach to compare the resources provided for birds among the most common management practices allowed in AES programs. Apart from assessing the cover and height provided by each fallow treatment, we combined information from multiple functional plant traits and vegetation characteristic to create trophic indexes that seek to inform about leaf and seed availability. Due to the particular situation of Iberian pseudo-steppes as a low productivity system, the adoption of the proposed schemes or certain fallow treatments by farmers would be more attractive if they were to combine environmental improvements with cost-minimization. So to address this reality, and since considering the farmer’s economy is critical to making progress towards maximizing AES efficiency, the economic cost associated with each treatment or agronomic practice was estimated.

In summary, i we aim to 1) experimentally compare the effects of the most common agronomic practices on bird resources provided by fallows; 2) predict habitat suitability among these practices for several steppe birds during the breeding period through a structural and functional approach; 3) identify fallow management treatments that better optimize bird benefits, taking the economic cost of implementation into account ; 4) contribute to progress in improving AES effectiveness and farmland bird conservation goals.

2. Material and methods

2.1 Study area and species

Our study area is located in the NE Iberian Peninsula, in a flat area of the Ebro basin with a Mediterranean continental climate and only 300–400 mm of annual rainfall. A total of four separate fallow lands sites were selected as study areas: Montcortes (41°42'35.22''N; 1°13'52.33''E), Ballobar (41°32'55.37''N; 0°5'59.06''E), Balaguer (41°44'38.92''N; 0°45'21.63''E) and Mas de Melons (Castelldans) (41°30'14.26''N; 0°42'40.18''E) owing to the homogeneous nature of the landscape.

All are included in Special Protection Areas (SPA), which are sites established under the 2009/147/EC Birds Directive and included in the Natura 2000 network (i.e., the European network of natural protected areas). These sites are classified as such due to the coexistence of many steppe bird species of conservation concern in the region (Brotons et al., 2004; Estrada et al., 2004), and so they benefit from an AES focused on steppe land bird conservation. According to regional AES, a fallow scheme provides interruption of cereal production for ≥1 years (the agreement can be renewed annually) with no agricultural activities allowed during the breeding period which is from the 15th of April to the 1st of September. The potential beneficiary species include Black-bellied sandgrouse (*Pterocles orientalis*) and Little Bustard (*Tetrax tetrax*), species classified as endangered and vulnerable respectively at a European level (BirdLife International 2015), and other species of conservation concern or protected species at the European, national or regional level: Stone-curlew (*Burhinus oedicnemus*), Short-toed lark (*Calandrella brachydactyla*), Calandra Lark (*Melanocorypha calandra*) and Pin-tailed sandgrouse (*Pterocles alchata*). All are ground-nesting species with specialized habitat requirements but depend on set-aside to a greater or a lesser extent during breeding period. Previous studies have described the vegetation structure and main food requirements where the considered species populations tend to be greater(Cardador et al., 2014; Giannangeli et al., 2004; Green et al., 2000; Homem de Brito 1996; Jiguet et al., 2002; Martin et al., 2010; Martinez 1994; McMahon et al., 2010; Morales et al., 2008; Morgado et al., 2009; Sanza et al., 2012; Silva 2010; Silva et al., 2013; Suarez et al., 1997; Suárez et al., 2009; Traba et al., 2013; Traba et al., 2015). From this information, a range of habitat suitability for the selected species has been defined in terms of vegetation cover and height, and food resources (Table 1).

2.2 Experimental design

We conducted a 3-year field experiment (from the 2012 to the 2014 agronomic season) to examine the development of vegetation communities on fallow lands under different cultural practices. In each of the four study sites, one fallow field (ranging from 14.54 to 5.18 ha) was divided into 21 plots of 200 m^2. With the aim to reproduce some of the most common cultural practices, the following treatments were applied in each experimental plot: chisel plow, set to a minimum tillage of 10 cm; shredding; a glyphosate herbicide spray at a 1.5 $l\ ha^{-1}$ dosage; alfalfa sowing, with *Aragon* seed variety at 30 $kg\ ha^{-1}$ dose. The applications were administered at different times according to common practices: "early dates" (February) for chisel and herbicide, and "late dates" (April) for chisel, herbicide and shredding. Alfalfa was sown once in October of the first season. Furthermore, some plots were untreated (control), giving a total of seven treatments repeated three times in each study area: early-chisel (EChi), late-chisel (LChi), early-herbicide (EHer), late-herbicide (LHer), late-shredding (Shre), early-alfalfa (Alf) and untreated/control (Cnt). At the end of each agronomic season (October), the vegetation of all experimental plots was mowed in order to remove an excess of organic matter while maintaining the cumulative effect of the previous treatments.

2.3 Vegetation sampling

Plant data were collected from five fixed quadrates of 0.25 m^2 located on each experimental plot each year in May, 15-20 days after the previous management. This timing coincides with AES enforcement as well as with the breeding season of the target bird species. Vegetation structure (cover and height) was measured per each 0.25 m^2 quadrate. Coverage of each species was visually estimated as a percentage of the area of the entire quadrate. Vegetation height was obtained by averaging the five measures of maximum height taken in each quadrate. A total of 118 plant species were identified to species level wherever possible.

Table 1. Habitat requirements of the bird species studied.

Bird species	Trophic resources	Structure patterns	
	Food	**Cover**	**Height**
Little bustard (***Tetrax tetrax***)	Mainly green plants (Jiguet et al., 2002)	25-75% (McMahon et al., 2010; Silva 2010)	Less than 50 cm (Martinez 1994;Morales et al., 2008; Silva 2010; Silva et al., 2013)
Stone-curlew (***Burhinus oedicnemus***)	Plant material, terrestrial invertebrates and occasionally small mammals (Giannangeli et al., 2004; Green et al., 2000 ; Traba et al., 2015)	Not exceed 50% (McMahon et al., 2010; Traba et al., 2013)	Less than 35 cm (Homem do Brito 1996)
Pin-tailed sandgrouse (***Pterocles alchata*)**	Mainly seeds (Suarez et al., 1997; Martin et al., 2010)	Not exceed 50% (Martin et al., 2010)	Less than 30 cm (Martin et al., 2010)
Black-bellied sandgrouse ***(Pterocles orientalis***)	Mainly seeds (Suarez et al., 1997; Martin et al., 2010)	Not exceed 50% (Martin et al., 2010; Traba et al., 2013)	Less than 30 cm (Martin et al., 2010)
Calandra lark (***Melanocorypha calandra***)	Mainly invertebrates and seeds (Sanza et al., 2012)	50-95% (Morgado et al., 2009)	10-45 cm (Cardador et al., 2014; Morgado et al., 2009)
Short-toed lark (***Calandrella brachydactyla***)	Mainly seeds (Suárez et al., 2009)	25-50% (McMahon et al., 2010)	Less than 30 cm (McMahon et al., 2010)

2.4 Trophic indexes

By using functional traits information obtained from different data bases along with field data, seed and leaf availability indexes were calculated to estimate the foraging value of each management type. Because of the lack of data for invertebrates, we could not calculate a trophic index for this food component, though it may also be relevant for chick survival or form an important part of the adults' diet during the breeding period (Delgado et al., 2009; Holland et al., 2006; Jiguet 2002). Nevertheless, invertebrate availability could be positively correlated with the herbivory index across management treatments given that most invertebrates and particularly the most abundant ones (usually the phytophagous group) are highly dependent on primary production (Di Giulio et al., 2001; Hoste-Danyłow et al., 2010).

2.4.1 Leaf availability index

To define leaf availability index, each plant species was given a value according to the data f (coverage x height x Specific Leaf Area (SLA, mm^2 mg^{-1}). The index of each plot was the result of summing each species´ index value. As a vegetation volume approach, cover and height data were taken into account. Coverage data was obtained by field sampling for each species. However, height data was taken in the field as a unique value, and the total of all the species was averaged. To avoid overestimation, the height value of each species was obtained from literature (de Bolòs et al., 1993), field data was utilized if the literature measure was higher than the average plot height, and vice versa when literature data was smaller than the average height of the plot. SLA is a plant leaf trait obtained from literature (Kattge et al., 2011), which is directly related to palatability, or the degree of toughness (low SLA) or softness (high SLA) of leaves´ tissues. This measurement ultimately determines the leaves' value to be assimilated by herbivories (Storkey et al., 2013; Weiher et al., 1999).

2.4.2 Seed availability index

In a similar way, seed availability was quantified for each species as the product of its coverage x seed mass (average of 1000 seed weight, g) and weighted by flowering period (months). The seed availability index was finally obtained by the summation of each species´ index, which had been previously calculated. Cover information was taken per species and seed mass data obtained from databases (Klotz et al., 2002; Royal Botanic Gardens Kew 2014). According to regional AES, it is prohibited to exercise management in these areas from the 15thof April to the 1st of September. Per this rule, we weighted the index highlighting the species in flower during this period (de Bolòs et al., 1993), giving 0 to species with no flower during the AES period and values 1, 2, 3 or 4, depending on the months in bloom. Considering the coverage and months of blossom (most were between two and four months) during birds´ breeding period gives an idea of the plants' fecundity and available resources. This assumption is based on studies in the region which confirm that both invertebrates (mainly harvester ants) and vertebrates remove seeds available on the soil surface during this period, causing a strong weed suppressive effect (Baraibar et al., 2009). This makes it necessary to consider the species in bloom in order to estimate the actual seed availability of the system at a specific time. High seed availability index values are not linked with an increase in seed mass. Due to the lack of information on the number of seeds produced by a plant and following the ecological rule directly relating the trade-off between seed size and number of seeds produced (Leishman 2001), we assume that species with similar seed mass will produce a comparable number of seeds. Averaging the seed weight of the most common plant species present in the study (Figure 3) reveals that all of them have a comparable seed weight (1.2 ± 0.20 mg) and thus similar seed production.

Both trophic indexes were standardized, resulting in typed variables with zero mean and a standard deviation of one.

2.5 Economical evaluation

Economic cost data of the implemented managements was provided by the agricultural services company CUPASA and supported by the data obtained in technical study which summarizes the information of costs practices in the Ebro Valley (Lloveras and Cabasés 2014). All the data was taken according to the average price of the season 2013-2014.With these values, we calculated the estimated annual cost of each treatment per hectare.

2.6 Statistical analysis

In a first step, we analyzed the differences in vegetation structure, coverage (in %) and height (in cm), between field managements. A linear mixed model (LMM) and a post-hoc Tukey´s pairwise comparison was utilized to determine differences among treatments, including locality as a random factor. The same analysis was done to estimate differences among treatments on dietary availability. Both trophic indexes values were square-root transformed.

Information provided from previous studies was used to build habitat suitability range models for the selected birds in terms of vegetation structure and food availability (Table 1). The degree of overlap between the mean values (±CI) of each variable per field treatment and the bird species requirements was quantified. To analyse flora community patterns in more detail, rank-abundance curves were constructed for each of the seven field treatments at species level.

Statistical analyses were performed using R (R Development Core Team, 2011) with VEGAN (Oksanen et al., 2011), lme4 (Bates et al., 2008) and BiodiversityR (Kindt and Coe 2005) packages.

3. Results

Plant cover shows a significantly positive correlation to height (R=0.465; P<0.001) and management practices display different habitats regarding vegetation structure (Figure 1). Late chisel differs significantly from the other treatments, leading to less plant coverage and height (a mean of 35% and ±30 cm, respectively) (Table 2). Early chisel application shows higher cover and height values (up to 50% and 55 cm, respectively) compared to late chisel management, while we found similar structural values between early and late herbicide applications (65-61% coverage and 41-43 cm height). We observe similar height values between late chisel and late herbicide treatments, whilst not in coverage. Shredding management is not significantly different from alfalfa sowing, late herbicide and early chisel and herbicide treatments. Alfalfa and unmanaged plots (control) are significantly different in both structural variables under late chisel management and they provide the highest values of cover and height (80-79% and 52-61 cm).

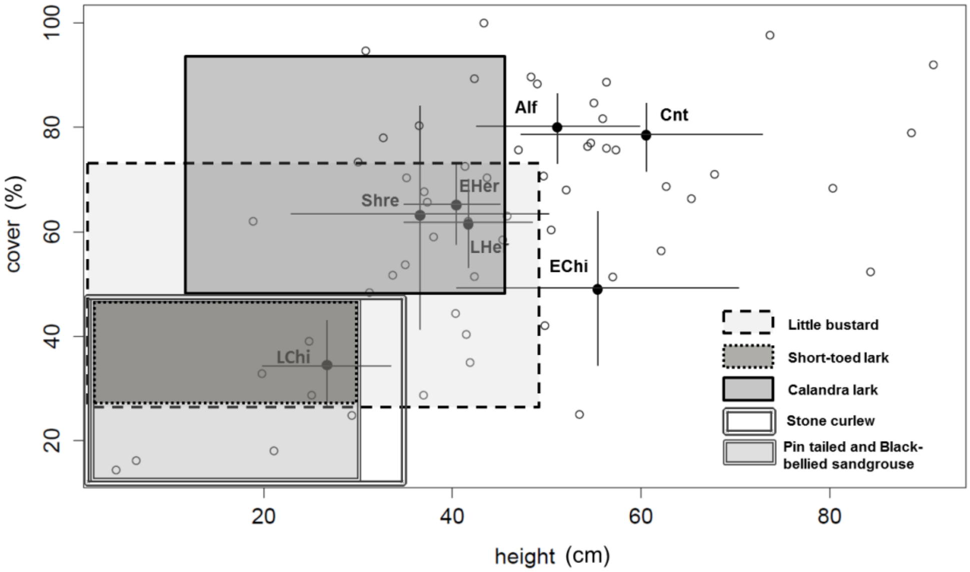

Figure 1. Average (and the 95% confidence interval) of vegetation coverage and plant height experimentally obtained across several fallow treatments (black dots) and optimal habitat range obtained from bibliography for the selected bird species (overlapping rectangles). Sample sites are marked with white dots.

The observed differences in vegetation structure greatly determine the fallow suitability for the different target species. Control plots and alfalfa sowed fields do not fit into the vegetation structure requirement of any of the target species, while the early chisel treatment partially does soon account of resulting tall, dense vegetation (Figure 1; Table 2). Moreover, the late chisel treatment provided fallows with a vegetation structure adequate for all species, except Calandra Lark. Furthermore, four species (Stone-curlew, Short-toed lark, Pin-tailed sandgrouse and Black-bellied sandgrouse) would only find an optimal habitat under this treatment. Finally, shredding and chemical treatments resulted in vegetation structure that fit the main requirements for two species: Little bustard and Calandra lark. Food availability indexes were positively correlated (R=0.804; $p<0.001$), indicating that the birds were finding more palatable leaves when there were more seeds available in the system (Figure 2). Since vegetation structure of

Table 2. Average of cover and height per treatment and post-hoc Tukey test results from linear mixed model between vegetation structures of the management practices.

