Ús de l'espai de l'hàbitat en el sisó (*Tetrax tetrax*) durant el període reproductor: aspectes aplicats a la conservació en hàbitats agraris

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Ús de l'espai i de l'hàbitat en el sisó *Tetrax tetrax* durant el període reproductor:

aspectes aplicats a la conservació en hàbitats agraris

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La vida es caprichosa.

Pau, 8 anys.

A en Bryant, en Pau, en Lluc i la Mar

CONTINGUT

INTRODUCCIÓ GENERAL

Extincions: pèrdues contínues, noves causes

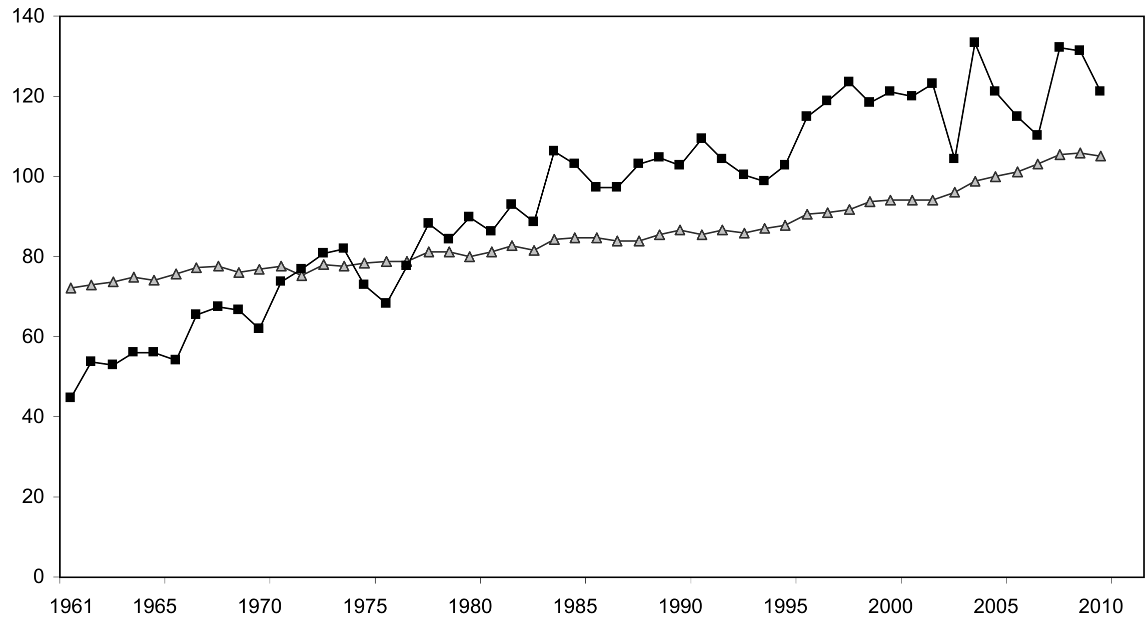
Des de l'explosió càmbrica, el procés d'especiació ha estat interromput per cinc grans episodis d'extincions massives, cadascun d'ells seguit per una recuperació gradual al llarg de milions d'anys de la diversitat d'espècies (Benton i Twitchett, 2003). Actualment les taxes d'extinció són majors que en el passat i representen una pèrdua de biodiversitat sense precedents, de manera que ens trobem en el sisè gran episodi d'extincions massives (Primack, 2004; IUCN, 2012). A diferència dels anteriors, originats per fenòmens naturals de gran impacte com ara erupcions volcàniques o col·lisions amb asteroides o altres canvis més graduals d'origen natural (Primack, 2004), el present episodi deriva de l'activitat humana (Leakey i Lewin 1996). Els principals impactes d'origen antròpic que han propiciat la pèrdua de biodiversitat són la destrucció, fragmentació i degradació de l'hàbitat, la contaminació, el canvi climàtic, la sobreexplotació de les espècies per a l'ús humà, la invasió d'espècies exòtiques i els efectes combinats entre tots aquests factors (Primack, 2004). La major destrucció de comunitats biològiques s'ha donat en els darrers 150 anys, coincidint amb el període d'explosió demogràfica de la població humana que ha suposat un increment sense precedents de l'ús dels recursos (Primack, 2004). De cara al futur, es preveu que la població humana mundial continuï creixent, i que les taxes d'extinció d'espècies continuïn essent elevades (Sala et al., 2000; Butchart et al., 2010).

Els ecosistemes agrícoles i la biodiversitat, una relació canviant

La primera alteració del paisatge a gran escala per causes antròpiques va tenir lloc en el Neolític, ara fa uns 7000 anys, amb l'aparició de l'agricultura. Els hàbitats primaris van ser transformats de forma progressiva en espais oberts propis dels primers estadis de la successió natural, com ara pastures, cultius i matollars, la qual cosa va suposar l'aparició d'un nou hàbitat: els ecosistemes agrícoles (Sutherland, 2004). Espècies d'ocells originàries d'ambients oberts van anar ocupant gradualment aquells ecosistemes agrícoles més similars als ambients originals. Per exemple, els ocells esteparis o pseudoesteparis van anar ocupant les planes cerealístiques amb un recobriment vegetal dominat per herbes o mates baixes (De Juana, 2005). Al llarg del temps, els ambients agrícoles es van anar expandint i van anar conformant un mosaic de cultius, pastures i bosquines (Campbell i Ortíz, 2011). Gràcies a aquesta heterogeneïtat, els paisatges agrícoles tradicionalment s'han caracteritzat per presentar una alta biodiversitat (Benton et al., 2003; Kleijn et al., 2006).

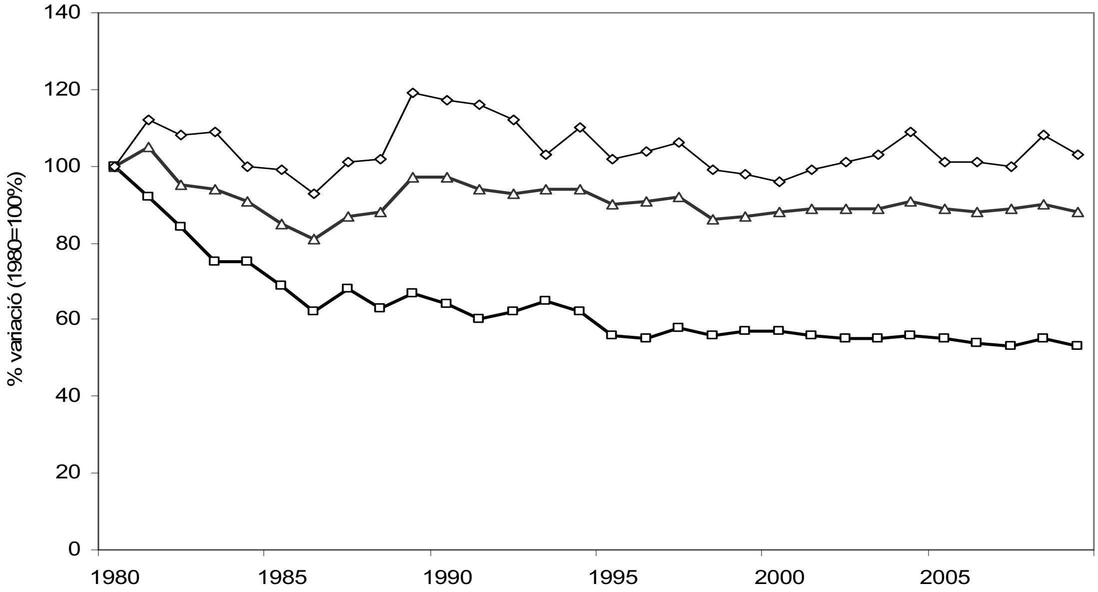
A partir de la segona meitat del segle XX, s'altera l'agricultura tradicional amb la introducció de noves pràctiques implementades amb l'objectiu d'augmentar la producció agrícola. Aquest procés rep el nom d'intensificació agrícola i es pot definir com l'efecte conjunt de l'increment d'aportació d'energia i matèria als cultius que té l'objectiu d'augmentar el rendiment de les collites (matèria produïda per superfície i any) (Suárez et al., 2009). La intensificació agrícola és un fenomen complex que engloba diversos processos que solen donar-se simultàniament, com l'ús generalitzat de productes químics, mecanització, transformació dels usos del sòl, canvis en la data de sembra i de collita, homogeneïtzació del paisatge i pèrdua d'hàbitats naturals (Stoate et al., 2001; Vickery et al., 2001; Robinson i Sutherland, 2002; Benton et al., 2003; Newton, 2004; Wilson et al., 2005; Donald et al., 2006; Kleijn et al., 2006; Bas et al., 2009). Aquests canvis han permès augmentar extraordinàriament la producció agrícola (Krebs et al., 1999; Wilson et al., 2005) (Fig. 1) però a la vegada, han causat i continuen causant una dramàtica pèrdua de biodiversitat (Krebs et al., 1999; Vickery et al., 2001; Robinson i Sutherland, 2002; Benton and Twitchett, 2003; Grice et al., 2004; Newton, 2004; Vickery, 2004; Stoate et al., 2009) tant en plantes (Wilson et al., 2005), invertebrats (Sotherton, 2000; Benton et al., 2002), mamífers (Flowerdew, 1997) com en ocells (Chamberlain et al., 2000; Bas et al., 2009). L'associació entre intensificació de l'agricultura i tendències regressives en poblacions d'ocells s'ha documentat arreu del món, tant a nord Amèrica (Brennan, 2005), com a Àfrica (Söderström, 2003), Àsia (Semwal, 2004) i Europa (Donald et al., 2001, 2006). Al vell continent l'impacte de la intensificació agrícola és especialment preocupant donada la basta extensió que ocupen els ambients agrícoles (prop de la meitat de la superfície dels països membres de la Unió Europea). Les actuals estimes poblacionals d'espècies d'ocells d'ambients agrícoles són les més baixes mai registrades (Pan-European Common Bird Monitoring Scheme:

Figura 1. Evolució de la productivitat agrícola entre els anys 1961 i 2010 en l'àmbit mundial expressada segons l'índex de producció neta d'aliments per persona (dòlars internacionals) (quadre negre), i en l'àmbit europeu expressada com a producció de cereal (en milions de tones) (triangles blancs). Font: www.faostat3.fao.org/



www.ebcc.info/pecbm.html), i la seva regressió s'ha estimat en prop del 44% en 25 anys, un percentatge molt superior a la davallada del 13% estimada per les espècies comunes (Pan-European Common Bird Monitoring Scheme: www.ebcc.info/pecbm.html) (Fig.2). De cara al futur, el context global és poc esperançador per a la preservació de la biodiversitat en els ecosistemes agrícoles. D'una banda, els actuals mecanismes per a revertir aquesta pèrdua són encara poc efectius. De fet, la implementació de polítiques agro-ambientals, si bé pot haver contribuït a suavitzar la tendència regressiva dels ocells d'ambients agrícoles en els darrers anys, no ha aconseguit aturar o revertir la pèrdua alarmant de biodiversitat en els ecosistemes agrícoles (Fig. 2). De l'altra, la previsió d'un augment del 50% de la població humana mundial en els propers 50 anys (Myers i Kent, 2004), obligarà a incrementar la producció agrícola per tal d'abastir d'alimentació a tota la població (Wilson et al., 2009). Es preveu que aquest augment de la productivitat comporti un seguit de processos, com ara la pèrdua d'hàbitats per a ser transformats en zones agrícoles, increment de l'ús de pesticides o l'augment de la eutrofització, que conduiran a l'extinció a moltes espècies (Thomas et al., 2004).

Figura 2. Tendència poblacional del conjunt de 145 espècies d'ocells comuns (triangle), 33 espècies d'ambients forestals (rombe) i 36 d'ambients agrícoles (quadre) en 25 països europeus en el període 1985-2009. Font: EBCC/RSPB/Dbirdlife/Statistics Netherlands.



El sisó

Un cas particular d'espècie amenaçada a causa principalment de la intensificació agrícola és el sisó (*Tetrax tetrax*) (Diagrama 1). En les darreres dècades aquesta espècie ha patit una forta regressió tant del nombre d'efectius com de l'àrea de distribució, que l'ha dut a l'extinció en molts països centreeuropeus (Cramp i Simmons, 1980). Actualment l'àrea de distribució està fragmentada en dos sectors: l'oriental, que comprèn des del sud-est de Rússia, Georgia, Kyrgyzstan, Kazakhstan, Ucraïna, fins al nord-oest de la Xina i l'Iran (Fig. 3); el sector occidental s'estén des de França, passant per la península Ibèrica fins al nord del Marroc, així com també la illa italiana de Sardenya (Birdlife International 2012) (Fig. 3). Més de la meitat dels efectius reproductors de la població mundial es concentren a la Península Ibèrica, mentre que les poblacions francesa o italiana són força menys nombroses (Birdlife International, 2012) (Taula 1). La tendència poblacional al sector més occidental de l'àrea de distribució és clarament regressiva, mentre que a l'oriental resta poc coneguda (Iñigo i Barov, 2010). La davallada de la població espanyola s'estima en el 20%-30% en 10 anys segons les fonts consultades (Birdlife International, 2004; García de la Morena et al., 2006) i a França fou del 80% entre els anys 1980 i 2000 (Jolivet, 1999).