	Average per treatment		**Post-hoc test between field treatments**					
	Coverage (%)	**Height (cm)**	**Control**	**Early-chisel**	**Early-herbicide**	**Late-chisel**	**Late-herbicide**	**Shredding**
Alfalfa	80 (± 7.4)	52 (± 8.5)	C: ns H: ns	C: *** H: ns	C: ns H: ns	C: *** H: *	C: ns H: ns	C: ns H: ns
Control	79 (± 8.8)	61 (±13)		C: *** H: ns	C: ns H: ns	C: *** H: ***	C: ns H: ns	C: ns H: *
Early-chisel	50 (±13.8)	55 (±14.6)			C: ns H: ns	C: ns H: *	C: ns H: ns	C: ns H: ns
Early-herbicide	65 (± 7.7)	41 (± 7.4)				C: *** H: ns	C: ns H: ns	C: ns H: ns
Late-chisel	35 (± 8.1)	28 (± 8.8)					C: *** H: ns	C: *** H: ns
Late-herbicide	61 (± 9.7)	43 (± 6.9)						C: ns H: ns
Shredding	63 (± 21)	38 (±13.3)						

Mean values (± SE), C: coverage, H: height, ns: non-significant result, * = <0.05, ** = <0.01 and*** = <0.001

alfalfa and control plots was not suitable for birds, trophic indexes were not calculated for these treatments. Both trophic index values were determined by management timing. Early treatments (February) led to significantly higher foraging values than treatments applied in April (around 2.5 ± 0.5 and 1.5 ± 0.5, respectively) (Table 3). However, shredding (only applied on April) supplied significantly comparable seed resources when compared with early chisel and early herbicide. Early chisel is the treatment which offers the greatest amount of food resources (2.7±0.7 and 2.5 ± 0.7 seed and leaf availability index values, respectively). Despite being the only valuable treatment in terms of vegetation structure for Stone curlew, Short-toed lark and both sandgrouse species, late chisel management is among the poorest regarding food resources (1.5 ± 0.4 and 1.3 ± 0.3 seed and leaf availability index values, respectively).

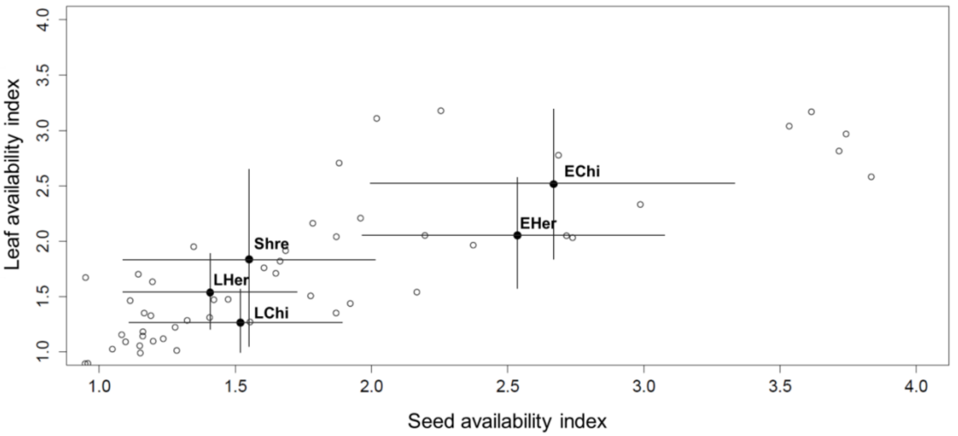

Figure 2. Leaf and seed availability indexes along field managements (95% confidence limits) in black dots. White dots indicate surveyed sites.

Table 3. Average of seed and leaf availability indexes per treatment and post-hoc Tukey test results from linear mixed model between trophic indexes of the management practices.

	Average per treatment		**Post-hoc test between field treatments**			
	Seed availability index	**Leaf availability index**	**Early-herbicide**	**Late-chisel**	**Late-herbicide**	**Shredding**
Early-chisel	2.7 (±0.7)	2.5 (±0.7)	S.I.: ns L.I.: ns	S.I.: *** L.I.: ***	S.I.: *** L.I.: *	S.I.: ** L.I.: ns
Early-herbicide	2.5 (±0.6)	2.1 (±0.4)		S.I.: ** L.I.: *	S.I.: ** L.I.: ns	S.I.: ** L.I.: ns
Late-chisel	1.5 (±0.4)	1.3 (±0.3)			S.I.: ns L.I.: ns	S.I.: ns L.I.: ns
Late-herbicide	1.4 (±0.3)	1.5 (±0.4)				S.I.: ns L.I.: ns
Shredding	1.6 (±0.4)	1.8 (±0.7)				

Mean values (± SE), S.I.: seed availability index, L.I.: leaf availability index,
ns: non-significant result, * = <0.05, ** = <0.01 and *** = <0.001

Among the patterns of rank-abundance, there was pronounced dominance of *Anacyclus clavatus* (Figure 3) in all seven treatments. . However, its dominance is less noticeable in early treatments (herbicide and chisel), comprising only around 30% of the total abundance, while it later increases by around 60% (70% in control plots). The presence of *Salsola kali* as the second abundant species in early treatments shows that the intervention time is a key factor for the germination of this late-spring species. Furthermore, late management led to the appearance of *Malva sylvestris* as a common species. Soil remotion seemed to promote graminoid species, such as *Lolium rigidum* that is always present as an important species in this type of management including alfalfa (after *Medicago sativa*). An increase in hemicryptophyte forms was observed in shredding treatment (*Seseli tortuosum* and *Crepis sp.*) since they have a greater likelihood of surviving due to the possession of perennial buds at ground level**.**

The economic cost of the agricultural work carried out reveals that shredding and herbicide application are the cheapest treatments (26€/ha and 26.7 €/ha, respectively), while alfalfa sowing is the most expensive one (295 €/ha). Alfalfa is, however, a perennial forage crop that is normally sown every two-four years (Table 4). Based on previous analysis, we constructed a ranking to 1) consider both the most suitable treatments for the target species selected, based on the vegetation structure and trophic resources, and 2) weigh the economic side (Table 5). Taking vegetation structure and food resources into account, the optimal treatments for the target species appear to be early herbicide application, shredding and chisel (early or late). If we consider both suitability for birds and the economic cost of each treatment, the shredding and herbicide treatments seem to be the best options. However, in the case of Stone-curlew, Short-toed lark, Pin-tailed sandgrouse and Black-bellied sandgrouse, only the effects of late chisel is suitable to their optimal habitat range.

Table 4. Economic cost of the management implemented.

Management Type		Dose/ha	€/u	€/ha	Total (€/ha)
Chisel		1	40	40	**40**
Shredding		1	26	26	**26**
Herbicide					**26.7**
	Glyphosate 45%	1.5	7.8	11.7	
	Application	1	15	15	
Alfalfa sowing					**295**
	Subsoiler	1	65	65	
	Seeder (*Precision Planting*)	1	50	50	
	Alfalfa seed (*Aragon*)	30	6	180	

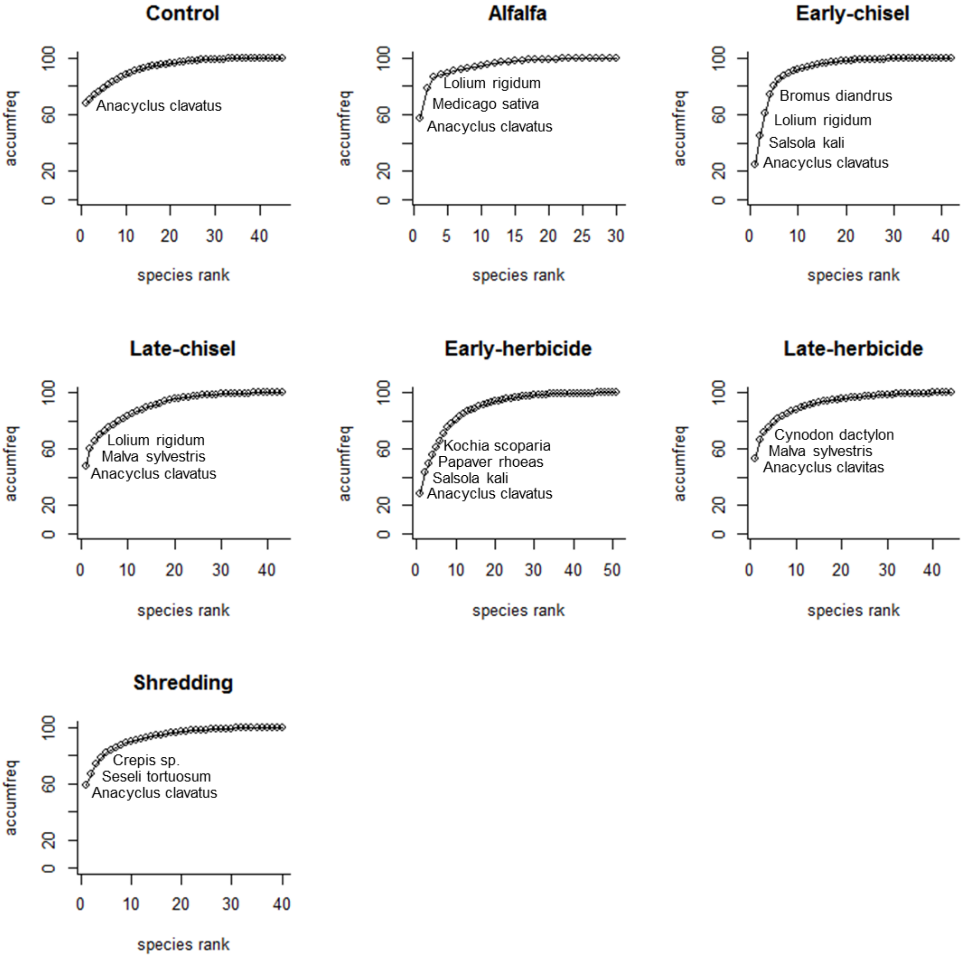

Figure 3. Rank abundance curves representing the accumulate proportional abundance (as a percentage) of the most common plant species present per management. The X-axis indicates the total number of plant species. Each point in a curve represents a plant species.

Table 5. Summary of the most effective treatments according to vegetation structure, foraging availability and economic cost for the bird species considered in the study.

	Ranking of the best treatments					
Bird species	**Provides good vegetation structure**			**Provides more food resources***	**Cheapest**	**Final Ranking**
	Treatment name	Coverage suitability	Height suitability			
Little bustard	**1.** E. Herbicide L. Chisel L. Herbicide **2.** Shredding **3.** E. Chisel	100% 100% 100% 89% 0%	100% 100% 72% 98% 34%	**1.** E. Chisel E. Herbicide Shredding **2.** L. Herbicide L. Chisel	**1.** Shredding Herbicide **2.** Chisel	**1.** Shredding Early Herbicide **2.** Late Herbicide **3.** Late Chisel **4.** Early Chisel
Calandra lark	**1.** E. Herbicide L. Herbicide **2.** Shredding **3.** E. Chisel	100% 100% 71% 0%	100% 100% 98% 17%	**1.** E. Chisel E. Herbicide **2.** Shredding L. Herbicide	**1.** Shredding Herbicide **2.** Chisel	**1.** Early Herbicide **2.** Shredding Late Herbicide **3.** Early Chisel
Stone-curlew	**1.** L. Chisel	100%	100%	**1.** L. Chisel	**1.** L. Chisel	**1.** L. Chisel
Short-toed lark **Pin-tailed sandgrouse** **Black-bellied sandgrouse**	**1.** L. Chisel	100%	67 %	**1.** L. Chisel	**1.** Chisel	**1.** L. Chisel

*according to the food preferences per species (i.e. Little bustard mainly herbivorous)

4. Discussion

Our results reveal that field management and timing can play a key role in the aptitude of fallows for steppe birds during the breeding season. Through an experimental approach, we show how different fallow agronomic practices and timings determine the vegetation structure, as well as the amount and type of food resources; two key factors behind bird habitat selection.

Among analysed managements, alfalfa sowing and untreated plots presented the greatest coverage and vegetation height. At the other end of the spectrum, we find the late chisel plots with twice lower values for the same variables. Early chisel, shredding and both herbicide treatments presented intermediate values. Application time appears to be an important factor in determining trophic availability, while early management provided more seed and leaves resources than late practices. This difference is reflected by the breaking of *Anacyclus clavatus´* prominence, allowing for the recovery of that species, and leading us to believe that early management promoted diversity enhancement.

Plant succession dynamics after different disturbance practices are the key to explaining the contrasting result between two treatments made at the same time. It is known that life forms are relevant to discriminate weeds according to physical or chemical disturbances (Gaba et al., 2013). Ploughing allows for equal weed expansion dominated by pioneer annual plants with fast life cycles (Sojneková and Chytrý 2015). Meanwhile, herbicides favour the establishment of perennial species as well as ones with a short interval between recruitment and anthesis (Gaba et al., 2013; Gulden et al., 2010). Glyphosate is a non-selective contact herbicide that can affect a wide range of weeds. However, phanerophytes, chamaephytes and most of the hemicryptophytes are less harmed, resulting in a rather heterogeneous habitat. The role of these biological forms against annuals allows for a sparse and patchy habitat with lower density vegetation. This diverse structure is also promoted by the layer of dead organic matter that remains on the soil surface after the herbicide treatment.

No treated fallows (control plots) and alfalfa-sowed ones offered vegetation cover and height values above the habitat selection ranges of the objective species. The over fertilization with pig slurry detected in many areas of the Ebro Valley

(Berenguer et al., 2008) may explain the lack of fitness, characteristic to the non-managed fallows, while the high nutrient load may be responsible for the overdevelopment of the vegetation. Areas that are encroached on by dense vegetation result in the loss of farming habitat and cause weed problems in future crop seasons, so it is usually a non-preferred scenario for farmers. This implies that in other circumstances (considering different climate or soil fertilization), the results could be lower than the ones obtained in our region. Even if our experimental approach is conditioned by the soil fertilization levels of the study area, all treatments should be affected in the same way by those soil conditions, allowing us to assume that the differences in vegetation structure we found between treatments would remain constant, or at least very similar, in other areas where steppe and birds reside.

Previous studies described the importance of legume fields as a good habitat for steppe birds and particularly for Little Bustard (Bretagnolle et al., 2011; Ponce et al., 2014). Here, alfalfa was not as successful as expected, probably due to dry weather conditions after sowing. This undermined the competitive capacity of alfalfa against other weeds that, along with the absence of any other treatment after the sowing date, led to an evolution similar to that of the control plot vegetation. Maybe an annual reseeding in these dryland areas could enhance alfalfa growth. Early chisel has the highest trophic index values, but it is above the optimal range of all the bird species in terms of vegetation height, suggesting that the latter would restrict the access to those food resources.

We predict that the early and late herbicide application together with shredding would offer the best conditions for Little Bustard and Calandra Lark, as these treatments match their optimal habitat range for both cover and height, according to bibliography. Nevertheless, if we also consider food resouces, only early herbicide application and shredding remain the best treatments for Little Bustard, while Calandra Lark prefers the former. It seems paradoxical to suggest an herbicide treatment as one of the best ways to achieve the optimal conditions on fallows for Little Bustard, considering that its diet is based on green leaf resources (Jiguet 2002), so shredding seems to be a more conservative option than any chemical treatment. Also, and based on the provided information, shredding and herbicide are among the less expensive farmland practices. The controversial role of herbicide in conservation is mainly because of its negative influence on floristic diversity and the invertebrate community (Boatman et al., 2004; Wilson et al., 1999), as some insect groups are important food sources for chicks. Pollination decline is a well-documented consequence of agricultural pesticide application, especially in places where spraying time coincides with flowering time (Nicholls and Altieri 2012). Nevertheless, previous studies have found that reduced herbicide inputs allow for the maintenance of a diverse invertebrate community (Vickery et al., 2002). In summary, we do not know the extent to which the benefits of early chemical application for some of the target species exceed the potential damage that application could cause to the insects or wildlife in general, which is why more specific studies are needed to explore the short and long-term effects of chemical treatments in fallows. Furthermore, it would be necessary to assess the invertebrate availability under different agronomic practices in future studies because breeding success for some bird species may be dependent on this kind of food supply (Holland et al., 2006; Holland et al., 2014; Jiguet 2002).

According to our results, the other four bird species (Stone-curlew, Short-toed lark, Pin-tailed sandgrouse and Black-bellied sandgrouse) would only find suitable vegetation structure conditions in late chisel treated fallows. Thus, even if this treatment does not offer the highest food resources that early treatments appear to provide, the microhabitat requirements of those species strongly limit the choices to manage fallows for them. Short vegetation height and low cover is reported by other studies as the optimal habitat for sandgrouse species (Martín et al., 2014), probably to better detect predators and reduce predation risk (Butler and Gillings 2004). The short toed lark also shows a positive response to bare ground, selecting low shrub cover, more herbaceous plants and low vegetation height (Moreira 1999; Suárez et al., 2002). It mainly feeds on seeds found on the ground, so this type of open microhabitat following mechanical treatment favors food accessibility and visibility (Llusia and Oñate 2005; Moreira 1999). Both processes (anti-predator behaviour and foraging strategy) would be favoured by late chisel treatments on fallows.

4.1 Conservation implications

Temporary non-crop habitat establishment specifically designed with biodiversity goals in mind are reported by several studies to offer suitable habitats for species of conservation concern (Cardador et al., 2014; Gillings et al., 2010; Huusela-Veistola et al., 2011; McMahon et al., 2010). To improve the effectiveness of management actions, conservation guidelines for steppe birds should consider microhabitat preferences giving importance not only to the amount of habitat provided but also to vegetation structure and food availability. Moreover, it is also necessary for managers and farmers to know how to achieve the desired microhabitats if biodiversity goals exist. This study contributes to better understanding of how to attain the most suitable vegetation structure and food availability in fallows designed for steppe bird conservation, whilst providing economic assessment of each agronomic practice, essential to maintaining an environmentally-concerned farming culture with conservative aims. Although it may be possible to find other ways to manage fallows, such as grazing (Kruess and Tscharntke 2002; Hoste-Danyłow et al., 2010), in our experiment we reproduce the most common agricultural practices so these results can be useful for other regions and farmland landscapes.

Our study shows that early management applications (February) play a relevant role in fostering habitats with more food resources for birds than applications made in early spring. A good example of effectiveness maximization would be the shredding and early-herbicide application treatment for Little bustard and Calandra lark, respectively, offering greater food resources and optimal habitat parameters at a minimum cost. In contrast, managing fallows for the other four target species (Greater short-curlew, Stone-curlew, Pin-tailed sandgrouse and Black-bellied sandgrouse) is more constrained by the sparse vegetation requirement of those species, only achieved through ploughing in early spring. It is clear from our results that for suiting the needs of different target species in the geographical same area, it is necessary to combine different types of management techniques and avoid the over implementation of a particular treatment at landscape scale. Instead, alternating patches with management that promote suitable habitat for foraging, such as early chisel, with others that offer good shelter and breeding conditions, such as herbicide applications, shredding and late chisel, could lead to the ideal heterogeneous mosaic needed to sustain a high diversity of bird species.

The main contribution of this study has been to experimentally assess how different microhabitats can be achieved through fallow management and to make predictions on how the resulting vegetation structures and food availability matches the main requirements of steppe land birds, one of the more threatened groups of farmland birds. Now, as a next step, a validation of the study results will be required to confirm the relationships between fallow management and our predictions on habitat suitability. Our study focuses on the breeding period, which is a crucial step in the life cycle of any species or population, but in future studies it would be desirable to explore the effects of fallow management on habitat suitability during the whole year, given that species' habitat requirements may be season dependent (Marfil-Daza et al., 2013).

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Chapter 4

Steppe bird responses to different management practices in fallow lands: towards an enhancement of agri-environmental schemes efficiency

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This chapter is in preparation

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Summary

Agricultural practices act as a filter modulating vegetation communities and thus, their structure and the potential to provide food resources, which primarily determines the habitat selection of steppe birds. In a previous study we experimentally identified the effect of different fallow field management on vegetation development. By analyzing the optimal steppe bird´s habitat range according to bibliography, we assessed the suitability of the habitat resulting from management implementation. With the aim to validate these results with actual data, we designed this study to analyze the response of three steppe bird species: Little bustard, Stone-curlew and Calandra lark to different management practices in 241 fallow fields of Catalonia (NE Iberian Peninsula) during breeding period. Bird censuses, vegetation surveys and surrounding habitat information were taken into account to construct the models. Tillage was related with sparse habitat structure, facilitating predator detection and conspicuousness for courtship, as well as ruderal vegetation, which provides for plentiful seeds and green plant availability. Little bustard males and Stone-curlews showed a positive response to this habitat type, while Little bustard females had a high propensity to find more dense areas to place their nests. Shredding, herbicide application or sowing were associated with a more compacted vegetation structure and invertebrate biomass availability; an important food resource for chicks and the basis of the Stone-curlew diet, which makes nocturnal excursions for food but prefers open habitats during the day. Calandra lark was also positively correlated with a denser vegetation habitat, preferring to fly than hide to avoid predators. However, all the species showed common preferences in terms of surrounding habitat characteristics: selecting open fields and avoiding the presence of numerous edges, linked with higher predation risk. This study shows that efficient fallow management to improve the steppe bird community is guided by understanding the response of vegetation to abiotic disturbances.

Keywords: fallow, habitat suitability, management practices, Calandra lark, Little bustard, Stone-curlew, vegetation assembly.

1. Introduction

In recent decades, agri-environmental schemes (AES) are intended to counteract the environmental impacts of modern farming techniques on biodiversity (Kleijn et al., 2006; Stoate et al., 2009). Strong consequences have been shown for the steppe avifauna, ranked as the most threatened group of birds in Europe with 83% of species having unfavorable conservation status and becoming the focus of important conservation efforts (Benítez-López et al., 2013; Guerrero et al., 2014; Tucker and Heath 2004). The agricultural pseudo steppes of the Iberian Peninsula houses a significant concentration of steppe bird populations that are classified as endangered at a continent-wide scale (Moreira 1999; Ponce et al., 2014). Because of their specialist character, this group of birds is strongly associated with dry cereal farmland habitats and traditional agriculture practices (Cardador et al., 2014; Moreira et al., 2012). Numerous studies have valued fallow lands as one of the most important measures related with biodiversity enhancement in agro-ecosystem and have further described it as a preferred habitat by most steppe birds (Cardador et al., 2014; Moreno et al., 2010; Siriwardena et al., 2000). Numerous studies have indicated differences in the microhabitat preferences among steppe bird species during breeding season (MacDonald et al., 2012; Morales et al., 2008; Traba et al., 2015). Vegetation structure and composition is associated with the foraging availability, nesting site or shelter from predators (Cardador et al., 2014; Delgado et al., 2009; Green et al., 2000; Toivonen et al., 2013; Traba et al., 2015), key factors that strongly determine the birds' habitat suitability. Agricultural practices are directly regulating the vegetation response and thus the habitat value for birds (Fried et al., 2012), however, the main management adaptations prescribed often do not take their requirements into account, resulting in useless conservation efforts for endangered farmland species.

As cereal pseudo-steppes of Iberian Peninsula represent low productive areas (Delgado et al., 2000; Oñate et al., 2005) proper knowledge regarding the effectivity of management practices to enhance steppe bird population viability in an area must be required before taking a percentage of arable land temporarily out of production. The abandonment to revert to a more natural condition often results in the loss of valuable farmland habitats due to encroachment by dense vegetation (Morgado et al., 2010). Also, the over fertilization with pig slurry which has been detected in some areas (i.e. the NE Iberian Peninsula) (Berenguer et al., 2008) accelerates the overdevelopment of the vegetation. Informed management is therefore necessary, as the knowledge of its effect on plant communities is key to ensuring high efficiency AES in fallow lands. However, most studies are based on describing bird habitat preferences without including information of the most suitable management practice(s) to achieve it. The translation of scientific knowledge into management strategies which are beneficial to wildlife and that can be implemented is necessary to progress towards an effective AES design and development.

In previous work, we assessed the vegetation structure and trophic resources provided by different fallow managements from an experimental approach (Chapter 3 thesis). The information of the specialized habitat requirements for the steppe bird species was supported by other studies in order to identify the management practices that will assist in maximizing the potential of fallow habitat to support their populations. In the foregoing work, we aim to validate the habitat suitability predictions made at field scale with real data for three ground-nesting steppe bird species: Little bustard, Stone-curlew and Calandra lark. Furthermore, although impacts at finer spatial grains have been shown to determine bird abundance, landscape structure and composition of the matrix is deeply influencing population dynamics (Devictor and Jiguet 2007; Gil-Tena et al 2015; Moreira et al 2005). Therefore, the study adopted here in is a multi-scale approach including information from surrounding habitats to adequately assess the requirements of steppe birds within a given habitat.

2. Methods

2.1 Study area and bird species

The study area was located in the Lleida Plains, on the eastern edge of the Ebro basin (north- east Iberian Peninsula); characterized by low annual rainfall (between 300 and 450 mm) and a contrasted continental climate. Trials were carried out in six agricultural regions within Important Bird Areas (IBAs) and included in the Natura 2000 network. These regions were: Mas de Melons-Alfés (7618.63 ha), Belianes-Preixana (6521.12 ha), Bellmunt-Almenara (4039.48 ha), Granja d'Escarp (1800 ha), Plans de Sió (10382.69 ha) and Segrià-Utxesa (7727.27 ha), where most of the steppe bird species of conservation concern are coexisting in the region (Brotons et al., 2004; Estrada et al., 2004). The three selected steppe bird species have high-conservation value at the European level (Annex I Directive 2009/147/EC), and include; the Little bustard (*Tetrax tetrax*), Stone-curlew (*Burhinus oedicnemus*) and Calandra lark (*Melanocorypha calandra*). Study areas are devoted predominately to extensive cultivation cereal crops (mainly barley and wheat), followed by tree crops, such as almonds and olives, and finally, fallows.

2.2 Sampling methods

A total of 241 fallow fields were surveyed, standardizing the number according to the region sizes as follows: Mas de Melons-Alfés, n= 54; Belianes-Preixana, n= 51; Bellmunt-Almenara, n=26; Granja d'Escarp, n=23; Plans de Sió, n= 71; Segrià-Utxesa, n=16. Only fallows higher than 1 ha were considered. Surveys were carried out in 2015 between the end of April and end of May, coinciding with the breeding and high activity period of these bird species.

2.2.1 Bird censuses

Bird censuses were performed once per each fallow field from 6 a.m. to noon, only in periods with good weather conditions and typically lasted for a duration of 10 minutes. A fixed point was located as a listening station by randomly selecting a boundary for the fallow field and establishing a buffer zone of 200 m. Each point was spaced at least 400 m from the nearest one. Furthermore, transect lines were performed, adapting length proportionally to the field size in order to maximize the efficiency in detecting bird species. The maximum number of individuals of each species recorded either acoustically or visually was used as an estimate of species abundance per fallow field.

2.2.2 Vegetation sampling

Habitat sampling was performed after the bird survey. A global characterization of the vegetation structure was developed on each fallow field by defining 10 categories from the combination of cover (0-5% (bare ground); 5-25%; 25-50%; >50%) and height (0-20 cm; 20-40 cm; >40 cm) data to describe structural heterogeneity. Additionally, detailed vegetation surveys were carried out by assessing and recording between 3 and 10 2x2 m plots per fallow field. Vegetation cover and average height of the plot was measured, in addition to the coverage of the main plant species (considered as any species occupying more than 20%).

2.2.3 Trophic resources

The availability of trophic resources such as seeds and leaves were calculated from the plant species information following the methodology developed in Chapter 3 of the thesis. Chick survival is highly dependent on invertebrate food supplies (Delgado et al., 2009; Holland et al., 2006) and many studies highlight grasshoppers as an important food type (Bretagnolle et al., 2011; Jiguet et al., 2002). Hence, the presence of the orthopteran species were recorded by two transects lines once per each fallow field. Body size of every individuals observed was also considered and included in one of the three groups of size categories: <2 cm, 2-4 cm, >4 cm. After averaging data from the two transect lines, the final number of individuals were multiplied by their size category (i.e.: <2 cm category= x1; 2-4 cm category= x3; >4 cm category= x5) to estimate an index of insect biomass by the relation of length and mass (Wardhaugh, 2013).

2.2.4 Management practices

Management practices performed in each fallow field during the 2014-2015 season was obtained by conducting farmer interviews. Furthermore, the crop types of the fields inside the 200 m buffer were categorized using Geographical Information Systems (GIS).

2.3 Explanatory variables

According to previous studies, we grouped the available information into three sets of explanatory variables which mainly determine bird habitat selection: vegetation structure, trophic availability and habitat structure (Table 1). Vegetation structure includes the different cover-height combinations registered in the field sampling. Habitat structure is divided into landscape composition and landscape configuration (McGarigal and McComb 1995). Based on our data, the predictors selected to explain landscape composition (inside the 200 m buffer) were: the Shannon Diversity Index (SHDI) of crop types, the percentage of non-crop areas (edges, fallow, oak wood, pinewood, plowed, reeds, riparian forest, set-aside, scrub and stubbles) and the percentage of suitable areas for the target species taken into account in our study (fallow, set-aside and scrub). To describe the configurational landscape heterogeneity, we focused on both field scale parameters, such as fallow field area and shape (perimeter area-1), and buffer scale, characterized as the mean of the perimeter area-1 (PAR) and the total border length (TBL) of the field patches within the 200 m buffer. Finally, as trophic availability we included: seed, leaf and insect (grasshopper) indexes.

Table 1. List of the explanatory variables used for the statistical analysis.

Vegetation structure	Habitat structure	Trophic availability
Bare ground (0-5% cover)	**Configurational**	Leaf availability index
Level 1 (5-25% cover, 0-20 cm height)	Field area	Seed availability index
Level 2 (5-25% cover, 20-40 cm height)	Field shape	Insect availability index
Level 3 (5-25% cover, >40cm height)	TBL	
Level 4 (25-50% cover, 0-20 cm height)	PAR	
Level 5 (25-50% cover, 20-40cm height)	**Compositional**	
Level 6 (25-50% cover, >40cm height)	SHDI	
Level 7 (>50% cover, 0-20 cm height)	% non-crop areas	
Level 8 (>50% cover, 20-40 cm height)	% suitable areas	
Level 9 (>50 % cover, >40 cm height)		

TBL: total border length; PAR: mean of the perimeter area^{-1} ratio; SHDI: Shannon diversity of crop types

2.4 Statistical analysis

To summarize environmental variation of vegetation structure and habitat structure data, two Principal Component Analysis (PCA) were conducted using varimax normalized rotation to maximize the correlations between the axes of the PCA and explanatory variables. The principal components (PCs) were taken as niche dimensions and used as predictors in our models.