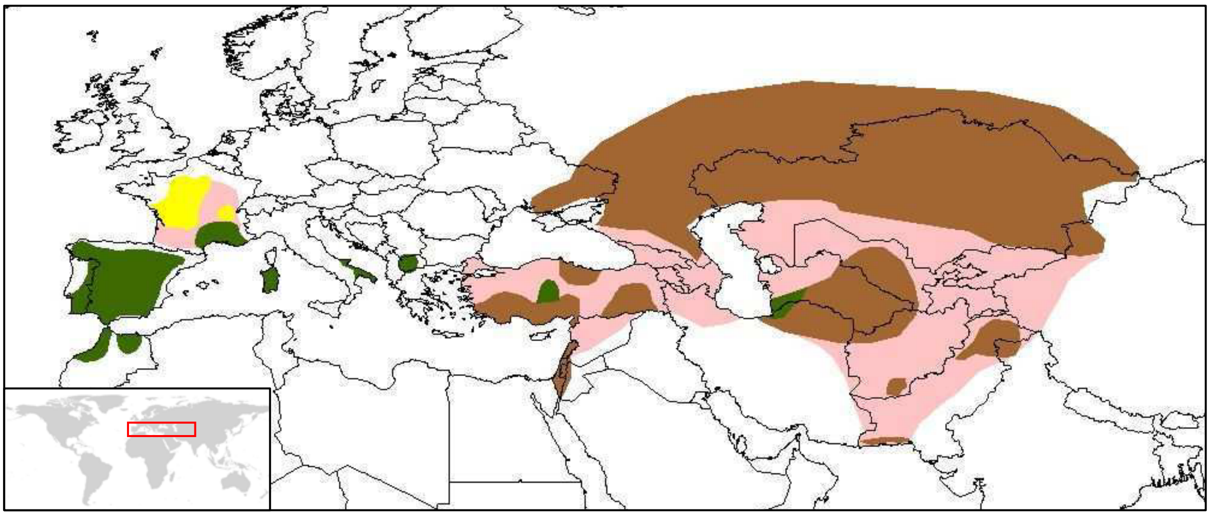
Diagrama 1. El sisó

El sisó (*Tetrax tetrax*) és una au estepària, de la família de les otídides (ordre dels Gruïformes), que a Europa habita majoritàriament en ambients agrícoles. Donada la regressió poblacional iniciada ja en el segle passat, principalment a causa de la intensificació de l'agricultura, el sisó és avui en dia una espècie amenaçada, catalogada globalment com a espècie "Propera a l'amenaça" i com a "Vulnerable" en l'àmbit europeu (Birdlife International, 2012).

El dimorfisme sexual és acusat durant el període reproductor. Les femelles (pes = 680 - 950 g) i els mascles de primer any presenten un plomatge críptic durant el període reproductor (Johnsgard, 1991). Els mascles, que són més corpulents (pes = 800 – 975 g), llueixen un plomatge nupcial característic amb un coll vistós de color blanc i negre (Johnsgard, 1991). Acabat el període reproductor tots els exemplars adopten el plomatge marró, de manera que al camp és difícil de distingir-ne l'edat o el sexe (Cramp i Simmons, 1980; Jiguet i Wolff, 2000).

Font: www.planetofbirds.com

Figura 3. Distribució mundial del sisó, amb presència de l'espècie durant tot l'any (en verd), només durant el període de cria (en groc), fora del període de cria (en marró), en pas (rosa).
Font: Birdlife International.



La biologia de l'espècie

El sisó es reprodueix segons el sistema d'aparellament per lek dispers (Gilliard, 1969). El lek (joc en finès) és una agregació de mascles que les femelles visiten amb l'únic objectiu d'aparellar-se (Höglund i Alatalo, 1995). En el cas del lek dispers l'agregació dels mascles és més laxa, la qual cosa els permet establir territoris més grans. En el sistema de leks, uns pocs mascles protagonitzen la major part de les còpules i la cura parental recau exclusivament en les femelles (Höglund i Alatalo, 1995).

En el sisó, els mascles amb plomatge nupcial són molt territorials i destinen la major part del temps a la parada nupcial, que és fruit de la combinació de tres comportaments (Jiguet i Bretagnolle, 2001): cant simple (vocalització simple del cant

Taula 1. Descripció de les poblacions reproductores de sisó incloses en el sector occidental de l'àrea de distribució. Fonts: Iñigo i Barov (2010); Birdlife International (2012); www.iucnredlist.org.

País	**Grandària** (mascles)	Any	Tendència	Catalogació*
França	1.487-1.677	2008	Estable	En perill d'extinció
Itàlia	250-400	2009	Regressiva	Amenaçada
Portugal	13.260-21.771	2006	Desconeguda	Vulnerable
Espanya	41.482-86.195	2006	Regressiva	Vulnerable

* Segons els criteris de la *International Union for Conservation of Nature* (UICN).

amb moviment del cap), parada sense salt (cops de peu i vocalització) i parada amb salt (cops de peu, salt amb batec d'ales i vocalització) (Fig. 4). La biologia reproductiva de les femelles de sisó és encara poc coneguda, atès que tenen un comportament molt reservat durant el període reproductor. La mida de posta sol ser de 3-4 ous i el període d'incubació de 20-22 dies (Cramp i Simmons, 1980). Les segones postes són rares però en cas de fracàs, poden realitzar fins a tres postes de reposició (dades pròpies). Durant les tres primeres setmanes de vida, els polls s'alimenten exclusivament d'insectes, sobretot ortòpters i coleòpters (Boutin i Métais, 1995; Jolivet, 2002). En els adults, la dieta està constituïda principalment per components vegetals que, durant el període reproductor, complementen amb una porció menor d'ingesta d'invertebrats (Boutin i Métais, 1995).

Acabat el període reproductor, els individus tenen un comportament gregari i formen grups que solen perdurar durant tot l'hivern (Cramp i Simmons, 1980). L'espècie presenta un patró de migració variable al llarg de la seva àrea de distribució a l'Europa occidental, essent migradores les poblacions més septentrionals, sedentàries les més meridionals i parcialment migradores les intermèdies (Cramp i Simmons, 1980; García de la Morena et al., 2004).

Figura 4. Parada nupcial, amb salt i batec d'ales, d'un mascle reproductor. Durant el període d'aparellament els macles mostren un comportament territorial i dediquen bona part del temps a la parada nupcial, que realitzen des d'un mateix punt del seu territori anomenat arena.

Fotografia:
Jordi Bas.

L'hàbitat durant la reproducció

El sisó és un ocell estepari que a Europa ocupa ambients agrícoles amb diferent grau d'intensificació. A la península Ibèrica, si bé també habita zones de prats i pastures vinculades a la ramaderia extensiva (Equipa Atlas, 2008), l'hàbitat principal de l'espècie són les pseudoestepes cerealístiques, zones seques de relleu pla o ondulat on predomina el cultiu extensiu de cereal de secà, amb poca cobertura arbòria, amb presència de farratges i zones de pastura com ara erms o guarets (Suárez et al., 1997). Múltiples estudis indiquen que els mascles reproductors estableixen el territori preferentment en guarets, erms o pastures on troben els recursos tròfics necessaris (Martínez, 1994; Jiguet et al., 2000, 2002; Wolff, 2001; Morales, et al., 2005b; Delgado et al., 2009). En l'esfera de microhàbitat, els mascles reproductors prefereixen vegetació baixa (entre 20-30 cm), que els proporciona refugi suficient per evitar la depredació i prou visibilitat per la parada nupcial (Martínez, 1994; Salamolard i Moreau, 1999; Morales et al., 2008). En canvi, les femelles prefereixen una major cobertura vegetal per tal d'assegurar-se el refugi, tot i que l'estructura de la vegetació ha de ser suficientment esparsa per a assegurar-se la visibilitat en la vigilància (Morales et al., 2008). Més enllà de les diferències entre sexes, els requeriments ecològics de les femelles reproductores són encara poc coneguts (Schulz, 1985; Lett et al., 2000; Villers, 2010; Silva, 2010), possiblement a causa de la dificultat d'estudiar-les donat el seu comportament extremadament amagadís. El gruix de la informació disponible prové de la població francesa de sisó, que ocupa ambients agrícoles més intensificats que els ocupats a la península Ibèrica. L'hàbitat de nidificació i de cria dels polls és poc conegut en l'espècie (Villers, 2010; Silva, 2010), i no hi ha estudis publicats sobre l'ús de l'hàbitat de les femelles amb polls durant la cria.

Amenaces i problemàtica de conservació

La davallada poblacional del sisó s'explica, en primer lloc, per la pèrdua d'hàbitat adequat per a l'espècie, a causa principalment de la intensificació agrícola, la transformació en regadiu, la conversió a cultius arbustius o arbrats i l'expansió dels usos del sòl de tipus urbà i industrial (Suárez et al., 1997; Iñigo i Barov, 2010). En segon lloc, per la manca de reclutament dels nous exemplars a la població reproductora a causa principalment dels efectes provocats per diversos processos associats a la intensificació agrícola, que actuen reduint l'èxit reproductor i incrementant la mortalitat de l'espècie. L'ús generalitzat de pesticides, la pèrdua d'espais amb vegetació natural com ara els guarets i la llaurada d'aquests, cada vegada més freqüent dels guarets, minven l'abundància d'insectes (Iñigo i Barov, 2010). La manca de recursos tròfics ocasiona la inanició, una de les principals causes de mort del polls de sisó, que durant les primeres setmanes de vida s'alimenten exclusivament d'artròpodes (Jiguet, 2002). Finalment, la col·lisió amb línies elèctriques i la caça il·legal són dos factors addicionals de mortalitat que contribueixen a agreujar encara més la delicada situació de les poblacions de sisó (Iñigo i Barov, 2010; Silva et al., 2010).

La recerca aplicada a la conservació

En el context global de pèrdua alarmant de biodiversitat, cap als anys 80 va néixer la biologia de la conservació, una disciplina d'estudi que té l'objectiu d'aportar un marc teòric general a la conservació de la biodiversitat (Primack, 2004). La biologia de la conservació representa una síntesi de diverses ciències que aporten principis i noves aproximacions per a la gestió dels recursos naturals (Primack, 2004). Com a disciplina científica, no només té com a finalitat generar nou coneixement, sinó utilitzar aquest nou coneixement per a preservar la diversitat biològica. Aquesta tesi s'emmarca en aquesta filosofia, de manera que les aportacions generades estan enfocades cap a la conservació del sisó.

A fi i efecte d'aturar la pèrdua d'espècies, és necessari i urgent disposar de la informació necessària per a entendre els processos pels quals les activitats humanes afecten negativament les poblacions, sobretot en el cas de les espècies amenaçades. Conèixer amb detall aquests processos, així com la biologia de les espècies afectades són aspectes determinants a l'hora de dissenyar mesures de gestió que afavoreixin la conservació d'una espècie amenaçada. Per tant, els estudis sobre els requeriments ecològics de les espècies associades a ambients transformats per l'home i sobre els factors que expliquen la regressió poblacional d'aquestes espècies són prioritaris en l'àmbit de la biologia de la conservació, ja que són una peça clau per a poder dissenyar mesures que permetin conciliar el desenvolupament humà amb la conservació de la biodiversitat (p. ex. Blanco et al. 1998, Tella et al. 1998, Arroyo et al. 2002, 2009, O'Connell i Yallop 2002, Carrete i Donázar 2005). En el cas concret dels ambients agrícoles, els mecanismes per a fer compatible l'agricultura amb la conservació resten encara poc coneguts, malgrat els esforços en la recerca duts a terme en els darrers anys (Berthet et al., 2012).

L'ús de l'espai

Un dels aspectes bàsics de la recerca aplicada a la conservació d'una espècie és entendre els factors que determinen la distribució espacial dels seus individus (Gittleman i Harvey, 1982; Mace et al., 1983). Per exemple, els tècnics encarregats de la gestió han d'entendre els moviments i la distribució espacial de les espècies que han de preservar, especialment aquelles més mòbils o associades a ambients molt dinàmics (Sinclair, 1983), per tal d'ajustar l'extensió de les àrees a protegir a les necessitats ecològiques d'aquestes espècies (Madsen, 1998a, 1998b). L'ús de l'espai és el resultat d'un procés complex pel qual l'individu intenta satisfer els seus requeriments tròfics, abastir-se de refugi, aparellar-se i reduir el risc de depredació o competència. Diversos factors poden determinar l'organització espacial dels animals com ara l'edat, el sexe, l'estadi reproductiu, la condició corporal o el clima (Mace et al., 1983; Rolando, 2002), si bé, el principal factor que condiciona l'ús de l'espai sol ser la disponibilitat i la distribució dels recursos tròfics (Brown, 1975; Schoener, 1983). Generalment es considera que existeix una relació inversa entre l'extensió de l'àrea vital i la disponibilitat dels recursos (MacArthur i Pianka, 1966), però en determinades circumstàncies, els individus poden engrandir l'àrea que utilitzen per tal de satisfer les seves necessitats vitals com ara l'aparellament, aconseguir un territori de cria millor, o ser desplaçats pel comportament territorial conspecífic (Whitaker, 2007). Per tant, el coneixement dels factors associats a la variació de l'ús de l'espai pot contribuir a identificar els recursos limitants i indicar les diferències entre els requeriments entre grups demogràfics o poblacions i l'hàbitat disponible (Whitaker, 2007).

L'ús de l'hàbitat

Un dels factors clau que determinen la distribució dels organismes és l'hàbitat i els recursos que aporta. Generalment, les espècies seleccionen els recursos que millor satisfan els seus requeriments ecològics i aquests recursos òptims seran més usats que els recursos de menor qualitat (Manly, 2002). La selecció dels recursos es dóna a diferents escales espacials de forma jeràrquica, des de l'àmbit biogeogràfic de la distribució de l'espècie, passant per l'àrea vital ocupada per l'individu, fins a la selecció de determinats recursos tròfics (com ara fonts d'alimentació) dins de l'àrea vital de l'individu (Manly, 2002).

En l'àmbit de la biologia de la conservació, l'estudi de la selecció de l'hàbitat és especialment útil ja que permet identificar l'hàbitat de qualitat de les espècies amenaçades i entendre les conseqüències dels canvis en els usos del sòl o en el clima (Manly, 2002; Morris et al., 2008), així com abordar projectes de restauració d'aquests mateixos hàbitats a fi i efecte de facilitar la recuperació de les espècies.

És la biologia de la conservació una disciplina inofensiva?