General Linear Mixed Models (GLMM) using zero-inflated Poisson distribution (for zero-heavy account data) and log-link error terms were performed to study the influence of the vegetation structure (PCveg), trophic availability and habitat structure (PChab) on the selected steppe bird´s occurrence. As vegetation structure is the main determining factor in a bird´s habitat choice (Whittingham et al., 2006), PCvegs were tested separately to discriminate the optimum habitat range for each of the species. Secondly, new models were constructed taking the interaction of this previous selection with trophic availability variables into account. PChab´s dealing with birds´ abundance were analyzed independently. Models were compared using the adjusted Akaike information criterion (AIC) (Burnham and Anderson 2002). The most parsimonious model was selected by fitting the lowest AIC scores and we only considered models with ΔAICc < 2 as the best fitted models for each predictive variable. Region was treated as a random factor.

To test the hypothesis that contrasting field management had selected for plant communities, a Canonical Correspondence Analysis (CCA) was performed (after first performing a Detrended Correspondence Analysis, DCA, to quantify the length of gradient and confirm that a unimodal model was appropriate). The analysis was conducted among field practices and vegetation structure variables (PCvegs). Analysis were carried out using Canoco 5.0 package (ter Braak and Smilauer, 2012) and R software (R Development Core Team, 2011) with LME4 packages (Bates et al.,, 2008) for mixed models.

Table 2. Percentages of ocurrence, mean and maximum bird density in fallow lands. Sample size corresponds to the number of surveyed fields.

Bird Species	Regions with presence	% of occurrence in fallow field	Mean ± se density (n=birds/ha)	Region with maximum density in fallow fields (n=birds/ha)
Little Bustard	All regions	25.3 (n=241)	1.54 ± 1.18	Belianes-Preixana 6.7 ± 5.58 (n=51)
Stone-curlew	All regions	21.9 (n=241)	0.8 ± 0.59	Belianes-Preixana 3 ± 2.8 (n=51)
Calandra lark	All regions	35.3 (n=241)	0.9 ± 0.12	Belianes-Preixana 2 ± 0.38 (n=51)

3. Results

The three target species studied were recorded in all the study regions and showed differences in their occurrence (Table 2). The major species density is outstanding by Little bustard (1.54 ± 1.18).

PCA analysis resulted in five principal components that explain 68.8% of the total variance for the vegetation structure variables (PCveg´s) while it was summarized into four components accounting for 90.6% of the total variance for the habitat structure variables (PChab´s). The loading factors, eigenvalues and percentage of variation explained by the PCA are shown in Tables 3 and 4, and the interpretation of each axis on the basis of the loadings of each variable is given in Tables 5 and 6 for PCveg and Pchab, respectively.

Results of GLMMs showed that the responses of steppe bird abundance to the different environmental factors changes among species (Tables 7, 8 and 9). The abundance of Little bustard were positively associated with open sparse vegetation areas, linked with leaf availability resource, and an avoidance of dense vegetation structure patches is shown (Tables 7 and 8). The models for Stone-curlew indicated that their abundance were positively influenced by a heterogeneous vegetation structure, represented by cleared areas and short plant heights. However, dense and homogeneous vegetation significantly increased Calandra lark abundance, which is also associated with an increment of insect biomass availability.

Regarding habitat structure (Table 9), common requirements were shared between the three bird species, explained by a positive association with increased field area and a reduction of crop diversity and length of field boundary in the surrounding landscape. Calandra lark abundance is also related with an increment of non-crop and suitable habitat areas, sharing their preference for regular field shapes with Stone-curlew.

In the CCA ordination diagram, the first axis reveals a 2.94% variation in management practices and 39.98% in the practices-habitat characteristics relationship (Fig. 1). The first two axes then depict 68.38% of the variance of the practices-habitat characteristics relationship. In the Monte Carlo test, the significance for the first axis was P = 0.011 (F = 4.8) and for all axes P = 0.009 (F =

1.6). The first CCA axis is guided by the effect of field practices on vegetation structure and the second revealed a gradient of vegetation density. A positive relationship is shown between grazing and sowing treatments and short vegetation height (PCveg2). Both herbicide applications combined with other practices, as well as shredding, promote other vegetation types. On the other hand, sparse vegetation (PCveg5) is positive correlated with the availability of leaves and seeds as trophic resources, while increased insect biomass is more closely related to areas of medium and high density cover.

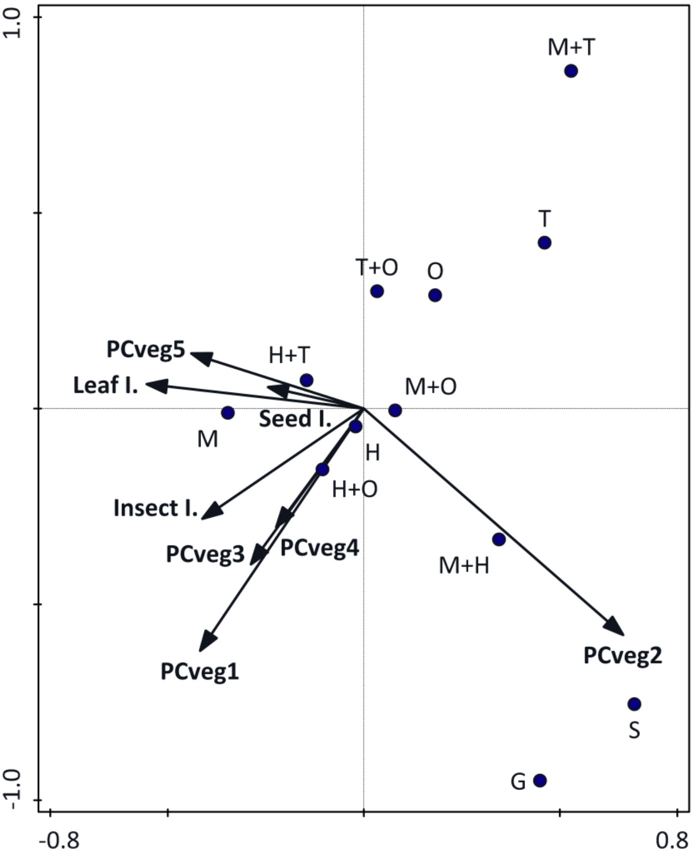

Figure 1. Canonical correspondence analysis biplot diagram displays the relationship of vegetation structure (principal components, PCvegs´s) and food availability (leaf, seed and insect indexes) in fields (arrows) with management practices (M: mowing/shredding; T: tillage; H: herbicide; G: grazing; S: sowing; O: others) (dots). Eigenvalues for axes 1 and 2 are 0.3237 and 0.2299 respectively.

Table 3. Factor loadings and eigenvalues resulting from the Principal Component Analysis (PCAveg´s) for eleven variables that explained vegetation structure. Loading values greater than 0.4 are in bold.

Variables	PCveg1	PCveg2	PCveg3	PCveg4	PCveg5
Bare ground	-0.24	-0.05	0.21	-0.27	**0.71**
Level 1	**-0.46**	0.27	-0.11	-0.25	-0.11
Level 2	**-0.39**	-0.03	**-0.46**	-0.09	-0.13
Level 3	-0.23	-0.23	**-0.55**	0.24	0.26
Level 4	-0.13	**0.58**	0.24	-0.02	**0.39**
Level 5	-0.26	-0.12	**0.49**	**0.48**	-0.04
Level 6	-0.23	**-0.42**	0.15	**0.38**	0.04
Level 7	0.33	**0.39**	-0.23	0.27	-0.24
Level 8	**0.42**	-0.07	-0.17	0.26	-0.35
Level 9	0.28	**-0.45**	0.11	**-0.52**	0.24
Eigenvalue	2.12	1.51	1.18	1.1	0.97
Explained variance (%)	21.2	36.3	48.1	59.1	68.8

Table 4. Factor loadings and eigenvalues resulting from the Principal Component Analysis (PCAhab´s) for seven variables that explained habitat structure. Loading values greater than 0.4 are in bold.

Variables	PChab1	PChab2	PChab3	PChab4
SHDI	0.13	0.23	**0.79**	-0.02
% non-crop areas	**-0.58**	-0.15	0.18	-0.22
% suitable areas	**-0.58**	-0.17	0.16	-0.21
Field area	**-0.46**	**0.38**	**-0.79**	0.38
Field shape	0.13	-0.13	-0.09	**-0.85**
PAR	0.15	**-0.74**	-0.19	0.11
TBL	0.20	**-0.57**	**0.51**	0.13
Eigenvalue	1.56	**1.24**	1.16	1.04
Explained variance (%)	34.7	56.6	75.9	91.6

SHDI: Shannon diversity of crop types; TBL: total border length; PAR: mean of the perimeter area^{-1} ratio

Table 5. Interpretation of the Principal Components that grouped vegetation structure´s variables. PC´s have been coded as PCveg´s.

PCveg	Positive correlated	Negative correlated	Description
PCveg1	Level 8	Level 1, Level 2	Gradient running from high-dense vegetation areas towards open habitats
PCveg2	Level 4, Level 7	Level 6, Level 9	Areas of short height vegetation (0-20 cm) vs highest height (>40 cm)
PCveg3	Level 5	Level 2, Level 3	Associated with mean values of cover and height vs low percentage of plant cover
PCveg4	Level 5, Level 6	Level 9	Mean values of plant coverage vs dense vegetation
PCveg5	Bare ground, Level 4		Bare ground, mean coverage and short height vegetation areas

Table 6. Interpretation of the Principal Components that grouped habitat structure´s variables. PC´s have been coded as PChab´s.

PChab	Positive correlated	Negative correlated	Description
PChab1		% of non-crop and suitable areas, Field area	Negatively correlated with big field sizes and landscapes with high percentage of both non-crop and suitable areas for bird species
PChab2	Field area	PAR, TBL	Big field sizes vs landscapes composed by irregular field shapes and long border lengths
PChab3	SHDI, TBL	Field area	Long border lengths and high diversity of crop vs big field size
PChab4		Field shape	Show a negative correlation with irregular field shapes

Table 7. Model selection details of the relationship between the three steppe bird species (Little bustard, Stone-curlew and Calandra lark) and the principal components extracted from the vegetation structure variables (PCveg´s). Only models which Δi < 2 are showed. The AIC, delta weight and the model selection probability (W_i) are listed; the selection probabilities are also summed for each parameter across all models across 95% confidence for the data set by summing all the W_i scores for all models in which the predictor was included; the parameter estimates (β) presented are the averages across all models (weighted by selection probabilities); the models represent 95% confidence for the data set.

Vegetation structure variables (PCveg´s)									
Variable	**Intercept**	**PCveg1**	**PCveg2**	**PCveg3**	**PCveg4**	**PCveg5**	AICc	Δi	W_i
Little bustard	X	X				X	458.23	0.00	0.36
	X	X				X	459.92	1.69	0.15
β (CI)	**0.44** (0.37,0.5)	**-0.06** (-0.09,-0.03)				**0.19** (0.15,0.23)			
Stone-curlew	X		X			X	474.01	0.01	0.081
	X		X				474.05	0.06	0.079
	X						474.07	0.07	0.078
	X					X	474.43	0.44	0.065
	X		X				474.97	0.98	0.050
	X				X		475.37	1.37	0.041
	X	X					475.44	1.45	0.039
	X					X	475.60	1.61	0.036
	X				X		475.63	1.64	0.036
	X					X	475.94	1.94	0.030
β (CI)	**0.77** (0.69,0.85)	--	**0.024** (0.003,0.04)		--	**0.028** (0.006,0.05)			

Vegetation structure variables (PCveg´s)

Variable	**Intercept**	**PCveg1**	**PCveg2**	**PCveg3**	**PCveg4**	**PCveg5**	AICc	Δi	W_i
Calandra lark	X	X			X		1105.61	0.00	0.126
	X	X					1105.81	0.19	0.114
	X	X		X			1106.23	0.62	0.093
	X	X	X				1106.30	0.69	0.089
	X	X					1106.66	1.05	0.075
	X	X			X		1106.67	1.06	0.074
	X	X		X			1106.72	1.11	0.072
	X	X	X				1107.09	1.48	0.060
	X	X	X	X			1107.12	1.51	0.059
	X	X				X	1107.41	1.80	0.051
β (CI)	**1.45** (1.37,1.52)	**0.073** (0.05,0.09)	--	--	--	--			

Table 8. Model selection details of the relationship between the three steppe bird species (Little bustard, Stone-curlew and Calandra lark) and the principal components extracted from the vegetation structure variables (PCveg´s) with trophic resources variables as interaction. Only models which Δi < 2 are showed. The AIC, delta weight and the model selection probability (W_i) are listed; the selection probabilities are also summed for each parameter across all models across 95% confidence for the data set by summing all the W_i scores for all models in which the predictor was included; the parameter estimates (β) presented are the averages across all models (weighted by selection probabilities); the models represent 95% confidence for the data set.

Vegetation structure (PCveg´s) * Trophic resources variables

Variable	Model selected				AICc	Δi	W_i
Little bustard	**PCveg5 x Leaf I.**				458.01	0.00	0.58
	Intercept	PCveg5	Leaf I.	PCveg5 x Leaf I.			
β (CI)	**0.71** (0.64,0.78)	--	**-0.19** (-0.23,-0.15)	**0.18** (0.13,0.22)			
Stone-curlew	**PCveg5 x Leaf I.**				450.24	0.00	0.94
	Intercept	PCveg5	Leaf I.	PCveg5 x Leaf I.			
β (CI)	**1.67** (1.6,1.72)	**0.49** (0.44,0.55)	**-0.71** (-0.75,-0.66)	**--**			
Calandra lark	**PCveg1 x Insects I.**				1087.53	0.00	0.99
	Intercept	PCveg1	Insects I.	PCveg1 x Insects I.			
β (CI)	**1.75** (1.72,1.78)	**0.08** (0.05,0.1)	**0.04** (0.02,0.04)	--			

Table 9. Model selection details of the relationship between the three steppe bird species (Little bustard, Stone-curlew and Calandra lark) and the principal components extracted from the habitat structure variables (PChab´s). Only models which $\Delta i < 2$ are showed. The AIC, delta weight and the model selection probability (W_i) are listed; the selection probabilities are also summed for each parameter across all models across 95% confidence for the data set by summing all the W_i scores for all models in which the predictor was included; the parameter estimates (β) presented are the averages across all models (weighted by selection probabilities); the models represent 95% confidence for the data set.

Habitat structure variables (PChab´s)

Variable	**Intercept**	**PChab1**	**PChab2**	**PChab3**	**PChab4**	AICc	Δi	W_i
Total species	X	X	X	X	X	2170.45	0.00	1.00
β (CI)	**1.97** (1.91,2.02)	**-0.12** (-0.13,-0.1)	**--**	**-0.29** (-0.3,-0.26)	**0.28** (0.25,0.3)			
Little bustard	X			X		459.64	0.00	0.36
	X			X	X	461.18	1.54	0.16
	X		X	X		461.52	1.88	0.14
	X	X		X		461.54	1.91	0.13
β (CI)	**0.52** (0.47,0.56)	--	--	**-0.23** (-0.27,-0.19)				
Stone-curlew	X	X	X	X	X	449.37	0.00	0.80
β (CI)	**0.51** (0.46,0.55)	--	**--**	**-0.31** (-0.34,-0.27)	**0.24** (0.2,0.28)			
Calandra lark	X	X	X	X		1053.56	0.00	0.64
β (CI)	**1.11** (1.02,1.18)	**-0.09** (-0.12,-0.07)	**0.05** (0.03,0.07)	**-0.17** (-0.2,-0.13)				

4. Discussion

The results presented here support the predictions made in the previous study based on bibliographic data. Furthermore, considering the surrounding habitat preferences (configuration and composition) allows for the development of more detailed ideas in order to improve conservation actions.

Little bustard is a sexually dimorphic species during mating time (Morales et al., 2008). Microhabitat selection of Little bustard females is guided by the need of shelter, finding well protected areas to place their nests, and the need for food; thus selection is positively related to vegetation density (Morales et al., 2008). By contrast, males are associated with highly conspicuous points, with no or very little vegetation cover, to make their sexual display at leks (Jiguet 2002; Traba et al., 2008). Our results associate a major abundance of Little bustards to this open vegetation structure, and because of the secretive behavior of females linked with their difficulty for detection (Mcmahon et al., 2010), we can assume that the majority of the individuals detected were males; and typical lek areas are being selected. These sparse vegetation habitats were also related to green weed availability, the major component of the adult Little bustard diet (Jiguet 2002).

According to our results, tillage is the main field practices that promote this habitat type; for instance, the degree of disturbance has an important role in assembling plant communities (Armengot et al., 2016; Hernández-Plaza et al., 2015). Soil tillage leads to an increase of niche availability, promoting the colonization of species with ruderal traits, which increase their fitness in disturbed environments (Gaba et al., 2013; Storkey et al., 2013). Ruderal communities are characterized by: high proportions of annual species with high specific leaf area (SLA), which is in turn directly related to the leaf palatability responsible for determining the assimilation value of the leaves by herbivores (Storkey et al., 2013; Weiher et al., 1999), a short life cycle, early flowering and small seeds (Albrecht and Auerswald 2009). These characteristics aid in increasing seed supply in the system, and thus their availability as a food resource. In contrast, other managing practices such as grazing, shredding or spraying herbicide favor the presence of perennial and biennial species (phanerophytes, chamephytes or hemicryptophytes) because of their selectivity action. These life forms are linked with a competitive behavior, associated with a high seed mass and lower SLA

(Storkey et al., 2013). Although perennial plants provide greater continuity of seed resources by overlapping blooming periods during the year (Isaacs et al., 2009), here we are assessing a specific period within this system: breeding time. Accordingly, the seed availability index is weighted to highlight the species in flower during the regional AES period (where management practices are prohibited from the 15th of April to the 1st of September), coinciding with the time of flowering/fructification of the majority of annual species, and so we assume that ruderal communities are able to provide a higher quantity of forage (seeds and leaves) than other competitive communities during spring-summer time. Moreover, polycarpy, highlighted as a characteristic trait of ruderal species, allows the plants to flower and produce several seed sets during their lifetime (Storkey et al., 2013). It must be taken into account, however, that regulating the timing of agricultural labor is key to adequately modifying vegetation structure. This fact was reflected in our previous study, where early treatments (applied in February) provided richer foraging habitat during breeding period than later ones (April) (Fig. 2).

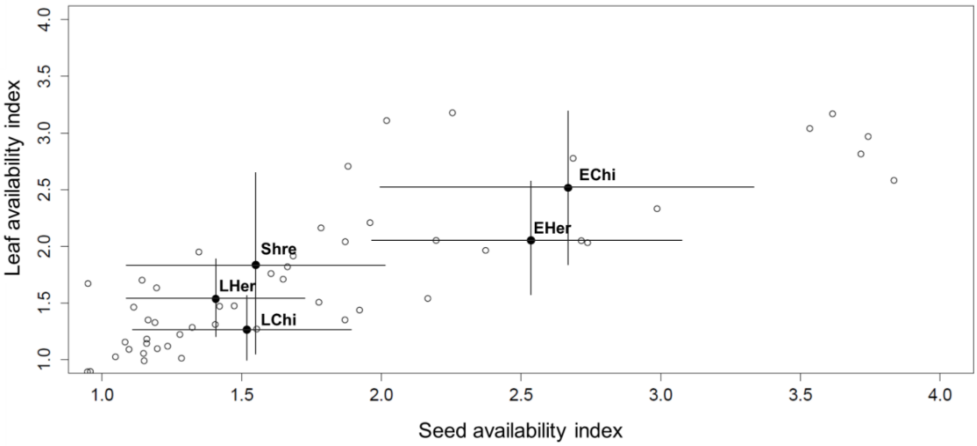

Figure 2. Result obtained in the previous study showing the average (and the 95% confidence interval) of leaf and seed availability indexes per field management (black dots). Sample sites are marked with white dots.

By comparing predicted range-values of vegetation structure to the ones got from bibliography is shown the bias on microhabitat selection is due to the differential sexual behaviour of Little bustard (Fig. 3). The range established by other studies depicted a clear difference between the optimum habitat for males vs females, and also differentiated between field practices. As we have shown in our results, tillage was linked with a sparse habitat where males are able to make their sexual display, and denser vegetation structures were associated with herbicide and shredding treatments, a preferred habitat for females.

Our results indicate that Stone-curlew is favored by similar microhabitats as Little bustard males, characterized by sparse vegetation and bare ground areas (Green et al., 2000). Flat terrains and stone coverage are the preference of Stone-curlew, as plants might constitute an obstacle in detecting and escaping from predation risk (Butler and Gillings 2004; Mcmahon et al., 2010). However, these species differ from one another in the trophic resources required. While Little bustard is an herbivorous species and only chicks and juveniles feed exclusively on invertebrates (Green et al., 2000), the diet of the Stone-curlew is based on little mammals, mollusks, earthworms and mainly arthropods (Green at al., 2000; Traba et al., 2013). These slightly dietary differences may facilitate their coexistence and avoid competition in environments where resources are scarce. Previous studies have found a strong positive correlation between vegetation volume (height and cover) and invertebrate biomass (Hoste-Danyłow et al., 2010; Stoate et al., 2009; Tscharntke et al., 2002) as opposed to the areas selected by Stone-curlew in our models. The outstanding elusive and nocturnal habits reported by other researchers (Traba et al., 2013) is associated with their feed patterns. Stone-curlew frequently makes foraging expeditions to higher density areas in order to profit off concentrations of insect prey (Green et al., 2000). This habitat selection is backed by the range previously established by literature (Fig. 3) and again, related with tillage treatments. Nevertheless, it is possible that they might have a wider habitat range due to that their feeding needs are linked with having enough vegetation (Traba et al., 2013), but are difficult to detect because of their nocturnal behavior.

In contrast to the previous species, the abundance of the Calandra lark increased with the height and cover of vegetation, as reported previously in other studies (Morgado et al., 2010; Sanza et al., 2012) (Fig. 3). This specie flies over the fields instead of hiding in vegetation to avoid predators (Mcmahon et al., 2010). For this reason, they are able to stay around high density fields and just land to eat when they are out of danger. Shredding and herbicide application treatments are also related to denser vegetation and among the practices linked with suitable habitat range for Calandra lark in the foregoing study. These findings are in agreement with results from our previous study.

Although local vegetation structure strongly influences habitat suitability, areas adjoining fallow fields have also an important role in determining the abundance of steppe birds. The reduction in habitat complexity has been linked to the declines in farmland biodiversity (Benton et al., 2003; Donald et al., 2001). A complex landscape with a high percentage of natural and semi-natural habitats and field boundaries appear to function as refuge for intensive agriculture practices for mammals (Smith et al., 2005), plants (Solé-Senan et al., 2014) or invertebrates (Asteraki et al., 2004), however, the contrasting response shown in our results are related to the habitat specialization character of this group of birds with most restrictive niche requirements. Landscapes with large fields and fewer margins have been reported to positively influence steppe bird abundance. These species are highly sensitive to habitat fragmentation, probably due to the connection between an increment of field edges and increased predation risks. Furthermore, they have a propensity to avoid tall structures and woody vegetation borders, requiring large open fields with clear views (Morgado et al., 2010; Vickery and Arlettaz 2012). Ground-nester species suffer higher predation in or close to field margins because predator density is often higher in edges and used as corridors to move around (Hamer et al., 2006; Vickery and Arlettaz 2012), therefore large and homogeneous patches allow steppe birds to exploit resources with unobstructed views, which aids in predator detection and a lower risk.

More frequent field use or higher crop diversity is closely related with the increase of edges, which can explain its negative influence on bird abundance. Farmland birds do however seem to use multiple habitat patches within the landscape mosaic, requiring fewer vertical boundaries structures within the area (Gil-Tena et al., 2015; Hamer et al., 2006). Evidence of this fact is shown in the results for Calandra lark, where their abundance is favored by expansive areas of non-cropped land or suitable habitats in the surrounding landscape.

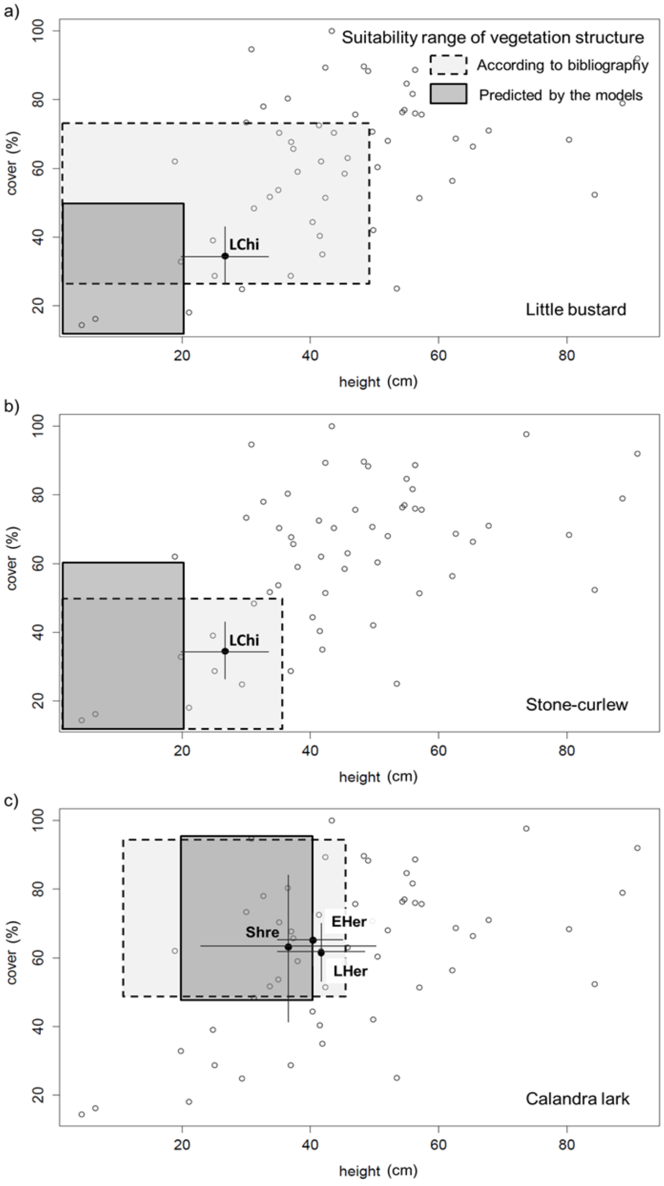

Figure 3. Comparison between the suitable range of vegetation structure obtained from bibliography (dashed square) and the one predicted by the models (continuous square) for Little bustard, Stone-curlew and Calandra lark. Average (and the 95% confidence interval) of vegetation coverage and plant height experimentally obtained per field treatment overlapping the suitable range is also shown (Lchi: late chisel (tillage); EHer: early herbicide; LHer: late herbicide; Shre: shredding).

4.1 Conservation implications

The results of this study reinforce the idea that steppe bird species show different preferences for local field characteristics during breeding time (Cardador et al., 2014; Concepción and Díaz 2011), revealing the importance of considering microhabitats before planning management strategies.

Determining field practices that provide a suitable habitat for birds regarding good vegetation structure and food resources is key for efficient fallow management. Possessing an understanding of how plant communities respond to abiotic factors is therefore necessary to modify the potential contribution of an area for the establishment of bird species. Here we identify that sparse vegetation areas derived from tillage management programs are linked with ruderal plant species, which supply ample green material and provide for ground availability of seeds. Furthermore, these areas of good detectability are preferred during the sexual display, as for Little bustard males, or to camouflage from predators, in the case of Stone-curlew. A denser or more irregular vegetation, consequence of shredding, herbicide, grazing or sowing, is often required for shelter and foraging –mainly invertebrates-, and has been directly related with the needs of Little bustard females, Calandra lark and Stone-curlew (during the night). Management timing must also be taken into account since it has been shown to strongly influence the plant community assembly. By knowing these effects, we are not only able to improve the habitat for the priority species, but also provide benefits to other non-target species that share similar microhabitat conditions or functional groups (such as herbivorous, granivorous, insectivorous, etc.).

Despite these local-habitat differences, all the species studied showed common habitat structure preferences, such as landscapes composed of big fields and homogeneous areas. Therefore, the identification of suitable areas which can potentially contribute to enhancing the species population viability at landscape scale must be required before developing appropriate management practices for a selected fallow field.

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Chapter 5

Spatial distribution of vegetation modifies the suitability of farmland birds' habitat in fallow lands

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This chapter has been submitted to Annals of Applied Biology

Spatial distribution of vegetation modifies the suitability of farmland birds' habitat in fallow lands

Summary

Fallow fields have been proposed as one of the main agri-environmental schemes to support the conservation of farmland biodiversity. However, little is known about the effect of common management practices on the vegetation configuration which is responsible for determining the establishment of steppe bird species, a group considered to be a good indicator of overall farmland diversity. Understanding the spatial distribution variability of weeds may be important for addressing effect(s) that the management practices have on vegetation structure and food availability, the two major factors determining bird-habitat selection. In this study, we compared two management techniques (herbicide application and shredding) in adjacent fallow fields for three agronomic seasons. 150 samples were taken from 50 m × 150 m grids in each field every May. Despite the common trend highlighted by an increase in coverage and a decrease in height for both techniques, herbicide treatment promoted a heterogeneous scenario because of its selectivity and efficacy for different plant species. This type of diverse habitat configuration is known to be suitable as shelter, foraging and nesting areas for farmland birds. The optimal structure-threshold was exceeded in the shredded fallow field compared to the herbicide treated one. Plant resources (leaves and seeds) that did not show variations, as well as insect availability, was related with taller vegetation, though birds exhibited preference for habitats with shorter plants. The most important role of vegetation structure is therefore as a primary filter for bird establishment, rather than providing a habitat with available trophic resources. Knowledge of the impacts of fallow vegetation distribution is important for enhancing the effectiveness of management plans, and improving the viability of bird species populations. To avoid plant encroachment with time, it is proposed that fallow should be maintained under the same management regime for a maximum of three years.