Els estudis sobre la biologia i ecologia d'una espècie animal, i en particular els referents a l'ús de l'espai i de l'hàbitat, sovint tant sols es poden realitzar mitjançant l'aplicació de tècniques de telemetria o marcatge. Aquestes tècniques permeten obtenir informació sobre múltiples aspectes de la biologia d'espècies rares o amb un comportament molt amagadís (Millspaugh i Marzluff, 2001), que seria gairebé impossible d'aconseguir a través de mètodes purament observacionals. És per això que aquestes tècniques han esdevingut una eina fonamental en l'àmbit de la biologia de la conservació.

Ara bé, la captura i manipulació dels animals és un mètode invasiu que pot ocasionar efectes adversos als animals, com ara una reducció de la massa corporal, canvis en el comportament, o fins i tot, augment de la mortalitat (Millspaugh i Marzluff, 2001). L'aparició d'efectes adversos podria violar l'assumpció sobre la qual es basen els estudis de radioseguiment: els animals radiomarcats han de ser representatius del conjunt dels animals de la població (Millspaugh i Marzluff, 2001). Estrictament, en un estudi basat en tècniques de radioseguiment, caldria confirmar que els efectes adversos són negligibles o inexistents, abans d'extrapolar els resultats obtinguts al conjunt de la població (Millspaugh i Marzluff, 2001). De fet, qualsevol estudi que utilitzi el radioseguiment hauria d'avaluar l'aparició d'efectes adversos en qualsevol dels processos que aquesta tècnica de monitoratge exigeix, i seria recomanable documentar els resultats del marcatge i radioseguiment tant si s'han detectat tals efectes adversos com si no (Millspaugh i Marzluff, 2001). Paradoxalment, l'ocurrència d'aquests efectes adversos no sol ser estudiada ni publicada en el món acadèmic, per la qual cosa les seves conseqüències o l'abast de les espècies afectades resten encara poc coneguts. Si l'aplicació d'aquestes tècniques en l'àmbit de la biologia de la conservació té la finalitat última de preservar l'espècie estudiada, cal assegurar-se que la seva utilització resulti el mínim de nociva per als individus. Des d'un punt de vista ètic, l'home no hauria d'ocasionar sofriment als animals, de manera que la captura i la manipulació s'haurien de dur a terme de forma que ocasionessin el mínim sofriment i molèsties als animals (Bolton 1997). A més, els estudis haurien d'aplicar les tècniques de captura que permetin capturar amb més eficàcia el grup demogràfic que es pretén estudiar, per ocasionar les mínimes molèsties als animals. Per tant, d'una banda és important conèixer les tècniques de captura més eficaces i segures segons l'espècie i grup demogràfic d'estudi i, de l'altra, són necessaris els estudis metodològics que avaluïn els mètodes de captura i manipulació emprats i aportin propostes per a fer aquests mètodes menys nocius (Millspaugh i Marzluff, 2001).

OBJECTIUS

Objectius generals

Amb aquesta tesi es pretén aprofundir en el coneixement d'aquells aspectes relacionats amb l'ecologia i la biologia reproductiva que, malgrat ser rellevants per la conservació del sisó, resten encara poc coneguts. En primer lloc s'aprofundeix en el coneixement de l'ús de l'espai i de l'hàbitat del sisó durant el període reproductor, i en segon lloc, es desenvolupen aspectes metodològics dins el marc de la biologia de la conservació, sempre amb l'objectiu final de contribuir a generar informació útil per a la preservació de l'espècie.

Objectius específics

CAPÍTOL 1. L'ús de l'espai i de l'hàbitat en el sisó durant el període reproductor

En aquest apartat s'estudia el comportament espacial i l'ús de l'hàbitat tant dels mascles com de les famílies (femelles amb polls) de sisó durant el període reproductor i es discuteixen aquests aspectes en relació al sistema d'aparellament i a l'èxit reproductor de l'espècie.

Article 1. *Comportament espacial dels mascles de sisó,* Tetrax tetrax*, en el lek*

El comportament espacial dels mascles de sisó durant el període reproductor és molt variable (Jiguet et al., 2000), però es desconeixen els principals factors que determinen aquesta variabilitat. La disponibilitat de recursos és un dels principals factors que determinen l'ús de l'espai d'un individu en moltes espècies d'ocells (Brown, 1975; Schoener, 1983), però en espècies formadores de lek el component social també pot determinar el comportament espacial dels individus (Jiguet et al., 2000; Wegge et al., 2003). En aquest article s'analitza la variabilitat de l'ús de l'espai dels mascles de sisó durant el període d'aparellament, se n'identifiquen els principals factors que la determinen, i es discuteixen els resultats obtinguts en relació al sistema d'aparellament de l'espècie.

Article 2. *Comportament espacial i èxit reproductor de les famílies de sisó en ambients cerealístics intensius*
Aquest treball té com a objectius: investigar la relació entre l'èxit reproductor i la fenologia de reproducció; determinar si el comportament espacial de les femelles amb polls està associat a l'èxit reproductor i a la fenologia de l'espècie, i identificar la relació entre la disponibilitat d'artròpodes i les pràctiques agrícoles amb la fenologia reproductiva de l'espècie. Es pretén també utilitzar els resultats obtinguts en relació a les característiques de l'ús de l'espai de les femelles amb polls per a proposar mesures de conservació que ajudin a incrementar l'èxit reproductor de l'espècie.

Article 3. *La sega del cereal i l'ús de l'hàbitat de les famílies de sisó en pseudoestepes cerealístiques*
En aquest treball s'investiga l'ús de l'hàbitat de les famílies de sisó per establir mesures de gestió que promoguin l'increment de l'èxit reproductor de l'espècie en pseudoestepes cerealístiques. Donat que en aquests ambients la sega del cereal suposa la pèrdua de la major part de la cobertura vegetal, es parteix del supòsit que les preferències d'hàbitat de les femelles amb polls poden estar condicionades per la sega del cereal. S'ha realitzat una anàlisi a l'escala de parcel·la agrícola considerant un gradient temporal, per tal d'identificar les diferències d'ús de l'hàbitat de les parcel·les de cereal abans i després de la sega del cereal.

CAPÍTOL 2: Aportacions metodològiques per a la captura i manipulació de sisons

La captura, manipulació i marcatge d'animals eventualment poden provocar als individus efectes adversos (ja siguin molèsties, lesions, o fins i tot la mort), essent algunes espècies altament susceptibles. Per tant, sempre que s'apliquin aquestes tècniques caldria avaluar l'aparició d'efectes adversos, especialment en el marc de projectes de recerca per a la conservació d'espècies amenaçades. En aquest sentit, és important emprar la tècnica de captura adequada que permeti capturar el tipus d'individus (joves, adults, mascles o femelles) estipulats pels objectius de recerca.

Article 4. *Tècniques de captura en el sisó* Tetrax tetrax *segons l'edat, el sexe i el període de captura*
En aquest article es descriuen quatre mètodes de captura adaptats a la biologia del sisó, que permeten capturar eficaçment exemplars en funció de l'edat, el sexe o època de l'any d'acord amb els objectius de recerca del projecte dins el qual s'emmarquen les captures.

Article 5. *Efectes adversos de la captura i manipulació en el sisó*
En aquest treball es quantifica l'aparició d'efectes adversos causats per la captura i manipulació dels sisons i se n' identifiquen els principals factors que en propicien l'aparició.

INFORME DEL DIRECTOR

La tesi doctoral presentada per Anna Ponjoan Thäns consta de 5 treballs científics, 4 d'ells ja publicats en revistes del SCI i un cinquè que es troba en forma de manuscrit pendent d'enviar. Cap dels coautors del articles ha utilitzat cap dels treballs, en tot o en part, en cap altra tesi doctoral.

A continuació es detalla la contribució de la doctoranda a cada un dels treballs, així com el factor d'impacte de les revistes on han estat publicats, si és el cas.

- Ponjoan, A., Bota, G., Mañosa, S. 2012. Ranging behaviour of Little bustard males, *Tetrax tetrax*, in the lekking grounds. *Behavioural Processes*, 91: 35-40. Factor d'impacte:1.652. La doctoranda, A.P.T. ha contribuït al disseny del treball, recollida de dades de camp, anàlisi de dades i redacció del treball.

- Lapiedra, O., Ponjoan, A., Gamero, A., Bota, G., Mañosa, S. 2011. Brood ranging behaviour and breeding success of the threatened little bustard in an intensified cereal farmland area. *Biological Conservation*, 144:2882-2890. Factor d'impacte:4.115. La doctoranda, A.P.T. ha contribuït al disseny del treball, recollida de dades de camp, l'anàlisi de dades i la redacció del treball.

- Ponjoan, A., Lapiedra, O., Bota, G., Mañosa, S. (en preparació). Cereal harvest and habitat-use of little bustard broods in a cereal pseudo-steppe. Manuscrit. La doctoranda, A.P.T. ha contribuït al disseny del treball, recollida de dades de camp, anàlisi de dades i redacció del treball.

- Ponjoan, A., Bota, G., Mañosa, S. 201o. Traping techniques for little bustard according to age, gender and season. *Bird Study*, 57: 252-255.

Factor d'impacte: 0.868. La doctoranda, A.P.T. ha contribuït al disseny del treball, recollida de dades de camp, anàlisi de dades i redacció del treball.

- Ponjoan, A., Bota, G., García de la Morena, E., Morales, M.B., Wolff, A., Marco, I., Mañosa, S. 2008. Adverse effects of capture and handling little bustard. *Journal of Wildlife Management*, 72: 315-319. Factor d'impacte:1.522. La doctoranda, A.P.T. ha contribuït al disseny del treball, recollida de dades de camp, anàlisi de dades i redacció del treball.

Barcelona, 19 de setembre de 2012.

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RESULTATS I DISCUSSIÓ GENERAL

La distribució dels animals és el resultat de la interacció entre els requeriments ecològics de l'espècie i els factors ambientals, els quals poden promoure la contracció o expansió de les àrees ocupades (Holt et al., 2005). Un dels principals factors ambientals que determinen la dinàmica poblacional de les espècies és l'hàbitat (Korpimaki, 1988; Siikamaki, 1995). Per tant, identificar correctament àrees d'hàbitat d'alta qualitat és d'interès, tant des d'un punt de vista teòric com aplicat a la conservació de les espècies. En ambients agrícoles l'hàbitat està fortament condicionat per l'activitat humana, bàsicament per les pràctiques agrícoles (Wilson et al., 2009). D'una banda, la intensificació de les pràctiques agrícoles ha causat l'empobriment de l'hàbitat i l'esgotament dels recursos tròfics (Donald et al., 2001; Newton, 2004; Wilson et al., 2009), paràmetres descrits com uns dels principals factors limitadors per a les poblacions d'aus (Martin, 1995; Penteriani et al., 2002; Sergio et al., 2003). De l'altra, en ambients agrícoles els hàbitats estan subjectes a canvis constants com a resultat de les pràctiques agrícoles, ja siguin alteracions sobtades (com ara la sega o l'aplicació de pesticides o fertilitzants) o canvis estacionals (per exemple, canvis en el tipus de cultiu sembrat, o rotació dels cultius) (Rodríguez-Teijeiro et al., 2009), els quals afecten directament l'ecologia i la dinàmica poblacional de les espècies d'ocells que hi habiten (Chamberlain et al. 2000; Donald et al., 2001; Atkinson et al. 2005). En aquesta tesi, per exemple, hem pogut veure com varia la disponibilitat d'aliment i la cobertura en les pseudoestepes cerealistes i els efectes que això comporta sobre la supervivència dels polls de sisó (Lapiedra et al., 2011). Per a la conservació dels ocells d'ambients agrícoles no només és important identificar l'hàbitat d'alta qualitat, sinó també entendre els processos pels quals la intensificació agrícola afecta la qualitat de l'hàbitat.

Ús de l'espai

Els resultats d'aquesta tesi mostren que l'ús de l'espai en el sisó durant el període reproductor varia de forma contínua entre un patró més estàtic, en el qual l'animal realitza moviments curts dins d'una àrea relativament petita, i un patró més expansiu, en el qual l'individu utilitza àrees àmplies, ja sigui com a conseqüència de moviments erràtics o bé per l'ús de varis centres d'activitats allunyats entre si. Els mascles utilitzen des de territoris petits (àrea mínima observada = 2 ha) constituïts per un únic centre d'activitat, fins a territoris de 284 ha formats per 2-5 centres d'activitat. Les femelles amb polls amb un patró sedentari utilitzen una àrea unes 9 vegades més petita (8.5 ± 3.9 ha) que aquelles amb un patró erràtic (71.2 ± 44.5 ha). Si bé aquesta variabilitat pot ser fruit de la combinació de diversos factors com ara molèsties d'origen antròpic (López-Jamar et al., 2010) o l'organització social dels mascles pròpia de les espècies formadores de lek, la disponibilitat i distribució de l'hàbitat de qualitat n'és un dels principals (Brown, 1975; Schoener, 1983).

El patró estàtic seria compatible tant amb una distribució homogènia com una d'heterogènia de l'hàbitat de qualitat, però el patró expansiu difícilment es pot emmarcar en un escenari de distribució homogènia dels recursos. Segons la teoria de l'*Optimal foraging* (MacArthur i Pianka, 1966) els animals tendeixen a reduir al mínim el temps i l'energia dedicada a buscar, capturar i consumir aliments, per tal de maximitzar l'energia consumida per unitat de temps. En hàbitats heterogenis, on la qualitat de l'hàbitat és molt variable entre tessel·les, és probable que els animals tendeixin a concentrar-se en aquells espais de major qualitat de l'hàbitat (Boitani i Fuller, 2000). En el cas que una tessel·la ofereixi suficients recursos per a satisfer els requeriments de l'animal, això es pot traduir en un patró espacial estàtic. Però si els recursos disponibles en una tessel·la són insuficients, l'animal es veurà obligat a desplaçar-se a altres tessel·les o a utilitzar altres hàbitats de menys qualitat, la qual cosa suposaria l'adopció d'un patró de tipus expansiu.