Keywords: Agri-environmental schemes; Fallow; Habitat suitability; Field management; Steppe birds; Weed distribution.

1. Introduction

Intensification of crop production in recent decades has lead to a decline of biodiversity in arable habitats (Storkey and Westbury, 2007), with detrimental effects on arable plants, pollinators and/or farmland birds (Marshall et al., 2003). One of the main interests of the European Union is to develop productive agricultural-management methods which aim to sustainably manage biodiversity through programs such as agri-environmental schemes (AES) (EEA 2004; Kleijn et al., 2006).

Some organisms are thought to be good indicators of overall farmland diversity because they belong to groups of species with high ecosystemic relevancy (Pocock et al., 2012). Farmland birds, for example, represent a group which is highly vulnerable to the effects of agricultural change. Their narrower niche requirements make them suitable indicators to be evaluated for management effects on wildlife diversity in arable fields (Butler et al., 2007; Stoate et al., 2001). A number of arable plant species are also considered “key species”, the loss of which indicates major changes in the agri-ecosystem. Besides being of intrinsic value, they have also been shown to assume an important ecological function as a resource for higher trophic groups (Albrecht 2003; Gerowitt et al., 2003). The decline of abundance and diversity of arable plants is associated with a reduction in farmland birds (Storkey and Westbury, 2007). This relationship is largely dictated by the availability of the most important resources, which directly influence farmland bird species' distribution; quantified as their nesting site and foraging habitat (Cardador et al., 2014; Delgado et al., 2009).

The arable plant communities resulting from the different management strategies differ markedly in their community composition and structure, influencing bird habitat choice (Bracken and Bolger, 2006; Firbanck et al., 2003; Storkey and Westbury 2007). It has special interest in temporary non-crop habitat patches such as fallow lands, a measure that incentives the enhancement of farmland biodiversity by satisfying a set of wildlife requirements (Huusela-Veistola et al., 2011).

Within this agroecosystem scenario, land abandonment constitutes a serious threat for many species because the lack of regular disturbances promotes habitats dominated by perennials and shrub expansion, which lead to the loss of farming habitat and a homogenization of the surface flora (Firbank et al., 2003; Hyvönen et al., 2011). Low-intensity management is required to achieve an optimum environment where vegetation structure and foraging areas will constitute a suitable habitat for farmland birds (Whittingham et al., 2006). However, plants are distributed unevenly within fields and the effect of a certain management technique is not expected to be homogeneous from one site to another (Izquierdo et al., 2009). The resulting vegetation structure influences bird habitat choice for breeding success and anti-predator behavior. Also, it affects energy gain (foraging), as seeds, invertebrates and leaves are the main food resources for steppe-birds (Evans et al., 2011; Delgado and Moreira 2000). Many studies report that high vegetation densities are often negatively correlated with bird selection (Benton 2003; Hoste-Danyłow 2010; Vickery 2001). As the Iberian Peninsula is home to a large proportion of Europe´s endangered birds (Delgado et al., 2000), several studies have focused on identifying their optimum habitat patterns (Cardador et al., 2014; Martín et al., 2010; McMahon et al., 2010; Morgado et al., 2010; Serrano and Astrain 2005; Silva et al., 2013; Traba et al., 2008).

It is known that management practices are modulating vegetation assembly in space and time on fallows, and consequently, the habitat's suitability for farmland birds (Mcmahon et al., 2010; Whittingham et al., 2006). Due to the lack of knowledge regarding the most suited management techniques in the context of bird conservation, here we aim to compare two of the most commonly utilized techniques on fallow lands: shredding and spraying with herbicide.

Owing to the fact that community structure is scale-related (Podani 2006), we aim to 1) quantify space-time changes in structure and food provided by the vegetation across two large fallow areas monitored during three years and comparing mechanical vs. chemical treatment; 2) differentiate optimum and unsuitable areas for farmland birds by setting optimal structure thresholds based on birds' habitat requirement information.

2. Material and Methods

The study was conducted at the Catalan Ebro basin (north-eastern Spain, 41° 42’ 24” North and 1° 08’ 93” West) over the course of three growing seasons (2012-2014). The field explored had been fallow for four years and was included in the Natura 2000 European Network due to its establishment as a Special Protection Area (SPA), under the 2009/147/EC Birds Directive. The landscape is predominantly flat and at a low altitude, has a semiarid Mediterranean continental climate and 300–400 mm of annual rainfall. We studied two adjacent 50 x 150 m plots (a total of 1.5 ha). Different treatments were implemented on each surface: either shredding or an herbicide spray (glyphosate at 1.5 l/ha dose), both applied in late winter/early spring. At the end of each agronomic season (October), the vegetation was cut in order to remove excess organic matter though maintaining the cumulative effect of the previous treatments. Sampling was performed in a 10 × 10 m^2 grid pattern, resulting in 150 sample units.

In each sample unit, vegetation structure (cover and height) was measured. Coverage of each species was visually estimated as a percentage of a surface area of 0.25 m^2. Vegetation height was obtained by averaging five measures of maximum height taken in each quadrant. Samples were taken once per year, at approximately the same time that AES are implemented (May-June), and sampling points were geo-referenced. The homogeneity in species composition and vegetation structure of the experimental fallow field was confirmed before any treatment was done in the first year of the experiment (data not shown). In 2012, the vegetation height and dead matter cover area were not taken into account, and as a consequence, we only represent 2013 and 2014 data for the structure analysis.

According to previous studies (Cardador et al., 2014; Martín et al., 2010; McMahon et al., 2010; Morgado et al., 2009; Serrano and Astrain 2005; Silva et al., 2013; Traba et al., 2008), we are able to determine a suitable habitat range regarding habitat structure requirements for the most vulnerable bird species present in our region, such as: Little bustard (*Tetrax tetrax*), Stone-curlew (*Burhinus oedicnemus*), Short-toed lark (*Calandrella brachydactyla*), Calandra lark (*Melanocorypha calandra*), Pin-tailed sandgrouse (*Pterocles alchata*) and Black-bellied sandgrouse (*Pterocles orientalis*). All are ground-nesting species, depending primarily on fallow land for breeding.

A maximum of 50% cover and 50 cm height fit into the optimal range of the selected species. This suitability threshold was applied for each field treatment and year to estimate the real useable area for birds.

2.1. Trophic availability information

2.1.1. Seed and leaf availability indexes

Following the criteria developed in Chapter 3 of this thsesis, trophic indexes were calculated using functional trait information (de Bolòs et al., 1993; Kattge et al., 2011; Klotz et al., 2002; Royal Botanic Gardens Kew, 2014) and field data. The leaf availability index was estimated as: [coverage x height x SLA (specific leaf area, $mm^2 mg^{-1}$)]. Leaf availability was quantified for each species as: [the product of its coverage x seed mass (the average individual weight of 1000 seeds)], weighted by the flowering period (months in bloom during the AES regional restriction, which is from April 15th to September 1st).

2.1.2. Invertebrate sampling

Pitfall trapping were used to sample ground dwelling arthropods in order to measure bird food availability. Although pitfall traps only capture a small proportion of the invertebrate fauna, previous studies have shown that are sufficient to catch the preys most frequently eaten by steppe birds **(Green et al. 2000; Traba et al. 2008)**. Five traps were set along each fallow plot of 50 m by 150 m, ensuring proper reflection of the plots' features. The traps were exposed for six days in May to relate insect availability with vegetation structure and plant trophic indexes (seeds and leaves). Traps were filled with a mixture of propylene glycol (antifreeze) and water, and were active for seven days. The invertebrates were then collected and kept in 70% alcohol until taxonomic determination in the laboratory (to Order), after which they were classified by size into three groups: >1.5 cm (group 1), 1.5 cm – 5 mm (group 2), <5 mm (group 3). This process was performed in May of 2013 and 2014.

2.2. Statistical analysis

A geostatistical semivariance analysis was used to examine the spatial heterogeneity pattern and spatial distribution of plant cover, height and trophic indexes. Spherical, exponential, and gaussian models were applied for fitting the semivariance data by using the GS+ software program, version 5.0 (Robertson 2000). Model parameters were then used in kriging to provide estimates of the variables at a non-sampled location (Table 1).

To examine the spatio-temporal stability of each variable analyzed, the Cramér-von Mises test developed by Syrjala (1996) was used to test the null hypothesis that the same variable has similar distribution. We compared the spatial pattern of site occurrence between pair of years and treatments within the same year. The analysis was performed in R (R Development Core Team 2011), using the R package "ecespa" (De la Cruz 2008). From the fitted semivariance data, the "area exceeding the suitable habitat threshold for birds" was calculated using the "simulation" function of the GS+ program. Areas with more than both 50% of cover and 50 cm height were labelled as "unfavorable habitats". The new maps obtained by simulation were used to estimate the percentage of land surface area that would exceed the defined threshold with 90% probability. Calculations were made by the Map Comparison kit (MCK) software (Visser and de Nijs 2006).

Relative differences between variables' values (cover, height and trophic indexes) were performed to get a new representation showing areas of increase or decrease over years and between treatments. The percentage of increase was also calculated by the MCK software.

3. Results and Discussion

Maps of vegetation height showed a decrease from 2013 to 2014 in both treatments, while coverage increased (Fig. 1A and 1B). Nevertheless, the values in the field treated with herbicide were always lower than those subjected to the shredding treatment.

In 2013, the shredded field was dominated by the *Poaceae* family, with *Hordeum murinum* as one of the main species (Table 2). In the following year, *H. murinum* remained just as abundant, but the vegetation composition changed and species from the *Asteraceae* family (*Lactuca serriola, Crepis vesicaria*) and *Galium parisiens* stood out. These species are opportunistic rosette and prostrate hemicryptophytes adapted to the shredding disturbance and frequently present in areas without mechanical soil disturbance (direct drilling) (Royo-Esnal et al., 2011). On the herbicide treated field, species from the *Poaceae* (*Lolium rigidum*) and *Asteraceae* (*Silybum marianum* and *Sonchus oleraceous*) families dominated in 2013, while in 2014 there was a clear predominance of the *Chenopodiaceae* family, represented by *Salsola kali*.

Table 1. Semivariogram model parameters as determined in GS+. Range - the separation distance over which spatial dependence is apparent; Nugget - the y-intercept of the model; Sill - the model asymptote; RSS - Residual Sums of Squares; R^2 - coefficient of determination; C/(Co+C) - spatial dependence.

				Semivariogram parameters					
Variable	Year	Treatment	Fitted Model	Range	Nugget	Sill	RSS	R^2	C/(Co+C)
Height	2013	Herbicide	Exponential	20.4	114.4	374.8	801	0.62	0.69
		Shredding	Spherical	53.3	109	218	655	0.91	0.50
	2014	Herbicide	Exponential	48.3	27.6	54.6	189	0.46	0.49
		Shredding	Gaussian	18.8	32.5	113	663	0.85	0.71
Coverage	2013	Herbicide	Exponential	26.8	221.3	363.6	5301	0.28	0.39
		Shredding	Exponential	38.7	274.1	548.3	4049	0.52	0.50
	2014	Herbicide	Spherical	46.2	176.7	722.6	2127	0.95	0.78
		Shredding	Exponential	676	84.6	200	320	0.75	0.57
Herbivory Index	2013	Herbicide	Exponential	176	0.67	1.34	0.96	0.56	0.50
		Shredding	Exponential	28.2	0.19	1.07	0.02	0.80	0.81
	2014	Herbicide	Exponential	29.4	0.37	1.46	0.18	0.55	0.74
		Shredding	Spherical	13.1	0.53	1.50	0.46	0.30	0.64
Granivory Index	2013	Herbicide	Exponential	32	0.75	1.66	0.11	0.46	0.55
		Shredding	Exponential	25.2	0.37	0.94	0.10	0.39	0.58
	2014	Herbicide	Exponential	15.6	0.36	1.42	0.08	0.27	0.74
		Shredding	Exponential	13.2	1.17	1.58	0.24	0.01	0.26

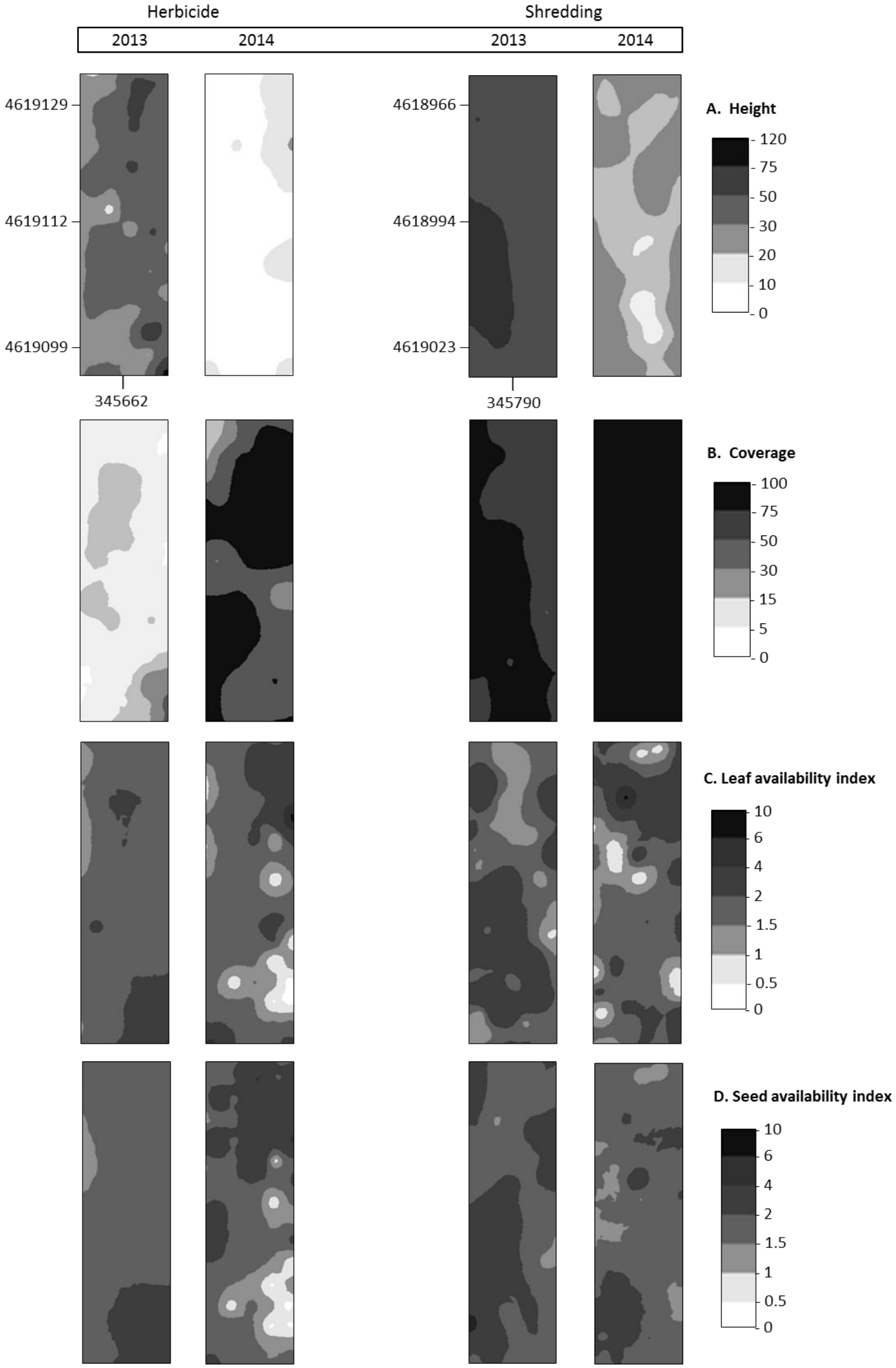

Figure 1. Kriged maps of vegetation for height (cm), coverage (%), leaf availability index and seed availability index in 2013 and 2014. Values increase from white to black colours.