Els resultats obtinguts indiquen que el patró expansiu respon a la variabilitat, tant en distribució com en qualitat, dels recursos disponibles. D'una banda, en els mascles de sisó el patró expansiu és més freqüent en ambients amb una distribució heterogènia de l'hàbitat d'alta qualitat per a la parada nupcial (el secà de Bellmunt), en el qual els territoris estarien situats en les zones amb major disponibilitat d'aquest hàbitat. De l'altra, en les femelles el patró expansiu està vinculat a l'ús d'hàbitat de menys qualitat (marges herbacis o rostolls i llaurats), mentre que el patró estàtic és propi de les femelles que utilitzen hàbitat d'alta qualitat (camps amb vegetació herbàcia).

En aquesta tesi també s'ha vist que el comportament espacial està fortament condicionat per les pràctiques agrícoles implementades en l'àrea d'estudi. El patró expansiu en les femelles reproductores és més habitual a finals de l'època de cria, quan la sega del cereal ha eliminat la major part de la cobertura vegetal i obliga a les famílies a resseguir els marges herbacis per tal de trobar alimentació, aixopluc de les altes temperatures i refugi davant dels depredadors. En les pseudoestepes cerealístiques la qualitat de l'hàbitat s'empobreix al llarg de l'època de cria a causa bàsicament de les pràctiques agrícoles i l'enduriment de les condicions climatològiques, la qual cosa obliga a les femelles amb polls a utilitzar àrees més extenses per tal de satisfer els seus requeriments ecològics. Les femelles amb polls amb un patró expansiu realitzen els desplaçaments llargs i ràpids, que en l'àrea d'estudi es donen principalment a causa de molèsties ocasionades per maquinària agrícola en funcionament (article 2). Per tant, tal i com s'ha descrit per altres espècies d'otídides (López-Jamar et al., 2010), les molèsties d'origen antròpic condicionen l'ús de l'espai dels sisons.

Globalment, els resultats sobre l'ús de l'espai mostrats en aquesta tesi apunten que els ambients cerealístics de secà amb cert grau d'intensificació ofereixen recursos limitats, de qualitat desigual i distribuïts de forma heterogènia. A més, la qualitat de l'hàbitat està subjecte a les pràctiques agrícoles implementades i tendeix a empobrir-se al llarg del període reproductor.

Una altra troballa important d'aquesta tesi és el fet que els individus que utilitzen àrees reduïdes són més efectius de cara a la reproducció que aquells que utilitzen àrees més extenses. El comportament espacial estàtic està associat, d'una banda, a les femelles amb més èxit reproductor, i de l'altra, als mascles més actius en la parada nupcial i per tant, considerats dominants. Així doncs, podem pensar que el comportament espacial més estàtic correspon a una tàctica de reproducció òptima, i que l'adopció d'altres comportaments espacials respon a algun tipus de limitació, per exemple, en la disponibilitat dels recursos. Cal matisar que, en el cas dels mascles, l'ús de l'espai està condicionat per la presència d'hàbitat adequat per a la parada nupcial i no per la disponibilitat de recursos adequats per a les femelles. El fet que els mascles dominants tinguin àrees més petites, indicaria que la formació de leks dispersos no té a veure amb la monopolització de recursos per a les femelles.

Així doncs, els resultats obtinguts posen de manifest que l'ús de l'espai en el sisó durant el període reproductor depèn, en bona part, de la disponibilitat i distribució de l'hàbitat de qualitat, aspectes que en ecosistemes cerealístics depenen principalment de les pràctiques agrícoles implementades. També s'ha vist una associació entre l'ús de l'espai i l'èxit reproductor de l'espècie. Per tant, conèixer amb detall els principals factors que determinen l'hàbitat de qualitat, permetrà dissenyar mesures de gestió de l'hàbitat que resultin en un increment de l'èxit reproductor de l'espècie, considerat un objectiu prioritari per a la seva preservació (Morales et al., 2005a; Iñigo i Barov, 2010; Lapiedra et al., 2011).

Ús de l'hàbitat

Segons els resultats mostrats al capítol 1, l'ús de l'hàbitat en el sisó en pseudoestepes cerealístiques respon a aspectes decisius per l'èxit reproductor: l'alimentació i la visibilitat en la parada nupcial dels mascles, i l'alimentació i el refugi en el cas de les femelles amb polls. Tant els mascles reproductors com les femelles amb polls, seleccionen positivament els usos del sòl no agrícoles amb cobertura herbàcia com ara guarets o erms. En pseudoestepes cerealístiques amb un grau d'intensificació elevat, aquests hàbitats són determinants per a l'èxit reproductor de l'espècie i compleixen diverses funcions al llarg del període reproductor que permeten satisfer les necessitats, tant dels mascles com de les femelles amb polls, malgrat els requeriments ecològics a l'esfera del microhàbitat siguin diferents entre sexes durant el període reproductor (Morales et al., 2008).

Una de les principals funcions de guarets i erms és que actuen com a font d'alimentació. Aquests hàbitats es caracteritzen per oferir una alta disponibilitat d'insectes i una gran complexitat en l'estructura de la vegetació (Henderson et al., 2000; Pépin et al., 2007; Rodríguez i Bustamante, 2008; Douglas et al., 2010).

En pseudoestepes cerealístiques els mascles reproductors seleccionen positivament guarets, erms o pastures (Martínez, 1994, 1998, 2002; Salamolard i Moreau, 1999; Jiguet et al., 2000, 2002; Wolff et al., 2001; Morales et al., 2005b; García et al., 2007; Traba et al., 2008; Delgado et al., 2009, 2010). Segons els resultats obtinguts (article 1), els mascles adults i amb major activitat nupcial, que són possiblement els dominants, disposen d'una proporció major de guarets i erms dins de l'àrea vital. Donat que l'aliment en aquests hàbitats és abundant, els mascles els utilitzarien per a satisfer els seus requeriments tròfics minimitzant els desplaçaments, la qual cosa probablement contribueixi a incrementar les oportunitats d'aparellar-se. Tanmateix, l'estructura de la vegetació és un aspecte clau en l'ús de l'hàbitat dels mascles reproductors, ja que necessiten una vegetació esparsa i baixa per tal de garantir la visibilitat durant la parada nupcial (Martínez, 1994, 1998, 2002; Wolff, 2001; Morales et al. 2008; Traba et al., 2008). Per tant, els guarets, erms i pastures constitueixen un hàbitat d'alta qualitat per als mascles reproductors de sisó, sempre que disposin d'una cobertura vegetal baixa i dispersa que els garanteixi la visibilitat durant a la parada nupcial.

La presència de guarets i erms també és un factor clau en l'ús de l'hàbitat de les famílies de sisó. D'una banda, l'abundància i accessibilitat als artròpodes és crucial durant la cria ja que aquests constitueixen la dieta dels polls de sisó durant les primeres setmanes de vida (Jiguet, 2002). A més, la inanició s'ha descrit com la principal causa de mortalitat dels polls de sisó (Bretagnolle et al., 2011). Donat que en l'àrea d'estudi la disponibilitat d'artròpodes és major en guarets que en cultius de cereal (article 2), aquests tenen un paper clau en la supervivència dels polls com a font d'alimentació. D'altra banda, la cobertura vegetal de guarets i erms està desvinculada del cicle agrícola (al menys temporalment en el cas dels guarets) i sol perdurar durant tot el període reproductor. Després de la sega del cereal, quan bona part del paisatge queda desproveït de cobertura vegetal, guarets i erms esdevenen una font de refugi crucial per a fer front a als possibles depredadors o a les severes condicions climàtiques. Per tant, la presència de guarets i erms amb cobertura vegetal és determinant durant la cria, ja sigui per evitar la inanició o la depredació dels polls.

Els resultats obtinguts en aquesta tesi indiquen que les femelles amb polls també seleccionen positivament els marges herbacis. És coneguda l'abundància i la riquesa de les poblacions d'artròpodes en els marges herbacis (Vickery et al., 2009), i de fet, en l'àrea d'estudi la biomassa d'artròpodes en marges és clarament superior que en cereal o guarets (article 2). Ara bé, la restricció espacial dels marges els fa molt atractius per als carnívors que solen utilitzar-los com a passadissos per desplaçar-se entre el mosaic agrícola (Sharpe, 2006). Si el benefici dels marges herbacis és l'abundància de recursos tròfics, el perjudici és un risc més elevat que en els usos agrícoles de depredació per carnívors (Wilson et al., 2001), al menys abans de la sega del cereal. La preferència de les famílies de sisó per camps de 2-3 ha, podria ser conseqüència del balanç entre els perjudici i els beneficis oferts pels marges. Aquesta mida permetria als ocells estar prou allunyats de les molèsties o la depredació associades als límits de les parcel·les, i a la vegada, prou propers a la vora del camp com per beneficiar-se de la major disponibilitat d'insectes dels marges herbacis (Vickery et al., 2009).

Per tal d'evitar la depredació, les femelles amb polls utilitzen l'hàbitat de forma diferent al llarg del període de cria. Després de la sega del cereal, les femelles amb polls busquen la presència de cobertura vegetal herbàcia en marges o guarets, ja que la prioritat és trobar amagatall davant possibles depredadors. Abans de la sega, és fàcil trobar amagatall entre la vegetació dels cultius de cereal, per tant, la prioritat ja no és el refugi sinó la visibilitat i la mobilitat dins aquests cultius. De fet, en l'article 3 s'ha observat que les famílies de sisó prefereixen parcel·les de cereal amb una activitat fotosintètica menor, la qual cosa podria indicar una selecció positiva del cereal de menor alçada i cobertura. Aquests resultats estarien d'acord amb estudis previs que indiquen una preferència per una alçada de la vegetació de fins a 30-40 cm a partir de la qual les femelles evitarien cobertures més denses (Morales et al., 2008; Silva, 2010). Aquest tipus d'estructura del cereal proporcionaria a la vegada, amagatall, visibilitat per a detectar els depredadors, i l'espai obert suficient per a facilitar la mobilitat en cas de fugida.

En conclusió, la presència d'espais no conreats amb vegetació herbàcia com ara guarets, erms o pastures és clau en l'ús de l'hàbitat del sisó durant la reproducció. Aquests espais són hàbitats d'alta qualitat i compleixen diverses funcions durant el període reproductor com a hàbitats òptims per a la establir l'arena dels mascles i realitzar la parada nupcial, com a font d'alimentació tant per a individus adults com per a polls, i com a refugi per a les famílies, especialment després de la sega.

Com afecten les pràctiques agrícoles a la cria del sisó?

Els resultats indiquen que l'èxit reproductor de l'espècie en la població catalana és baix i, segons les estimes obtingudes en models demogràfics (Morales et al., 2005a), insuficient per a assegurar la viabilitat de la població. El radioseguiment ha evidenciat que al llarg de l'època de cria un percentatge elevat de les femelles (22.7 %)

desisteix de criar (article 2). Això podria ser degut al fet que la condició física d'algunes femelles fos insatisfactòria per a fer front al desgast energètic de la cria, o bé, que les femelles només assumirien l'esforç reproductor en condicions ambientals clarament favorables. En ambients agrícoles extensius les femelles nidifiquen en erms i pastures (Delgado i Moreira, 2000; Silva, 2010), mentre que en ambients cerealístics més intensificats nidifiquen bàsicament en camps de cereal (article 2). En pseudoestepes cerealístiques intensificades la disponibilitat d'erms, guarets i pastures seria insuficient per a sustentar la població de femelles reproductores, que dependrien de l'estructura del cereal per a nidificar. L'estructura de la vegetació en els cultius de cereal canvia anualment en funció de les pràctiques agrícoles implementades (sobretot de les varietats sembrades, però també de l'aportació d'aigua, el tipus de sòl, ús de fertilitzants etc.) i també de les condicions climàtiques. Per tant, l'estructura de la vegetació del principal hàbitat de nidificació de l'espècie en pseudoestepes cerealístiques és molt variable, la qual cosa pot fer que les femelles no sempre trobin les condicions adequades per a pondre els ous.

Els resultats obtinguts en aquesta tesi han permès quantificar el fracàs reproductor. Aquest és un paràmetre poc conegut en l'espècie i les poques dades publicades fins ara provenen de la població francesa occidental, que no ocupa pseudoestepes cerealístiques sinó ambients agrícoles més intensificats. Durant la incubació, a la plana de Lleida fracassen el 53% dels nius. Aquest percentatge és superior al de la població francesa occidental, estimat en el 36% (Bretagnolle et al., 2011). En aquesta localitat francesa, la majoria de les pèrdues s'atribueixen a treballs amb maquinària agrícola (un 70%) i només un 7% a la depredació (Bretagnolle et al., 2011; Villers, 2010), mentre que a la població catalana, les pèrdues de nius es donen equitativament per treballs agrícoles com per depredació (43% en ambdós casos) (article 2). La magnitud d'aquesta diferència pot estar condicionada en part per la limitada mida de mostra de les estimes de la població catalana, per tant, cal considerar-la amb cautela. És plausible que diferències en el risc de depredació o en l'abundància de depredadors puguin explicar, al menys parcialment, les diferències de fracàs entre localitats. Tanmateix, la població francesa occidental ocupa ambients agrícoles més intensificats i això podria també condicionar l'èxit reproductor de les poblacions. Si el principal substrat de nidificació de les femelles de sisó a la plana de

Lleida és el cereal (article 2), a la població francesa occidental són els cultius d'alfals i farratges (conjuntament allotgen el 74% dels nius) (Bretagnolle et al., 2011). El fet que aquests cultius més intensius solen suposar una major activitat agrícola (règim de sega més curt, diverses segues a l'any, etc.) conjuntament amb el fet que el sisó té un període de posta molt llarg (de principis de maig a finals de juliol) (Villers, 2010), podrien explicar el major impacte de les operacions agrícoles en la població francesa. Tant l'elevada taxa de fracàs dels nius com les possibles diferències en les causes entre poblacions és una línia de recerca a considerar de cara al futur i de rellevància per a la preservació de l'espècie.

Després de l'eclosió dels ous, les pèrdues durant la cria a la plana de Lleida s'han estimat en el 38% (article 2). Aquesta elevada mortalitat s'explica principalment per l'empobriment de l'hàbitat com a conseqüència de la intensificació de l'agricultura (Bretagnolle, 2011). La combinació de diverses pràctiques agrícoles intensives com ara l'ús de productes fitosanitaris (herbicides o pesticides), la llaurada dels rostolls o dels guarets, la pèrdua de marges herbacis o la degradació de les comunitats vegetals, etc. hauria causat un empobriment de la diversitat i escassetat en les poblacions d'artròpodes en els ambients agrícoles (Jonsen and Fahrig, 1997; Vickery et al., 2009). Els canvis relacionats amb la intensificació de l'agricultura també podrien afavorir un augment de la depredació. D'una banda, s'ha documentat que la intensificació de l'agricultura propicia un increment de la densitat de depredadors generalistes (Evans, 2004). De l'altra, l'ús de varietats de cereal més primerenques ha permès avançar la sega respecte a la fenologia tradicional, i la mecanització de l'agricultura permet conrear àrees molt extenses. De fet, a l'àrea d'estudi la sega suposa la pèrdua de la cobertura vegetal de prop del 80% de la superfície en només 7-10 dies, fet que suposa la pèrdua de bona part del refugi disponible.

Per tant, les pràctiques agrícoles modulen la qualitat de l'hàbitat i condicionen l'èxit reproductor de l'espècie. En ecosistemes cerealístics amb cert grau d'intensificació, els polls de sisó estan exposats a un alt risc de patir inanició o depredació, especialment després de la sega del cereal.

Aportacions per a la conservació

Aquesta tesi aporta nous coneixements en l'àmbit de biologia reproductiva del sisó, útils per al disseny de mesures de gestió dirigides a incrementar l'èxit reproductor de l'espècie. En primer lloc, la gestió de l'hàbitat hauria de potenciar la presència de guarets, erms o pastures, que actuaran com a font d'alimentació i refugi, durant tot el període reproductor i sobretot després de la sega. D'acord amb els resultats obtinguts, es proposa crear una xarxa de parcel·les amb cobertura vegetal herbàcia permanent durant tot el període reproductor. Aquestes parcel·les haurien de tenir una superfície de 2-3 ha, la mida de parcel·la seleccionada per les famílies en l'àrea d'estudi. Aquestes parcel·les haurien d'estar separades uns 500 m, la distància mitjana entre els centres d'activitat de les femelles amb polls. La vegetació herbàcia d'aquestes parcel·les tant podria ser silvestre com un cultiu de lleguminoses. Algunes experiències de gestió que han utilitzat sembrats de lleguminoses (alfals, trepadella o veça) han tingut èxit en el seu objectiu d'incrementar l'èxit reproductor de l'espècie (Bota et al. 2009; Bretagnolle et al., 2011). Els sembrats de lleguminoses, gestionats amb finalitats de conservació, tindrien l'avantatge de mantenir la verdor de la planta fins a finals del període de cria, de manera que podrien satisfer la part vegetal de la dieta, almenys de la femella. Un aspecte important de les parcel·les gestionades és l'estructura de la vegetació, que hauria de ser prou variable per a satisfer els requeriments ecològics d'ambdós sexes. Idealment, alguns espais d'aquesta xarxa haurien d'estar recoberts per una vegetació prou oberta i dispersa perquè sigui atractiva pels mascles reproductors, mentre que convindrien altres espais amb vegetació lleugerament més densa per tal d'oferir refugi a les famílies de sisó. Seria aconsellable evitar la presència de cultius arbrats com ara oliveres o ametllers al voltant de les parcel·les gestionades amb guarets o lleguminoses. Concretament seria bo evitar la presència o proliferació dels cultius arbrats en les 5-10 ha (superfície que correspon a la mida mitjana dels centres d'activitat de les femelles) entorn a les parcel·les gestionades.

És també important mantenir la presència de marges herbacis entre els camps. Es recomana que, en promig, una parcel·la agrícola disposi de com a mínim 0.04 ha de marge herbaci. Caldria evitar la crema, aplicació d'herbicides o sega de la vegetació dels marges, almenys fins a finals del període de cria. Es coneix que els marges tenen efectes beneficiosos sobre les poblacions d'ocells i sovint les mesures de conservació s'han dirigit a promoure'ls (Vickery et al., 2009; Casas i Viñuela, 2010). En el cas del sisó, aquestes mesures serien positives però no suficients donat que els marges difícilment poden aportar tots els recursos necessaris per l'espècie donada la seva poca extensió.

En relació a la mida de les parcel·les agrícoles, es recomana evitar la proliferació de parcel·les agrícoles més grans de 3 ha, ja que les parcel·les de majors dimensions no són seleccionades per les femelles amb polls en l'àrea d'estudi.

Finalment, es proposen algunes millores en relació als cultius del cereal i les pràctiques agrícoles que habitualment es fan servir a l'àrea d'estudi. En primer lloc, caldria evitar la proliferació de cultius de cereal amb una estructura de la vegetació vigorosa, massa densa o alta, per a ser utilitzada com a possible hàbitat de nidificació. També fòra convenient potenciar les varietats de cereal tardanes, la qual cosa permetria retardar la sega del cereal. Això permetria augmentar la disponibilitat de refugi pels polls i per tant, reduir la depredació. Es recomana controlar l'ús de pesticides amb l'objectiu d'incrementar l'abundància de les poblacions d'insectes, especialment d'artròpodes, així com també reduir les molèsties ocasionades per les tasques agrícoles durant el període de cria, per exemple, utilitzant les tècniques de sega menys nocives per a la fauna. Finalment, es recomana afavorir el manteniment del rostoll després de la sega, ja sigui mitjançant la promoció de la sembra directa, com del retard del llaurat fins al mes d'agost.

És la biologia de la conservació inofensiva? El sisó com a cas d'estudi

El disseny de mesures de gestió destinades a la conservació d'una espècie amenaçada, s'ha de sustentar en el coneixement sobre els requeriments ecològics de l'espècie objectiu i sobre els mecanismes que provocaren la regressió poblacional d'aquesta. En animals amb un comportament molt amagadís, com és el cas de les femelles reproductores de sisó, sovint la mera observació no és suficient per a generar aquest coneixement i cal recórrer al marcatge o a la telemetria. No obstant, aquestes tècniques impliquen la captura i manipulació dels animals, la qual cosa pot causar efectes adversos com ara la miopatia, un procés patològic degeneratiu del teixit muscular que es caracteritza per danys en el teixit muscular cardíac i esquelètic i desequilibris fisiològics relacionats amb un esforç o estrès extrems (Williams i Thorne, 1996). Les causes que originen la miopatia són variades, com ara processos patològics o esforços musculars aguts o extrems com ara la fugida a l'atac d'un depredador. Quan la miopatia està relacionada amb la captura, captiveri, manipulació o transport d'animals salvatges o domèstics, llavors rep el nom de miopatia de captura (Hulland, 1993; Williams i Thorne, 1996). Els principals mecanismes fisiològics relacionats amb la miopatia són la hipertèrmia i l'acidosi metabòlica, causada per elevats nivells d'àcid làctic, que s'originen en la glicòlisis anaeròbica com a resposta a una intensa activitat muscular (Wobeser i Howard, 1987; Williams i Thorne, 1996). La patogènesi de la miopatia de captura ha estat descrita per Bartsch *et al.* (1977), Spraker (1980), Chalmers i Barret (1977), i Williams i Thorne (1996). Els símptomes clínics són variables segons l'espècie afectada i poden aparèixer i desenvolupar-se durant la captura i manipulació o alguns minuts, hores, dies o setmanes més tard (Basson i Hofmeyr, 1973; Williams i Thorne, 1996). Generalment inclouen increment de la taxa respiratòria i cardíaca, hipertèrmia, dificultats en la mobilitat com ara parèsia, atàxia, mobilitat reduïda, manca de coordinació i, en alguns casos, la mort (Williams i Thorne, 1996).

En condicions apropiades, qualsevol espècie de vertebrat pot patir miopatia de captura, si bé alguns grups són més susceptibles que d'altres (Williams i Thorne, 1996). Entre els mamífers, la patologia ha estat extensament descrita en artiodàctils (Chalmers i Barrett, 1977; Flanagan i Phillips, 1982), sobretot en cèrvids (Wobeser et al., 1976; Beringer et al., 1996; Montane et al., 2002; Jacques et al., 2009), i també en úrsids (Cattet et al., 2008a; Cattet et al., 2008b). Entre els ocells, s'han documentat episodis de miopatia de captura en varis de grups com ara galliformes (Spraker et al., 1987; Hofle et al., 2004; Abbott et al., 2005), grues (Windingstad et al., 1983; Carpenter et al., 1991; Hanley et al., 2005), ànecs (Bollinger et al., 1989; Dabbert i Powell, 1993), picots (Ruder et al., 2012), estruços (Tully et al., 1996) o limícoles (Rogers et al., 2004). Arran de les captures de sisó dutes a terme durant la realització d'aquesta tesi, es va documentar per primera vegada l'aparició de la miopatia de captura en el sisó (Marco *et al.,* 2006). Entre les otídides s'havia descrit un cas aïllat d'aquesta patologia en hubara (*Chlamydotis undulata macqueenii*)

(Bailey et al., 1996) i s'havia detectat un altre cas en pioc (*Otis tarda*) (Colàs, com. pers.).

No existeix un tractament eficaç i genèric per a curar els efectes de la miopatia de captura (Williams i Thorne, 1996). S'han documentat diversos tractaments com l'administració d'una solució de Ringer (Carpenter et al., 1991; Tully et al., 1996), de Diazepam (Williams i Thorne, 1996), o de bicarbonat sòdic per a contrarestar l'acidosi (Harthoortn et al., 1974; Petit, 1993; Tully et al., 1996), o l'administració intramuscular de seleni i vitamina E, ja que el dèficit d'aquests components en la dieta s'han identificat com a factors de risc (Williams i Thorne, 1996; Abbott et al., 2005; Businga et al., 2007). A banda de la disparitat de substàncies administrables, la dosis de moltes d'elles és desconeguda per a moltes espècies d'ocells (Williams i Thorne, 1996). Si l'administració de substàncies és complicada, els tractaments alternatius són ben escassos. En condicions adequades de captivitat, Rogers et al. (2004) van aconseguir recuperar el 80% dels limícoles afectats per miopatia de captura mitjançant un tractament d'exercitació de la musculatura als ocells afectats, que va permetre'n la regeneració. Tant l'administració de substàncies com l'exercitació de la musculatura suposen la manipulació dels animals que de fet, és la causa principal d'aparició de la miopatia de captura. És doncs paradoxal que el remei a aquesta patologia passi per tornar a manipular els animals, ja que els efectes negatius de l'estrès provocat per la nova manipulació podrien ser més severs que els beneficis del tractament.

Donat que no existeix una solució genèrica a la miopatia de captura, la prevenció és l'eina més eficaç per a combatre aquesta patologia. La prevenció té a més, una component ètica afegida, pel fet d'estalviar sofriment a l'animal capturat. Sovint els casos de miopatia de captura es donen en el transcurs de la captura, captiveri, manipulació o marcatge amb finalitat científiques o de conservació (Spraker et al., 1987; Nicholson et al., 2000; Hofle et al., 2004); per tant generalment les espècies afectades són espècies amenaçades o d'alt interès de conservació. L'ús del marcatge o la telemetria en l'àmbit de la biologia de la conservació estaria justificat quan els possibles efectes nocius o molèsties provocades per la captura, marcatge o seguiment dels animals siguin mínims, i sempre menors que els beneficis d'obtenir informació fonamental per a la conservació de l'espècie amenaçada.

Segons els resultats mostrats en el capítol 2 d'aquesta tesi, l'edat, el mètode de captura i especialment el temps de manipulació i captiveri són els principals factors de risc d'ocurrència de miopatia de captura en el sisó. Aquests havien estat descrits prèviament com a factors de risc de l'aparició de la miopatia (Spraker et al., 1987; Williams i Thorne, 1996; Nicholson et al., 2000; Hofle et al., 2004), si bé també es coneix l'efecte d'altres factors com la hipertèrmia (Chalmers i Barrett, 1977; Williams i Thorne, 1996; Nicholson et al., 2000; però veure Spraker et al., 1987), la humitat relativa elevada (Nicholson et al., 2000; Hofle et al., 2004), deficiències de vitamina E o seleni en la dieta (Hulland, 1993; Abbott et al., 2005), la condició física o possibles malalties (Atkinson i Forrester, 1987), així com la susceptibilitat pròpia de l'espècie i un cert grau de variació individual (Dabbert i Powell, 1993; Hofle et al., 2004). Gràcies al model generat a partir de 151 sisons capturats en diversos projectes de recerca, s'ha determinat que l'escurçament del temps de captiveri és determinant per evitar l'aparició de miopatia de captura i s'ha establert el temps màxim de retenció en 20 minuts, moment a partir del qual s'aconsella alliberar l'animal. Aquest llindar de temps s'ha aplicat en les captures de sisons posteriors a les incloses en aquesta tesi, i el resultat no podia ser millor: s'han marcat 14 exemplars i cap ha sofert miopatia de captura. Per tal de realitzar tot el procediment de marcatge dins d'aquest termini és aconsellable, en primer lloc, establir un protocol de captura i manipulació que reculli, per ordre de prioritats, tots els passos a seguir. Cal restringir les mesures biomètriques o els marcatges als essencials d'acord amb els objectius de recerca. En segon lloc, el personal involucrat en les captures ha de ser conscient de la problemàtica i coneixedor del protocol (Williams i Thorne, 1996). L'especialització de les tasques agilitza notablement el procés de manipulació, ja que permet als membres de l'equip treballar de forma simultània i sincronitzada. D'altra banda, també és recomanable aconseguir que el temps de retenció sigui gairebé nul, estipulant que l'animal s'ha de treure de la trampa immediatament després d'haver-lo capturat, fet que ha obligat als manipuladors a estar sempre alerta mentre la trampa estigui funcional.