Table 2. Most frequent plant species of the weed community and their relative abundance (%) for each year and treatment.

Shredding 2013		Shredding 2014	
Hordeum murinum	36.5	*Lactuca serriola*	17
Lolium rigidum	14	*Hordeum murinum*	15
Bromus madritensis	13	*Galium parisiense*	14
Bromus rubens	11	*Crepis vesicaria*	12.5
		Leontodon taraxacoides	10.5
Herbicide 2013		Herbicide 2014	
Lolium rigidum	39	*Salsola kali*	66.5
Silybum marianum	12.5	*Sonchus oleraceous*	10
Sonchus oleraceous	10	*Lactuca serriola*	9

Table 3. Monthly total rainfall and mean temperature for the growing periods in north-eastern Spain in two consecutive seasons (from September to May).

Month - Year	Rainfall (mm)	Trimestral (mm)	Temperature (ºC)	Trimestral (ºC)
September 2012	33.6	-	19.7	-
October 2012	78.3	-	15.4	-
November 2012	38	149.9	9.5	14.9
December 2012	4.2	-	6.0	-
January 2013	36.6	-	4.7	-
February 2013	13.2	54	5.3	5.3
March 2013	52.7	-	9.2	-
April 2013	76.5	-	11.5	-
May 2013	45.1	174.3	12.9	11.2
September 2013	3.1	-	19.3	-
October 2013	13.2	-	16.4	-
November 2013	85	101.3	8.5	14.8
December 2013	10.8	-	3.5	-
January 2014	61.9	-	6.7	-
February 2014	24.9	97.6	6.7	5.7
March 2014	6.7	-	9.6	-
April 2014	73.3	-	14.0	-
May 2014	14.9	94.9	15.5	13.0

Source: Servei Meteorològic de Catalunya.

The inter-annual difference of species composition was an expected effect derived from the weather differences. Total rainfall from September 2012 to May 2013 was more abundant than during the same period the following season (378mm > 294mm) (Table 3), with significant differences in rainfall distribution throughout the season: winter 2013 was drier than in 2014 (a total rainfall from December to February of 54 mm in 2013, and 98 mm in 2014). Moreover, the mean annual temperature in 2014 was 2°C and 1.4°C higher in January and February, respectively, while the temperature in April and May was approximately 2.5°C higher in 2014 than in 2013. These conditions (a milder, wetter winter and hotter, drier spring) might have provoked the earlier development of grass species in 2014, compared to the same dates in 2013. Rainfall and temperature differences result in vegetation cover and height variation (De Juana and García, 2005). At the sampling dates, we did not identify dead species and their abundance when we measured total coverage and height. As a consequence, in 2014 less drought-sensitive species were found at the sampling dates. Shredded fields were characterized by graminoid forms, undetected in 2014 as dominant but equally present, and uniform in coverage. In the case of the fallow field treated with herbicide, we found a different scenario characterized by unequal plant growth. The post-treatment weed communities result from their inherently different (and heightened) tolerance to the herbicide (Gaba et al., 2013). This treatment also favored species with extended germination periods (after the application date), or germination of seeds dispersed from plants in the surrounding areas. An alternation of uniform short vegetation cover was later observed to be primarily graminoids like *Lolium rigidum* intermixed with biennial shrub species such as *Silybum marianum* or fast growing therophytes, such as *Salsola kali*. As *L. rigidum* is well controlled by glyphosate, its unexpected domination in 2013 could be partially explained by the high density of this species the year before, which might have prevented a good wettability of the herbicide, hence affecting its effectiveness (García et al., 2014). *S. kali* is typically a spring-summer germinating species favored by warm weather in Mediterranean climates (Borger et al., 2009), that became dominant in 2014. It was also present in 2013, but masked by other species which were found dead in 2014 because they had already completed their life cycle. These characteristics turned the herbicide treated field into a heterogeneous mosaic.

Table 4. Differences between the spatial distributions of vegetation height, coverage and trophic indexes using the Cramer-von Mises type test (Ψ, Syrjala, 1996) and percentage of structural variable increments in 2013 and 2014. Ns: non-significant; * P < 0.05; ** P<0.001. In parenthesis: the percentage of increase.

		Along years		Between managements
		2013	2014	2013-2014
Height	Herbicide	-	-	Ψ= 12.7** (1 %)
	Shredding	-	-	Ψ= 5.2** (18 %)
	Herbicide-Shredding	Ψ= 3.6** (100 %)	Ψ= 20.8** (100 %)	-
Coverage	Herbicide	-	-	Ψ= 19.2** (99 %)
	Shredding	-	-	Ψ= 7.4** (100 %)
	Herbicide-Shredding	Ψ= 19.8** (100 %)	Ψ= 8.2** (100 %)	-
Leaf ava. Index	Herbicide	-	-	Ψ= ns
	Shredding	-	-	Ψ= ns
	Herbicide-Shredding	Ψ= ns	Ψ= ns	-
Seed ava. Index	Herbicide	-	-	Ψ= ns
	Shredding	-	-	Ψ= ns
	Herbicide-Shredding	Ψ= ns	Ψ= ns	-

The comparison of the distribution function (Table 4) indicated that differences in height and coverage were statistically significant between 2013 and 2014 for the herbicide ($\psi = 12.7$, $P< 0.05$; $\psi = 19.2$, $P< 0.05$, respectively) and shredding treatments ($\psi = 5.2$, $P< 0.05$; $\psi = 7.4$, $P< 0.05$, respectively). As a consequence, the percentage of increase or decrease was measurable. The increase of height values over the years was 1% in the herbicide treated plot and 18% in the shredded one. With respect to the coverage, the increase over time was 99% in the herbicide plot and 100% in the shredded plot. Differences between treatments within a year were statistically significant in all cases and showed a 100% increase in coverage and height values in the shredded plots compared to the herbicide treated ones. However, no statistical differences were found between field treatments tested or over time for any of the trophic indexes (Fig. 1C and 1D; Table 4).

Table 5. Percentage of threshold exceeded for birds´ habitat suitability.

	% of threshold exceeded	
	2013	2014
Height (>50cm)		
Herbicide	0.16	0
Shredding	0.20	0.03
Coverage (>50%)		
Herbicide	0.07	34
Shredding	11	95.5

Birds have varying vegetation structure requirements that determine their establishment because they affect the accessibility and visibility required to make an active nest defense (Benton et al., 2003; Vickery et al., 2001). By setting height and coverage thresholds (>50% of coverage and >50 cm of height) it has been possible to quantify the field area potentially unsuitable for the majority of bird species. Our results showed an opposite trend between these two variables over time (Table 5). Vegetation height decreased, making the area unfit for bird use; from 0.16% to 0% in 2013 and from 0.20% to 0.03% in 2014 for herbicide and shredding treatment, respectively. Coverage showed a greater change leading to an increase of the unsuitable area over time, from 0.07% to 34% in the herbicide treated field and from 11% to 96% in the case of the shredding treatment.

Foraging is also crucial for patching selection, and food availability is similarly influenced by the changes of habitat structure (Cardador et al., 2014; Mcmahon et al., 2010). However, differences in seed and leaf availability were not found. These results suggested that the vegetation changes along succession were providing similar trophic services to farmland birds that the ones before. Spatial architecture of the vegetation is the primary determinant of bird establishment, thus responsible for restricting their potential territory availability (Giralt et al., 2008; Hoste-Danylow et al., 2010; Toivonen et al., 2013). It is the first filter for the birds' habitat selection, and is strongly conditioned by management practices.

Table 6. Number of invertebrates trapped per size group in the fallow treated with herbicide in 2013 and 2014. Mean values±SD.

Herbicide 2013				Herbicide 2014			
Treatment	Taxonomic order	Abundance	Total abundance	Treatment	Taxonomic order	Abundance	Total abundance
Group 1 (>1.5cm)	Arachnida	5 (±1.73)	30 (±3.84)	Group 1 (>1.5cm)	Hymenoptera	1 (±0.5)	1 (±0.5)
	Coleoptera	10 (±2.55)					
	Hymenoptera	15 (±4.06)					
Group 2 (5mm-1.5cm)	Arachnida	13 (±1.14)	9 (±1.54)	Group 2 (5mm-1.5cm)	Arachnida	4 (±1.41)	26.8 (±10.03)
	Coleoptera	11 (±1.92)			Coleoptera	33 (±7.41)	
	Diptera	7 (±1.67)			Diptera	3 (±1.5)	
	Hymenoptera	5 (±1.22)			Hymenoptera	80 (±15.25)	
					Isopoda	14 (±0.45)	
Group 3 (<5mm)	Arachnida	6 (±0.44)	3 (±0.91)	Group 3 (<5mm)	Arachnida	2 (±0.7)	21 (±8.94)
	Coleoptera	6 (±1.64)			Coleoptera	4 (±1.15)	
	Dermaptera	1 (±0.45)			Hymenoptera	57 (±11.35)	
	Hymenoptera	1 (±0.44)					
	Orthoptera	1 (±0.45)					

Table 7. Number of invertebrates trapped per size group in the shredded fallow in 2013 and 2014. Mean values±SD.

Shredding 2013				Shredding 2014			
Treatment	Taxonomic order	Abundance	Total abundance	Treatment	Taxonomic order	Abundance	Total abundance
Group 1 (>1.5cm)	Arachnida	3 (±0.54)	15 (±6.09)	Group 1 (>1.5cm)	Arachnida	4 (±1.3)	4.25 (±1.22)
	Coleoptera	2 (±0.52)			Coleoptera	8 (±1.82)	
	Hymenoptera	40 (±9.08)			Hymenoptera	4 (±0.83)	
					Orthoptera	1 (±0.45)	
Group 2 (5mm-1.5cm)	Arachnida	10 (±1.73)	5.25 (±1.35)	Group 2 (5mm-1.5cm)	Arachnida	19 (±2.49)	26.67 (±8.95)
	Coleoptera	2 (±0.51)			Coleoptera	18 (±2.61)	
	Embioptera	1 (±0.44)			Diptera	1 (±0.45)	
	Hymenoptera	8 (±0.45)			Hemiptera	4 (±1.3)	
					Hymenoptera	107 (±15.6)	
					Isopoda	11 (±0.84)	
Group 3 (<5mm)	Arachnida	7 (±1.52)	3.67 (±1.03)	Group 3 (<5mm)	Arachnida	4 (±0.83)	40 (±11.7)
	Dermaptera	1 (±0.45)			Hymenoptera	110 (±10.37)	
	Orthoptera	3 (±0.54)			Isopoda	6 (±1.79)	

Arachnida, Coleoptera and Hymenoptera were the taxonomic orders of invertebrates most represented in pitfall traps, both for the two different treatments and for the selected size groups (Table 6 and 7). It has been demonstrated that breeding success and chick growth are highly correlated with invertebrate food supplies (Holland et al., 2014; Delgado et al., 2009). Studies highlight Coleoptera, Arachnida and Orthoptera as the preys that mainly influence chick survival (Marshall et al., 2003; Jiguet 2002). The foraging efficiency is also influenced by prey size; the larger the prey, the more profitable (Vickery et al., 2001). Furthermore, many researchers have found a strong positive correlation between vegetation height and invertebrate biomass (Hoste-Danyłow et al., 2010; Tscharntke et al., 2002). This is in accordance with our results, which showed a decrease in larger invertebrates (>1.5 cm) along with a decrease in vegetation height. On the contrary, medium and small invertebrates (5 mm-1.5 cm and <5 mm, respectively) increased in abundance. The large number of medium size individuals (group 2) registered in 2014 was, however, mainly due to ants. The presence of ants and their role as a food supply for birds during breeding has been controversial because the formic acid they produce has toxic effects on birds (Herrera, 1984; Judson and Bennett, 1992).

Birds show a clear preference to foraging in open habitats with short vegetation, which allow them to have better accessibility to insect prey as well as better detection of their predators (Hoste-Danyłow et al., 2010). The higher availability of invertebrates in taller vegetation contrasts with bird habitat structure choice, suggesting that vegetation structure plays a more important role than food abundance. This is in agreement with the main role of vegetation structure on birds' habitat predilection.

3.1 Conclusions

Management practices in fallow lands are key factors in the modification of vegetation structure, thus providing resources for farmland birds, and leading to a more suitable, or unsuitable, habitat. In our study, we tested herbicide application and shredding as the most common field treatments developed in these non-crop areas. Herbicide application in late winter (March) provided a heterogeneous habitat structure, offering good shelter and breeding conditions by combining short vegetation with tall scrubs together with a good foraging habitat. This particular treatment also maintains a larger land area suitable for birds, compared with the shredding treatment. As herbicide spraying can modify the population density and habitat use of birds, it is a controversial scheme that is often contrary to conservation patterns. Fallow lands are frequently considered as conservation-worthy, but even still, belong to agro-systems and hence, are susceptible to be treated as arable lands. However, if herbicide application is done during the birds' breeding off-season, this would provide both improved habitat structure and a reduction of its environmental impact.

In spite of the significant differences between herbicide application and shredding, there was a common trend, irrespective of the treatment, towards higher coverage and structure homogenization, hence worsening the habitat suitability for farmland bird species over time. Furthermore, the observed reduction of the vegetation height was also related with the decrease of large invertebrates, an important resource for birds during their breeding period. Although these changes were not shown in the vegetable trophic resources, the design of conservation management programs requires an understanding of their influence in the short- and mid-term. According to our results, a maximum of three years of fallow under the same management would be the limit for maintaining a suitable habitat for farmland birds. Therefore, the alternation of management practices is proposed, as it could achieve a break in the normal vegetation trend, providing a richer and more appropriate landscape for birds.