La probabilitat de patir miopatia de captura augmenta quan s'utilitza la xarxa canó en relació a altres mètodes, tal i com s'ha observat en altres espècies (Spraker et al., 1987; Williams i Thorne, 1996; Hofle et al., 2004). La detonació dels canons i l'efecte de la xarxa sobre els individus, que sovint queden retinguts en posicions pocs naturals, fan que aquest sigui un mètode de captura especialment estressant (Dabbert i Powell, 1993; Williams i Thorne, 1996). Alguns autors relacionen el grau de lesions musculars amb el temps que l'animal passa sota la xarxa i recomanen treure els animals de la xarxa el més ràpidament possible (Bollinger et al., 1989). D'altra banda, no s'ha detectat l'aparició de miopatia de captura en cap dels ocells capturats amb la trampa embut, la qual cosa indicaria que aquest és un mètode segur per a la captura de femelles amb polls.

L'edat és un altre dels factors que més contribueix a l'aparició de la patologia, essent els sisons mascles de primer any més susceptibles a patir miopatia de captura. En cas de capturar mascles de primer any caldrà rebaixar dràsticament el temps de manipulació i el temps total de retenció de l'animal. Els diversos mètodes de captura descrits en el capítol 2 (la trampa embut, els llaços en leks, els llaços en grups o el salabre) permeten atrapar individus en funció del sexe, edat o període del cicle vital que sigui d'interès per a l'estudi. L'ús del mètode de captura adequat permet maximitzar l'eficàcia de les captures d'acord amb els objectius de la recerca, fet que suposa un estalvi de recursos humans i econòmics. A més, el coneixement de les tècniques de captura pot contribuir a evitar exposar a un risc innecessari a exemplars que no siguin vàlids per a la recerca en curs i proporciona una eina més per a evitar l'aparició de la miopatia de captura en el sisó, aspecte especialment rellevant donada la seva susceptibilitat (Marco et al., 2006). Per tal d'evitar la captura de mascles joves de sisó, es recomana utilitzar la trampa embut quan l'objectiu de la recerca sigui la captura de femelles o polls de sisó. La trampa d'embut és un mètode de captura específic per a atrapar femelles amb polls amb el qual s'evita la captura de mascles joves. Si l'objectiu de recerca és la captura de mascles en el període reproductor, caldrà utilitzar la trampa de llaços tenint en compte que existeix la possibilitat d'atrapar també mascles joves. Segons l'experiència adquirida al camp, els reclams femella atrauen els mascles joves, per tant, és recomanable utilitzar reclams mascles per tal de reduir les possibilitat de capturar un individu jove.

En conclusió, en futurs projectes de recerca es recomana considerar l'ús de metodologies que no impliquin la captura dels exemplars, per exemple ús de càmeres o la identificació individual de mascles reproductors (Arroyo i Bretagnolle, 1999). Si la captura és indispensable per a assolir els objectius de recerca, cal escollir el mètode de captura més eficaç i segur d'acord als objectius de recerca. Es recomana l'elaboració d'un protocol de captura que especifiqui els factors determinants per a l'aparició de la miopatia de captura en el sisó (temps de manipulació i captiveri, mètode de captura i edat) i que també pugui considerar altres factors descrits en la bibliografia. El protocol també hauria d'especificar els passos a seguir i les tasques a realitzar per a cadascun dels membres del personal involucrat en les captures. Un cop acabada la manipulació de l'animal, en el cas que hagi estat radiomarcat, es recomana observar detingudament la mobilitat de l'animal en el moment de l'alliberament, així com fer-ne un seguiment exhaustiu durant al menys els 3 primers dies per tal de comprovar l'estat de les capacitat motores (Cox i Afton, 1998). Finalment, és aconsellable la publicació de l'aparició d'efectes adversos de la captura i manipulació, ja que la informació és la base per a trobar solucions a aquesta problemàtica.

CONCLUSIONS

1. No existeix una tècnica de captura genèrica per al sisó, sinó que cal combinar diversos mètodes de captura en funció del període de captura, així com del sexe i edat dels individus que es vulguin capturar.

2. El sisó és una espècie especialment susceptible a patir els efectes adversos de la captura i manipulació dels exemplars. Els efectes descrits en aquesta tesi són compatibles amb la miopatia de captura.

3. L'aplicació de tècniques de captura i marcatge estaria justificada quan, d'una banda, no sigui possible obtenir la informació mitjançant tècniques que no es basin en la captura dels animals. De l'altra, es maximitzin els beneficis obtinguts per a la conservació de l'espècie i es minimitzin els perjudicis ocasionats als animals.

4. El temps de retenció, la tècnica de captura i l'edat de l'animal són els principals factors que expliquen l'aparició dels efectes adversos. Per evitar-ne l'aparició, cal minimitzar el temps de manipulació (que no ha d'ultrapassar els 20 minuts), prioritzar l'ús de les trampes de llaços enlloc de la xarxa canó, així com intentar evitar la captura d'exemplar joves.

5. L'ús de l'espai en el sisó durant la reproducció varia de forma continua entre un patró espacial més estàtic, en el qual l'animal ocupa una àrea petita i concentrada, i un patró més expansiu, en el qual l'individu ocupa àrees extenses, ja sigui com a conseqüència de llargs desplaçaments o per l'ús de varis centres d'activitat.

6. L'ús de l'espai està fortament condicionat per la qualitat de l'hàbitat, de manera que els animals amb àrees vitals més reduïdes són els que tendeixen a utilitzar en major proporció l'hàbitat d'alta qualitat.

7. Els individus que utilitzen àrees reduïdes són més efectius de cara a la reproducció que aquells que utilitzen àrees més extenses. Per tant, es pot entendre que l'ús d'àrees petites i d'hàbitat d'alta qualitat correspon a una estratègia òptima de reproducció, i l'adopció d'altres estratègies es deu possiblement a algun tipus de limitació en els recursos.

8. L'ús de l'espai dels mascles en el lek respon principalment a la dominància social i a la disponibilitat d'hàbitat d'alta qualitat per a la parada nupcial, però no de la monopolització dels recursos idonis per a les femelles. Els mascles tendeixen a empetitir l'àrea vital i a augmentar l'ús d'hàbitat d'alta qualitat a mesura que augmenta la seva edat i el seu estatus social.

9. En pseudoestepes cerealístiques intensificades, els guarets, erms o cultius de lleguminoses constitueixen un hàbitat d'alta qualitat tant pels mascles com per les femelles amb polls durant la reproducció.

10. L'èxit reproductor del sisó en la població catalana (estimat en 0.27 polls/femella) és insuficient per a garantir-ne la viabilitat. És necessari i urgent endegar mesures de gestió de l'hàbitat encaminades a incrementar l'èxit reproductor de l'espècie.

11. La fenologia de posta és un aspecte determinant per a l'èxit reproductor en el sisó, essent les postes tardanes les que més fracassen.

12. Els exemplars que utilitzen freqüentment els guarets, erms o cultius de lleguminoses, assoleixen major èxit reproductor. La gestió per a la conservació encaminada a augmentar l'èxit reproductor del sisó hauria de promoure l'abundància de guarets, erms o lleguminoses en pseudoestepes cerealístiques. Es recomana la creació de parcel·les de 2-3 ha i separades uns 500 m entre si, sense presència de cultius arbrats en 5-10 ha al voltant seu. La cobertura herbàcia dins d'aquestes parcel·les consistiria en vegetació

silvestre o cultiu de lleguminoses i es mantindria durant tot el període reproductor.

13. En pseudoestepes cerealístiques els marges herbacis constitueixen una font d'alimentació i refugi important per a les famílies de sisó, per tant es recomana que, de mitjana, la parcel·la agrícola disposi de 0.040 ha de marge herbaci.

14. Cal aprofundir en el coneixement de la biologia reproductiva de l'espècie, sobretot en relació a la cria dels polls, per trobar mecanismes que permetin revertir la tendència poblacional regressiva del sisó a Europa.

15. En pseudoestepes cerealístiques les pràctiques agrícoles intensives afecten a la qualitat de l'hàbitat de reproducció del sisó i minven l'èxit reproductor de l'espècie. Amb les pràctiques agrícoles actuals, la conservació de les espècies en les pseudoestepes cerealístiques està en entredit. És necessari trobar noves fórmules que permetin compatibilitzar la producció agrícola amb la conservació de les espècies.

SUMMARY

Biodiversity and agriculture

During the second half of the 20th century, worldwide agricultural intensification allowed an unprecedented increase of crop production (Krebs et al., 1999; Wilson et al., 2005), but it has also brought a simultaneous dramatic loss of biodiversity. Agricultural intensification is a complex process involving increasing levels of mechanisation and chemical use, land use transformation, changes in sowing and harvest dates, landscape homogenization and a progessive loss of natural habitats (Benton et al., 2003; Donald et al., 2006; Newton, 2004; Stoate et al., 2001) that may have severe impacts on biodiversity (Grice et al., 2004; Krebs et al., 1999; Robinson and Sutherland, 2002). In Europe, farmland is the most widely distributed habitat, representing around 45% of the total area. Consequently, it is of critical importance to the conservation of European biodiversity (Stoate et al., 2009). Among agricultural habitats, cereal pseudo-steppes (i.e. dry extensively farmed areas with low or no forest cover, dominated by mixed rotational crops of winter cereals, fodder and grazed fallows (Suárez et al., 1997) hold the largest proportion of declining priority bird species in Europe (Birdlife International, 2004).

Several agri-environmental schemes (AES) have been implemented in order to reduce the loss of biodiversity in these European areas, aiming to support the farming practises that are more compatible with environment and wildlife conservation (Kleijn et al., 2006). AES have proven to be generally effective only when their objectives are well-defined and their prescriptions are based on a precise knowledge of the requirements of the target species, as well as on the understanding of the mechanisms involved in the population decline (Donald et al., 2006; Kleijn et al., 2006). Hence, identifying the ecological requirements and the cause of decline of farmland bird populations is crucial to design efficient management practices.

The little bustard as study case

The little bustard (*Tetrax tetrax*) is an endangered ground-nesting and sexually dimorphic bird that has suffered rapid population declines and range constrictions

throughout Europe during the last decades, mainly attributed to agricultural intensification (BirdLife International, 2004). It is ranked as "Near Threatened" at a global scale (IUCN, 2011) and "SPEC 1" and "Vulnerable" in Europe (BirdLife International, 2004). The Iberian cereal pseudo-steppe agro-systems remain as a stronghold for the species, harbouring the bulk of the world little bustard population (García de la Morena et al., 2004, 2006), but this habitat is extremely vulnerable to agricultural intensification (Stoate et al., 2001; Suárez et al., 1997).

The little bustard is an exploded lekking species (Jiguet et al., 2000). In exploded leks, displaying males are sparsely distributed and aggregation is not detectable until they are mapped over a large area (Höglund and Alatalo, 1995). From their second year of life onwards, little bustard males exhibit breeding ornamental plumage and territorial behaviour and typically spend most of the time displaying at the same place (called arena), which is preferably situated in fallow fields with low herbaceous vegetation (Martínez, 1994, 1998, 2002; Salamolard i Moreau, 1999; Jiguet et al., 2000, 2002; Wolff et al., 2001; Morales et al., 2005b; García et al., 2007; Traba et al., 2008; Delgado et al., 2009, 2010). Although recent studies have found sexual differences on microhabitat selection regarding vegetation structure and habitat preferences (Morales et al., 2008), available information on the ecological requirements of broods in this species is very limited (Lett et al., 2000; Schulz, 1985), due to the secretive behaviour of hens and broods. Although low breeding success has been claimed to be the main threat for the viability of future little bustard populations (Morales et al., 2005a), the surprising lack of studies dealing with ecological requirements of broods hinders the implementation of efficient conservation practices.

Capture and handling birds

Capturing wild animals for research or conservation purposes may cause some adverse effects, which is only acceptable if these are outweighed by conservation benefits (Millspaugh and Marzluff, 2001). Thus it is necessary to evaluate possible adverse effects when animals are trapped, especially when captures are conducted with conservation research purposes (Millspaugh and Marzluff, 2001).

Objectives and structure

The main objective of this thesis is to investigate the ranging behaviour and habitat use of little bustard during the breeding season in an increasingly intensified cereal pseudosteppe, with the aim of designing management practices to ensure future population viability. This thesis also includes methodological aspects which should be considered when capturing and handling animals for research purposes.

Chapter 1. Ranging behaviour and habitat use of the little bustard during the reproductive season

Article 1. *Ranging behaviour of little bustard males,* Tetrax tetrax*, in the lekking grounds*

The main objectives of this research were: to analyse the variation in the ranging behaviour of little bustard males during the mating season; to identify the main underlying factors causing ranging behaviour variation; to discuss the implications of our findings in relation to the mating system of the species.

Article 2. *Brood ranging behaviour and breeding success of the threatened little bustard in an intensified cereal farmland area*

The aims of this study were: to investigate the relationship between little bustard breeding success and breeding dates; to determine if the ranging pattern of the broods was associated to breeding success and breeding phenology; to identify the potential decoupling between arthropod availability and agricultural practices with breeding phenology; to use our findings on the characteristics and structure of the home range of broods to design a feasible management scheme aimed at raising breeding success.

Article 3. *Cereal harvest and habitat-use of little bustard broods in a cereal pseudo-steppe*

Our aim here was to investigate the habitat use and preferences of little bustard broods in a cereal pseudo-steppe, to establish the guidelines that should allow the design of AES aimed to increase little bustard reproductive success in such habitats. Given that vegetation cover experiences dramatic seasonal changes during the reproductive period of little bustards in cereal farmlands, we hypothesized that habitat preferences of broods may be affected by cereal harvest. Hence, we adopted a plot-based, multi-temporal approach to identify differential habitat use of cereal plots by little bustard broods before and after harvest.

Chapter 2: Methodological aspects of capturing and handling birds

Article 4. *Trapping techniques for little bustard* Tetrax tetrax *according to age, gender and season*

Here, we provide information on the design, use and success of four trapping techniques designed to take account of the behaviour and habitat requirements of little bustards according to age, sex and season.

Article 5. *Adverse Effects of Capture and Handling Little Bustard*

The main objectives here were: to evaluate the frequency of occurrence of mobility disorders in little bustards after capture, handling, and radiotagging; to identify factors associated with the occurrence of mobility disorders; to show how an analysis of capture and handling protocols can give relevant cues on how to reduce the incidence of mobility disorders in sensitive species.

Results and discussion

Ranging behaviour and use of habitat

Our results highlighted that the ranging behaviour in the little bustard during the breeding period varies continuously from a static pattern, in which the animal makes short movements within a relatively small area, to a wandering pattern in which the individual uses large areas, either as a result of wandering movements or by the use of several core areas. Although other factors such as anthropogenic disturbances or social constraints might also play a role (López-Jamar et al., 2010), our findings suggest that ranging variability may be mainly determined by the availability and distribution of high-quality habitat. The static pattern might be compatible with a homogeneous, but also with a heterogeneous distribution of high-quality habitat. However, the wandering pattern can hardly be compatible with a homogeneous distribution of resources. According to the *Optimal Foraging Theory* (MacArthur and Pianka, 1966) animals tend to minimize the time and energy devoted to search, capture and consume food, in order to maximize the energy consumed per unit of time. In heterogeneous habitats, where habitat quality is highly variable between patches, animals would tend to concentrate on areas of higher habitat quality (Boitani and Fuller, 2000). If patches offer enough resources to fulfill their ecological requirements, individuals might range according to a static pattern. But if resources are scarce in one patch, the animals will be forced to move to other patches or to use lower-quality habitats, resulting in a wandering ranging behavior. Among little bustard males, the wandering pattern is more common in environments with a heterogeneous distribution of high-quality displaying habitat (Bellmunt area). Among hens, the wandering pattern is linked to the use of lower-quality habitat (field margins or stubble and ploughed fields), while hens ranging according to the static pattern tended to use high-quality habitats (herbaceous crops or fallow fields). Hence, the presence of the wandering spatial pattern in the studied area could suggest that intensified cereal pseudo-steppes might offer scarce resources, distributed heterogeneously through different-quality habitat patches.

Ranging behaviour of little bustard males was not only affected by resources but also by social dominance, related to the lek mating system. The ranging behaviour of a given male may be determined by a tendency to reduce and concentrate the home range as age and social status increase, and several fine-tuning mechanisms adjusting the ranging behaviour to the prevailing environmental or social factors on a given site and year.

In this thesis we also observed that individuals using small areas tended to achieve higher breeding success. The static spatial behavior was associated with successful broods and also with the most active displaying males, which we considered to be dominant. Therefore, the static pattern would correspond to an optimal reproductive strategy, and the adoption of other spatial behaviors would respond to some kind of restriction, e.g. the availability of resources.

Thus, the results showed that the use of space for on the little bustard mainly depends on the availability and distribution of habitat quality. In cereal pseudo-steppes habitat the habitat quality is subject to agricultural practices and tends to impoverish during the rearing period, mainly due to worsening climatic conditioncs and the cereal harvest that remove most of the vegetation cover. According to our findings, in cereal pseudo-steppes the permanent and semi-permanent vegetation plots (fallow fields, sttepe-srubland and legominous fields) could be considered as high-quality habitat not only for displaying males but also for broods. These land uses together with herbaceous field margins may act as food and shelter sources during the entire breeding season.

Conservation implications

We estimated on 0.27 chicks/female the breeding success in the Catalan little bustard population, which is not enough to guarantee the long term viability of the population (Morales et al., 2005a). Based on our findings, the increase of the breeding success of little bustard populations occurring in cereal pseudo-steppes should be a management priority. We suggest the enhancement of habitat quality in order to increase food and shelter availability in cereal agro-systems during the breeding season. We propose the creation of 5–10 ha green cover plots – the size of the observed Temporal Settlement Areas (TSA) of hens – where plant cover should be maintained throughout the entire little bustard breeding season to provide shelter and food for little bustard broods. These plots should be placed approximately 500 m from each other – the mean distance between TSAs – and connected by wide high-quality herbaceous field margins to facilitate movements between them. Within these plots, the presence of tree crops should be avoided, and the abundace of fallow fields, steppe-scrubland or legumionus crops with vegetation cover during the entire breeding season should be promoted.

Capture and handling birds

A combination of trapping methods and strategies are needed to capture little bustards according to sex, age and season. We recommend the use of snares to capture displaying males, funnel traps to capture females or medium-sized to large chicks, and hand-held nets to catch small chicks. We do not recommend capturing in pre-mating or post-mating flocks owing to the high occurrence of capture-related disorders.

Capturing wild animals for research or conservation purposes may cause some adverse effects, which is only acceptable if these are outweighed by conservation benefits. We observed that little bustard is fairly susceptible to suffering ataxia and paresia after release as a result of restraint associated with capture and manipulation. Longer handling time, longer restraint time, use of cannon nets, and capture of juveniles were indentified as inducing factors for these disorders. Staff awareness and teaming during capture and handling is crucial to minimize the risk of occurrence of adverse effects. We also recommend not to exceed 20 minutes of total time of handling and restraint, to keep the risk of occurrence of mobility alterations to a minimum. Caution must be extreme when capturing juvenile birds or when using cannon nets. Under these circumstances, we recommend to keep the total time of handling and restraint below 10 minutes.

Conclusions

1. A combination of trapping methods and strategies are needed to capture little bustards depending on its age or sex and capture season. We recommend the use of snares to capture displaying males, funnel traps to capture females or medium-sized to large chicks, and hand-held nets to catch small chicks. We do not recommend capturing in pre-mating or post-mating flocks owing to the low capture success and the high occurrence of capture-related disorders.

2. The little bustard is a susceptible species to developing mobility alterations after capture and handling, which are compatible with capture myopathy.

3. Handling time, restraint time, trapping technique and age are inducing factors for mobility disorders compatible with capture myopathy. The risk of mobility disorder occurrence could be reduced by keeping handling and restraint time below 10–20 minutes, particularly when using cannon nets or when capturing juveniles.

4. Ranging behaviour on the little bustard during the breeding season varies from a static spatial pattern, with individuals having a small and concentrated home range, to a expanded spatial pattern, on which individuals occupied large areas due to longer distant movements or to the use of several core areas.

5. Those individuals occupying smaller and more concentrated areas tended to use higher proportion of high-quality habitat. So in the little bustard the use of habitat mainly depends on the quality of habitat.

6. Those individuals occupying smaller and more concentrated areas achieved higher breeding success. Hence, the use of small areas with high-quality habitat would be an optimum reproductive strategy, while other strategies might developed when resources are scarce.

7. Social dominance and resource availability, but not the monopolization of female resources, may affect ranging behaviour of males during the breeding season. The ranging behaviour of a given male may be determined by a tendency to reduce and concentrate the home range as age and social status increase, and several fine-tuning mechanisms adjusting the ranging behaviour to the prevailing environmental or social factors on a given site and year.

8. Habitat use of little bustard broods varied from a sedentary pattern, with broods using small areas with situated in high-quality habitat, to a wandering pattern, in which broods move longer distances, used larger areas and less quality habitat.

9. Fallow fields, steppe-scrubland and leguminous crops has been identified as high-quality habitat for males and females during the reproductive season in intensified cereal pseudo-steppes.

10. Breeding success on the Catalan little bustard population (estimated on 0.27 chicks/female) is too low to ensure its viability. Consequently, increasing the breeding success should be a management priority for the conservation of the species.

11. We found that late broods had reduced survival chances, what might indicate that breeding phenology is a contributing factor on the breeding success of little bustard broods.

12. Breeding succes was higher for those individuals using fallow fields, steppe-scrubland or leguminous crops more frequently. In cerealistic pseudo-steppes, management efforts should promote the presence of these land uses to increase breeding success. We recommend the promotion of 2-3 ha plots covered by natural fallows fields, steppe-scrubland or leguminous crops. These plots should be placed approximately 500 m from each other – the mean distance between TSAs – and connected by wide high-quality herbaceous field margins. Tree crops should be minimised 5-10 ha arround these plots.

13. In cereal pseudo-steppes the presence of herbaceous field margins is crucial for little bustard broods due to its function as food and shelter source. We recommend that agronomical fields might have 0.040 ha of herbaceous field margin in average (i.e. in a plot of 1 ha, this would represent a 1-meter wide herbaceous margin).

14. Further studies on the breeding biology of hens and broods should be conducted in order to achieve new mechanisms to revert the regression of the European little bustard populations.

15. In cereal pseudo-steppes, agricultural intensification might affect the quality of the breeding habitat, causing a reduction of the breeding success of the little bustard. Hence, species' conservation is not ensured in the present cereal pseudo-steppes with high level of intensification. New strategies are needed to make compatible the agricultural production with the species conservation.

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Capítol 1

L'ús de l'espai i de l'hàbitat en el sisó durant el període reproductor

Chapter 1

Ranging behaviour and habitat use of the little bustard during the reproductive season

Comportament espacial dels mascles de sisó, *Tetrax tetrax,* en el lek

Anna Ponjoan, Gerard Bota, Santi Mañosa

Resum

En aquest treball s'ha estudiat l'ús de l'espai durant el període reproductor de 18 mascles de sisó (*Tetrax tetrax*). La mida del kernel 95% s'ha estimat en 60 ± 50 ha i l'àrea del cluster 85% en 17 ± 17 ha. Els resultats indiquen que l'estructura de l'àrea vital és tant rellevant com la mida a l'hora d'explicar la variabilitat del comportament espacial dels mascles, que principalment és deguda a l'edat, la qualitat de l'hàbitat i la localitat. El comportament espacial és variable, des de mascles que defensen àrees vitals de mida petita i amb hàbitat d'alta qualitat, a mascles que utilitzen una àrea vital molt més extensa formada per diversos centres d'activitat.

Els resultats indicarien que la dominància social i la disponibilitat dels recursos poden afectar al comportament espacial dels mascles durant el període reproductor. També, les característiques del sistema d'aparellament per lek seria determinant en l'ús de l'espai dels mascles durant el període reproductor. El comportament espacial d'un mascle estaria determinat per la tendència a reduir i concentrar l'àrea vital a mesura que l'edat i la posició social incrementen, i per diversos mecanismes d'ajust del comportament espacial a les condicions ambientals o als factors socials d'un lloc i any determinats.

Article 1

Ranging behaviour of little bustard males, *Tetrax tetrax*, in the lekking grounds

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Abstract

We investigated the ranging behaviour during the breeding season of 18 radiotracked little bustard (*Tetrax tetrax*) males, a disperse-lekking species inhabiting the cereal pseudo-steppes. The average kernel 95% home range was 60 ± 50 ha and the average cluster 85% area was 17 ± 17 ha. Range structure was as relevant as home range size for explaining the variation in the ranging behaviour of males, which could be partially explained by age, habitat quality and site. Ranging behaviour varied from males defending small and concentrated home ranges with high habitat quality, to males holding larger home ranges composed by several arenas. Our results suggest that social dominance and resource availability may affect ranging behaviour of males during the breeding season. Also, mating systems constraints may play a role on the use of space of males within the lekking ground. The ranging behaviour of a given male may be determined by a tendency to reduce and concentrate the home range as age and social status increase, and several fine-tuning mechanisms adjusting the ranging behaviour to the prevailing environmental or social factors on a given site and year.

Keywords: farmland birds, home range, lekking behaviour, little bustard, mating system.

1. Introduction

The ranging pattern of particular individuals is the result of a complex process by means of which they try to fulfil all their needs, involving food, shelter, mates and the reduction of predation risk or competition. Extrinsic factors such as time of the year, habitat quality or population density, as well as intrinsic factors, such as age, gender, body condition or social status, may interact to finally shape the way in which a given individual ranges across space (Alonso and Alonso, 1992; Combreau et al., 2000; Garza et al., 2005; Novoa et al., 2006; Sardà-Palomera et al., 2011; Rhim, 2006). Although resource availability constraints are the factors most frequently identified as ultimately determining the home range shape and size in birds, in lekking species social interactions may also affect the ranging behaviour of males (Alonso and Alonso, 1992; Combreau et al., 2000; Jiguet et al., 2000; Wegge et al., 2003). In lek mating systems, males defend small, clustered courts visited by females to mate (Ligon, 1999). The social organisation of males within a lek is hierarchical, and only a few males contribute to the next generation (Ligon, 1999). The little bustard (*Tetrax tetrax*) is a near-threatened steppe-land bird (BirdLife, 2004) exhibiting a so-called exploded lek mating system (Jiguet, 2002; Morales et al., 2001). From their second year of life onwards, little bustard males exhibit breeding ornamental plumage and territorial behaviour and typically spend most of the breeding season displaying at the same place (called arena), preferably situated in fallow fields with low herbaceous vegetation (Martínez, 1994). In exploded leks, displaying males are considerably separated and aggregation is not detectable until they are mapped over a large area (Bradbury, 1981). It has been argued that this low aggregation potentially allows females to reduce male harassment. It may also allow males to hold larger territories, so they can include larger amounts of the female preferred habitat for foraging or nesting (Jiguet et al., 2000; Ligon, 1999), which differs from the males' preferred displaying habitat (Morales et al., 2008). In that situation, we would expect that higher ranking males would have larger and less concentrated ranges than lower ranking ones, and we would not be talking about a real lek mating system, but about a resource-based polygyny system (Jiguet et al., 2000). Alternatively, higher status males may simply try to occupy or defend optimal displaying places. In this case, higher status males will tend to have smaller home ranges in optimal displaying habitat. The aim of our research was (1) to analyse the variation in the ranging behaviour of little bustard males during the mating season; (2) to identify the main underlying factors causing ranging behaviour variation; (3) to discuss the implications of our findings in relation to the understanding of the mating system of the species.