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Chapter 6

General discussion and main conclusions

General discussion

The experimental work presented in this thesis achieves a more complete understanding of fallow lands as an important habitat within the agricultural matrix for supporting farmland biodiversity, and to provide vital ecosystem services (Donald et al., 2006; Stoate et al., 2009). Agricultural intensification has been identified as a major cause of wildlife decline across Europe during the last three decades, a process which encompasses a wide range of components including land consolidation, increased mechanization and chemical use or the spread of monocultures, leading to species loss and biotic homogenization (Benton et al., 2003; Ma and Herzon 2014; Tscharntke et al., 2005). The role of fallow lands as an agri-environmental scheme to slow and eventually halt this decline was assessed by focusing on steppe birds as group representative of farmland diversity; mainly because of their strong association with farmland habitats and unfavorable conservation status on a European scale (Benítez-López et al., 2013; Butler et al., 2007). The threats to biodiversity are also affecting the supply of basic wildlife services (Kremen 2005), and as such, the provision of attractive structures for pollinators was also estimated to identify the inherent capacity of fallow lands for providing necessary ecosystem services. Many studies have related landscape complexity/heterogeneity with higher biodiversity in the farmed landscape, whether measured at a small or large scale (Benton et al., 2003; Fahrig et al., 2011). Complex spatial patterns of fields, with different sizes, variable patch arrangements, and longer field borders, is likely to offer shelter from agricultural practices, thus increasing species diversity known as “configurational heterogeneity”, while different cover crops or land uses (i.e. different field crops and semi-natural habitat availability) result in higher landscape complementation and is expected to increase species or species groups, or “compositional heterogeneity” (Gaba et al., 2010; Gabriel et al., 2005; Gámez-Virués et al., 2015; Fahrig et al., 2011). This generalization, however, cannot be assigned to all groups of species.

Steppe birds have a specialized character, and are highly sensitive to habitat fragmentation. They exhibit preference for open landscapes composed of big fields and limited edges that obstruct views for predator detection; especially in the case of ground-nesting species (Morgado et al., 2010; Vickery and Arlettaz 2012) (Chapter 4). Field edges are in fact negative structures for providing valuable plant characteristics that would enhance pollinator numbers in fallow lands (Chapter 2). Although field edges have been reported as an important reservoir of plant species biodiversity (José-María et al., 2010; Solé-Senan et al., 2014), the recurrent disturbances on these habitats leads to a homogenization of the floral community (mainly represented by graminoid-ruderal species) with little attractiveness for pollinators. Nevertheless, the presence of semi-natural habitats around fallow field acts as a source-sink of weed species, increasing their diversity on flower types (Chapter 2). These less disturbed habitats favored the presence of stable plan communities, providing resources for both specialist insect pollinators, and for generalists.. Non-crop habitats and crop patch diversity in the surrounding landscape are also related with the positive response by birds; though the presence of multiple habitat patches is compromised by more edges (Gil-Tena et al., 2015; Hamer et al., 2006) (Chapter 4).

Even though linking multiple scales are required to determine the variation on biological communities and regional scale aggregates environmental heterogeneity, conservation strategies are often implemented at small local sites (Gabriel et al., 2006; Rundlöf et al., 2007). Abiotic disturbances at field scale such as management practices, act as filters selecting for the best plant ecological strategies (Raevel et al., 2012; Duflot et al., 2014), thus allowing for the existence of different microhabitats which strongly determine the value, both for birds by modifying habitat structure and food resources availability, (Butler and Norris 2013; Cardador et al., 2014; Green et al., 2000) and for pollinator insects, by selecting floral syndromes that determine the supply of pollinator resources (Fenster et al., 2004; Poveda et al., 2005). The use of functional traits (morphological, physiological or phenological characteristic of a species) as a means of classification is an effective approach to relate the responses and effects of the environmental changes with the plant community responsible for influencing the relationship between higher trophic levels and ecosystem service availability (Fried et al., 2012; Ma and Herzon 2014). Through this approximation, we are able to understand the functional mechanism that modifies microhabitat suitability and satisfies the requirements of the species in managed fallow lands, in order to improve conservation measures.

Our results reveal the importance of management on fallow habitats for steppe bird populations; especially since the over fertilization with pig slurry in many abandoned areas of the Ebro Valley (Berenguer et al., 2008) is encouraging the overdevelopment of much of the vegetation (Chapter 3). Shrub encroached areas did not fit into the range of habitat suitability for the steppe bird species selected; neither for the habitat ranges obtained from bibliography (Chapter 3) nor for the responses collected from field censuses (Chapter 4). These vegetationdevelopment is also noticeable along the age-gradient succession for pollination interaction (Chapter 2). Early fallow stages, characterized by ruderal species linked with floral characteristics that promote the attraction of generalist pollinators, as well as late stages, are represented by perennial and competitive species which promote the interaction with specialist pollinators, and correspond to functional homogenous phases. Mid-successional communities have the capacity to host a wide range of pollinators based on the coexistence of plant forms and phenologies. This prototypical mid-successional community model can be achieved by imposing intermediate levels of disturbance on the system. Hence, the need for management, together with the proper knowledge of its effects on vegetation configuration and functionality are highlighted here.

Soil tillage promotes the colonization of pioneer ruderal species, increasing their fitness in disturbed areas (Gaba et al., 2013; Sojneková and Chytrý 2015; Storkey et al., 2013), and leading to an open vegetation habitat structure (Chapter 2, 3 and 4). According to literature, the requirements of the Stone-curlew, Short-toed lark, Pin-tailed sandgrouse and Black-bellied sandgrouse are more constrained by sparse vegetation, so late chisel treatment (April) was shown as the most accurate practice for them (Chapter 3). High specific leaf area (SLA) related with the palatability of plants, fast life cycles, and polycarpy (which allows for the production of several seed sets in their lifetime) are among the characteristic of this group of ruderal plant species (Albrech and Auerswald 2009; Storkey et al., 2013) related with food supply availability. The ruderal character of the plant community after tillage treatment is reflected in the dominance of graminoid forms, offering poor habitat quality in terms of attractiveness for pollinators (Ricou et al., 2014) (Chapter 2), but considered to be one of the most important plant families for bird diet (Holland et al., 2006).

According with the validation study (Chapter 4), Little bustard and Stone-curlew showed a positive response towards this habitat type. Little bustard is mainly an herbivorous species and males prefer conspicuous areas for courtship during the breeding period. Females, however, exhibit extremely secretive behavior, selecting protected areas with high vegetation density and good food resources composed mainly of insects, a key source for chick survival (Jiguet 2002; Morales et al., 2008; Traba et al., 2008). The marked sexual dimorphism of the species suggests that the field census results provide more pertinent information for Little bustard males, corroborating previous studies that report on the detection difficulty of females (Mcmahon et al., 2010; Morales et al., 2008). Therefore, the practices selected as suitable for Little bustard according to literature data (shredding and herbicide) (Chapter 3) are describing female preferences during breeding time, while tillage would provide a good structure and foraging habitat (green plant material) for Little bustard males (Chapter 4). The avoidance of plant coverage and the preference for flat and bare-ground areas constitute the habitat available after tillage, like that which is also chosen by the Stone-curlew (Green et al., 2000; Mcmahon et al., 2010) (Chapter 3 and 4). However, their diet preferences of mainly arthropods, together with their crepuscular habits (Green et al., 2000; Traba et al., 2013) suggest that Stone-curlews usually make excursions to denser vegetation areas to feed during the night (Chapter 4).

Alternatively, the selective action of shredding and herbicide spraying favor the presence of perennial or biennial forms (Chapter 2, 3 and 5); reflecting the densest vegetation scenario. However, these management techniques do not modulate the vegetation assembly in the same way. After shredding, species that concentrate their leaves near the ground, such as rosette and prostrate hemicryptophytes, have more likelihood of surviving (Juárez-Escario et al., 2013). Meanwhile, the typical scenario after herbicide application is characterized by unequal plant growth (Chapter 2, 3 and 5). The inherently different tolerance levels to herbicides allows for a diversification of plant structures (Gaba et al.,, 2013). Phanerophytes, chamaephytes and most hemicryptophytes are less harmed, whereas effects on annuals creates contrasting patchy habitats intermixed with perennial-shrub species. The coexistence of various plant forms and phenologies favours the overlapping of flowering periods, allowing for a higher foraging availability of pollinators during the year. The predominance of open entomophilous corolla plant forms occurring in this community also posed a certain attractiveness for pollinators (Chapter 2). This scenario of heterogeneous vegetation would coincide with the suitable mid-disturbance level previously discussed. By contrast, shredded fallow fields showed an equally plant growth, leading to a denser and more homogeneous vegetation structure (Chapter 5). Even still, the dominance of anemophilous corollas, mainly related with graminoid species, and open entomophilous flowers was also highlighted (Chapter 2). It can thus be said that both herbicide and shredding practices lead to a denser vegetation structure, compared with tillage management (Chapter 4).

Several studies have indicated a positive correlation between vegetation volume (height and cover) and invertebrate biomass (Hoste-Danyłow et al., 2010; Stoate et al., 2009; Tscharntke et al., 2002), and this pattern was further confirmed by our results (Chapter 4 and 5). Breeding success and chick growth are highly dependent on the availability of insect supply (Holland et al.,, 2014; Delgado et al.,, 2009), which would explain the choice of these closed areas by Little bustard females during the breeding period and by Stone-curlews for nocturnal expeditions (Chapter 4). Calandra lark also found these areas to be a suitable habitat, as reported by other studies (Morgado et al., 2010; Sanza et al., 2012) (Chapter 3 and 4). Although this specie flies over fields to detect predators, they often avoid areas with more borders, as this reduces visibility and requires more vigilance (Mcmahon et al., 2010; Sanza et al., 2012); behavior reported by the majority of the species within the steppe birds group (Chapter 4).

The use of herbicides in a conservation study often causes controversy because of its negative influence on floristic diversity and the invertebrate community (Boatman et al., 2004; Wilson et al., 1999). Here, we aim to present selectivity patterns following the most common practices conducted within agricultural areas and allowed by the agri-environmental schemes. Although chemical application could presumably be beneficial for some target species, future assessment of its potential damage to insects or wildlife in general is first required.

Forage crops in fallow lands, such as alfalfa, have been described as a pollinator-friendly cover and as a good habitat for steppe birds, particularly for Little Bustard (Bretagnolle et al., 2011; Ponce et al., 2014; Wratten et al., 2012). However, the dry weather conditions after sowing compromised the competitive capacity of alfalfa against other weeds, leading to a habitat with cover and height values above the suitable range of the target bird species (Chapter 3). Also, the very early soil removal caused by sowing (October) favored the germination of graminoid species and reduced the area's attractiveness to potential pollinators (Chapter 2). We can therefore confirm that both management type and disturbance timing are key to modifying the vegetation response, and are what ultimately determine both the fitness of the fallow lands, as well as the provision of ecological functions (Chapter 2 and 3).

Grazing was suggested as an alternative management practice in fallows to avoid accumulation of herbaceous biomass and shrub encroachment, characteristic conditions of non-managed areas (Chapter 3). Other studies have assessed the impacts of grazing on plant community structure, concluding that the selective action of the livestock leads to a patchy distribution and irregular pattern contributing to vegetation heterogeneity on a local scale (Azcárate et al., 2011; Erdós et al., 2011; Lin et al., 2010). This idea is mostly corroborated by our results (Chapter 4). Although the responses of spatial distribution of vegetation are dependent on the grazing pressure, their mode of selectivity promotes the maintenance of open areas, and the development of ruderal species (fast-growing, high SLA, etc.), thus providing a suitable foraging habitat for a wide range of taxa (Erdós et al., 2011; Frenette-Dussault et al., 2012).

Our results highlight that, due to the different microhabitat requirements of the steppe bird species, it is necessary to combine types of management techniques and avoid the over implementation of any particular treatment. Furthermore, habitat homogenization achieved after three years under the same management practice, confirm the importance of taking implementation timing into account (Chapter 5). However, a conservation scheme will never succeed if it only considers the needs of a target group or priority individual species, and does not address the possible problems or difficulties that farmers must face. Although there is economic support via AES to compensate for the yield losses during fallow time, these cereal pseudo-steppe areas are low producing systems and so considering the farmer’s economy is critical to making progress towards maximizing AES efficiency. Providing economic assessment of each agronomic practice is essential to maintaining an environmentally-concerned farming culture with conservative aims (Chapter 3).

The most important contribution of this study was to experimentally unravel the influence of current management practices and landscape features over the assembly of plant communities, which are strongly interlinked with conservationist goals. The relevance of these findings are supported by the intense social debate recently emerged in this region because of the stoppage of irrigation due to the critical status of some steppe bird species. New and effective management plans are therefore required to reverse this situation.

Moreover, a replication of the same study during the post-fledging stage and winter season, critical survival periods for many species, would complement our findings.

Main conclusions

In this thesis, the role of fallow lands as a suitable temporal habitat for steppe birds and insect pollinators has been further confirmed. As the improvement over biodiversity is explained on the basis of the arable weed community, the crucial importance in understanding their biological strategies as a response to disturbances to make valuable predictions of their effect on higher trophic levels is highlighted. These studies allowed us to propose the promotion of more effective conservation measures in fallow lands according to the different target group needs.

- The importance of fallow lands for higher trophic levels in semi-arid regions is contingent upon the effect of different biotic and abiotic factors that modify vegetation structure and functional characteristics of these uncropped areas.
- A high proportion of non-cropped areas in a landscape favor the presence of steppe bird species. Nevertheles, compositional heterogeneity must be linked with big field size.

- Steppe birds often avoid areas with high proportion of field borders because it reduces their visibility and thus increases predation risk. This group of birds shows preference towards landscapes composed of big fields and regular shapes.
- The presence of graminoid species in fallow lands is promoted by the increment of field borders length in the surroundings, a group that impoverishes habitat for pollinators. Alternatively, the presence of valuable plant species is encouraged by a high percentage of seminatural habitats around fallow fields.
- The overdevelopment of vegetation in unmanaged fallows point up the key role of the field practices as a means to achieve a profitable habitat for the conservation target species studied. Timing of management operations is also strongly associated with the phenology and functional characteristics of the future vegetation assembly.
- Utilizing management strategies that lead to mid-successional plant communities is the most optimal for enhancing pollinator interactions. However, steppe birds show a marked variance in microhabitat requirements among species, especially during breeding time.
- The selective action of herbicide application promotes the coexistence of plant species that follow different ecological strategies leading to a heterogeneous vegetation structure which coincides with the preferred mid-successional habitat predicted.
- Both herbicide and shredding practices, generate a medium-dense vegetation habitat related with a high invertebrate biomass. They constitute a suitable habitat for Calandra lark (*Melanocorypha calandra*), Little bustard (*Tetrax tetrax*) females, and are probably used as a forage area by Stone-curlew (*Burhinus oedicnemus*) during the night. Also, herbicide application and shredding are among the cheapest practices, contributing to generate both a cost-effective and conservation-worthy design that could serve as an incentive to farmers.

- Tillage management promotes an open vegetation habitat associated with the homogenous colonization of ruderal plant species. Pin-tailed sandgrouse (*Pterocles alchata*), Black-bellied sandgrouse (*Pterocles orientalis*), Short-toed lark (*Calandrella brachydactyla*), Stone-curlew (*Burhinus oedicnemus*) and Little bustard males (*Tetrax tetrax*) are positively related with these conspicuous areas which provide for good predator detection, seed accessibility and more palatable plant material.
- Alfalfa sown in fallow fields of dry-land areas does not demonstrate effective competition with the weed community and thus does not provide a suitable habitat for the biodiversity conservation targets in these areas.
- A combination of the optimal management practices within the same areas will be ideal for meeting the needs of the different target species. Moreover, alternation of the field treatments after a maximum of three years of the same implementation is recommended to maintain suitable habitat conditions.

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