2. Material and methods

2.1 Study area

The Lleida Plains are situated on the northeastern edge of the Ebro Valley (Catalonia, Spain). The annual rainfall is low (between 300 and 450 mm) and the climate is continental (Bosch, 2004). The little bustard population in the area has been estimated at 700–1300 breeding males (Bota et al., 2004). We conducted our research in two pseudo-steppe Special Protection Area (SPA) sites: Bellmunt-Almenara (ES0000477) and Secans de Belianes-Preixana (ES0000479). The Bellmunt area (1769 ha) (41◦47 N, 0◦57E) was dominated by cereal crops (ca. 80%) with dispersed patches of scrub-steppe or fallow fields (ca. 12%). Female density in this area was estimated at 0.68 ± 0.80 female/100 ha and displaying male density at 2.9 ± 0.5 males/100 ha (unpublished results). The Belianes study site (2583 ha) (41◦35N, 0◦59E) was a farmland area dominated by cereal crops (ca. 83%) with a lower availability of scrub-steppe patches or fallow fields (ca. 3%). Female density in Belianes was estimated at 1.44 ± 0.82 female/100 ha and displaying male density at 3.2 ± 0.6 males/100 ha (unpublished results).

2.2 Home range descriptors

During the breeding season, we caught 18 males (8 in Bellmunt and 10 in Belianes) using snares (Ponjoan et al., 2010). We fitted all birds with TW3 backpack transmitters with a 3-year lifespan battery (Biotrack, Dorset, UK) and 32 g of weight, which corresponded to 4.4% of the bodyweight of the smallest bird and 3.6% of the mean weight of captured birds. These percentages are below the 5% safety threshold indicated by Kenward (2001) for harness mounted tags. We classified males as young (first spring), young adult (second spring), or adult (third spring or older). Young adults and adults males exhibit breeding ornamental plumage and territorial behaviour (Johnsgard, 1994), but they can be distinguished by means of plumage pattern (Otero, 1985). We determined the sex of first spring female-like males by genetic analyses of blood samples (0.1 ml collected by femoral vein puncture). Marked males were tracked once a day and five days per week from 1st April to 15th June over one to three mating seasons from 2002 to 2005. We monitored birds from ground vehicles using a handheld 3-element Yagi antenna and a portable scanning receiver (ATS R4000; Advanced Telemetry Systems Ltd.). The incremental analysis of the Ranges7 software (South et al., 2005) indicated that 14 locations were sufficient to obtain stable range estimates, similar to those used in previous bustard studies (Hingrat et al., 2004; Jiguet et al., 2000). The four locations recorded immediately after a bird was released were not taken into account, in order to avoid confusion resulting from possible alterations in the ranging behaviour associated with the capture (Kenward, 2001).

We described two characteristics of the ranges, their size and the distribution of fixes within them, using different estimators implemented in Ranges7 (South et al., 2005). As estimators of size (ha) we used the following parameters: (i) *MCP95*, the area of the Minimum Convex Polygon encompassing 95% of the bird locations (the 5% locations farthest away from the recalculated arithmetic mean centre were excluded); (ii) *Kernel95*, the area of the 95% core weighted kernel density estimator, using the reference method to determine the smoothing parameter. This home range size estimator has been successfully used in other little bustard studies (Jiguet et al., 2000); (iii) *Cluster85*, the area resulting from a cluster analysis joining 85% of fixes in groups based on the nearest neighbour distance.

To describe the distribution of fixes within the ranges, we first estimated the following parameters: (i) *Units*, the number of independent clusters per range identified by the cluster 85% analysis; (ii) *Partial*, the proportion between the sum of the area of the separate clusters divided by the area of a single minimum convex polygon encompassing all of them. Then we conducted a Principal Component Analysis to summarise the information conveyed by *Units*, *Partial* and *Cluster85*. We used the resultant first component, called *Aggregation*, as an indicator of the level of aggregation of fixes within each range.

In ranges composed of several cluster units, these can be used simultaneously by moving constantly from one to the next, or sequentially by conducting very few movements between clusters. We calculated the proportion of movements within a single unit in relation to the total number of movements, as an index of sequential (high proportion) or simultaneous (low proportion) use of the cluster areas.

2.3 Habitat use

Each year, we mapped patches of scrub-steppe and fallow fields of the entire area used by each male. These land uses are considered the most suitable habitats for displaying, because the structure of the vegetation provides both conspicuousness and potential food resources (Martínez, 1994; Salamolard and Moreau, 1999). We used digital 1:5000 maps and Arcview 3.2 software (Environmental Systems

Research Institute Inc., 1996) to estimate habitat use by calculating: (i) *Habitat C85*, the area (ha) of optimum display habitats within the clusters 85%; (ii) *%Habitat C85*, the proportion of area of optimum display habitats within the clusters.

2.4 Display rate

In 2003, we estimated the number of snort calls/min and the number of wing-flashes/min on 10 young adult or adult males (7 in Bellmunt and 3 in Belianes), in the peak of the mating season (from 5th until 23rd of May). We conducted 32 focal observation sessions (median: 3 sessions/individual) during the two hours after dawn or before sunset. During 20 min, we counted the number of snort calls (the basic display, consisting of a brief vocalisation uttered with a sharp toss of the head), and the number of wing-flashes (foot stamping, snort calling and finally a wing beating with the feet on the ground or jumping 20–100 cm) (Jiguet and Bretagnolle, 2001) performed by each male. Snort calls involve male–male interactions, while the wing-flash display is performed in the presence of females, supporting its inter-sexual function (Jiguet and Bretagnolle, 2001).

2.5 Statistical analyses

In order to avoid pseudoreplication caused by including individuals tracked during several years, we calculated the mean value for each home range descriptor and individual across years, and used every individual average as a sample unit (Hurlbert, 1984). We used the chi-square test to assess the assotiation between categorical variables. We checked for normality and homogeneity of analyzed variables by visual inspections of plots of residuals against fitted values. We used ANOVA for continuous variables showing a normal distribution, and Mann–Whitney *U* or Kruskall–Wallis tests for non-parametric variables. Individual differences on home range descriptors between consecutive seasons were analyzed by means of two-related sample t-test. To assess associations between display rates and home range descriptors we used two-tailed Spearman rank correlation coefficient. Statistical analyses were performed using SPSS v.12.0 (SPSS, 2001).

We used general linear mixed models (GLMM) with normal error and link identity function to assess which factors determined the size and *Aggregation* of home ranges. We checked for normality and homogeneity by visual inspections of plots of residuals against fitted values. To ensure normality, both response variables were $\log_{10}$ transformed (Zuur et al., 2007). We included in the model the home range area (*Kernel95*) as dependent variable and *age* (young, young adult, adult), *site* (Belianes, Bellmunt), *%Habitat C85* (proportion of optimal displaying habitat within the cluster area) as fixed factors. We also included the number of fixes per ranges as a fixed factor to dismiss its possible effect on home range size. As some males were tracked in different seasons, the identity of the bird was fitted as random factor in the models to account for repeated measures taken at this level (Pinheiro and Bates, 2000). We also considered *year* (2002, 2003, 2004, 2005) as a random factor because we could not control for this effect. Only variables with a significant effect ($P < 0.05$) were retained in the final model. To assess the validity of the mixed effects analyses, we performed like-lihood ratio test comparing the models with fixed effect to the null models with only random effects. We rejected results in which the model including fixed effects did not differ significantly from the null model. We conducted another GLMM following the same procedure but using *Aggregation* as dependent variable. GLMM models were conducted with R v.2.13.1 (R Development Core Team, 2009).

3. Results

3.1 Home range description

We obtained 40 ranges, among which we recorded two extremely large values (*MCP95* = 7595 ha and 658 ha, respectively), corresponding to 2 males who spent less than 5 days in the lekking ground and subsequently moved to post-breeding areas (38 and 10 km away). Further analyses were based on the 38 remaining ranges (1146 radiolocations; 30 ± 7 fixes/range), corresponding to 18 males that stayed within the lekking ground during the entire breeding season. We observed a large variation on the size and shape within these 38 ranges (Fig. 1), most of which occupied < 40 ha (Fig. 2) and included 1–3 cluster units (Fig. 3). Based on the individual mean (n = 18 individual ranges) home range size was estimated on 70 ± 41 ha (*MCP95*) or 60 ± 50 ha (*Kernel95*), and core area on 17 ± 17 ha (*Cluster85*).

3.2. Factors related to ranging behaviour

The final GLMM fitted to *Kernel95* included *age* (coefficient = −0.164, $t = -2.548$, $P = 0.021$), *site* (coefficient = −0.691, $t = -4.578$, $P < 0.000$) and proportion of optimal displaying habitat within the cluster area (*%Habitat C85*) (coefficient = −0.011, $t = -7.008$, $P < 0.000$). We did not detect a significant effect of the number of fixes per range on home range size. Results indicated that range size was larger in Bellmunt than in Belianes, and larger for non-adult than for adult birds (Table 1).

Range size also decreased with higher proportion of display habitat within the cluster areas.

The Principal Component Analysis explained 66.3% of the variation of the aggregation of fixes within a range. The first component of the analysis, called *Aggregation*, was positively correlated with *Partial* (r = 0.952) and *Cluster85* (r =

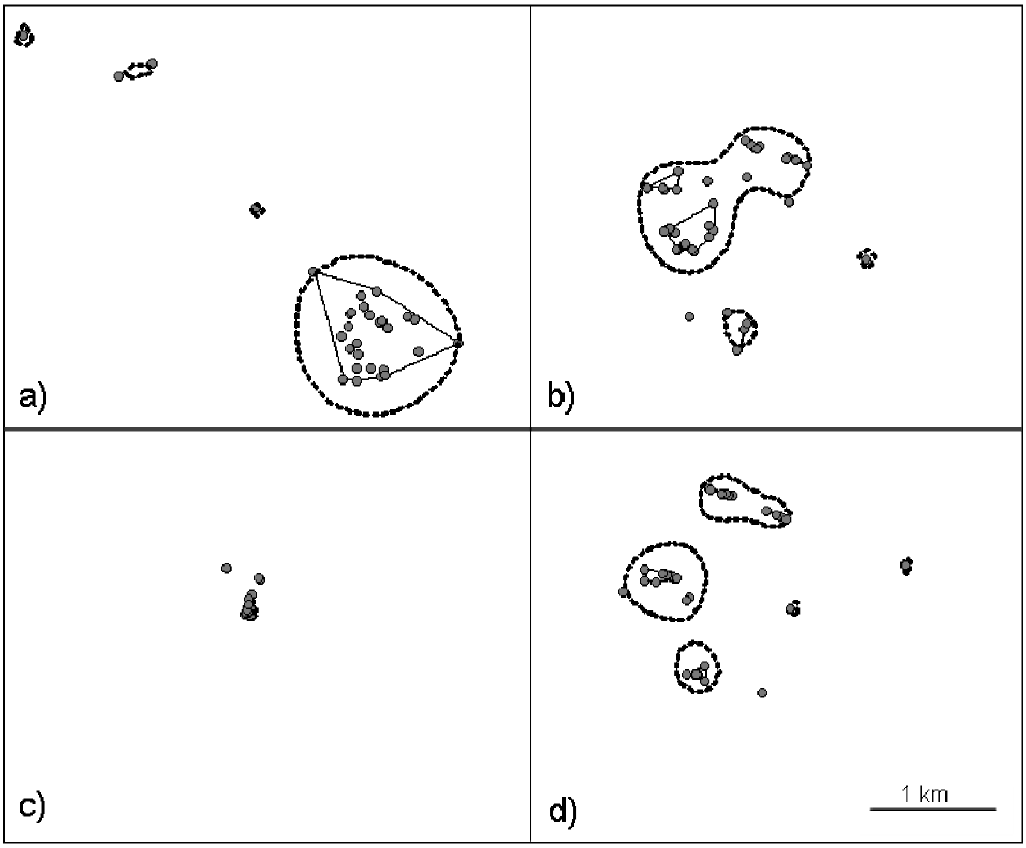

Fig. 1. Four examples of the ranging pattern (dotted line, Kernel95 area; bold line, Cluster85 area; dots: fixes) of little bustard males radiotracked in the Lleida Plains during the mating season (a: young; b: young adult; c: adult from Belianes; d: adult from Bellmunt). All ranges at the same scale.

0.475) and negatively correlated with *Units* (r = −0.927), so it can be viewed as a descriptor of the concentration of locations. High values of *Aggregation* indicate ranges with locations concentrated in a single cluster area, which constitute most of the range, while low values correspond to more patchy or fragmented ranges, made up of 3–5 units which constitute only a small fraction of the total range. The final GLMM fitted to *Aggregation* included only *site* (coefficient = 0.221; $t = 2.016$; $P = 0.040$). The model shows that in Belianes male ranges tended to be more concentrated, while in Bellmunt males settle in a higher number of units (Fig. 3). The proportion of ranges with a single unit was significantly higher in Belianes (52.6%) than in Bellmunt (21.1%) (Chi-square test: df = 1, $P = 0.044$) (Fig. 3). We also observed that the proportion of optimal displaying habitat within the cluster area was significantly higher in Bellmunt than in Belianes (Mann–Whitney test, $U = 85$, $P = 0.005$) (Table 1).

Among males with several cluster units, the proportion of movements within a single unit varied significantly in accordance with the number of units within the range (ANOVA, $F_{2.21} = 10.344$, $P = 0.001$). The post hoc tests revealed significant

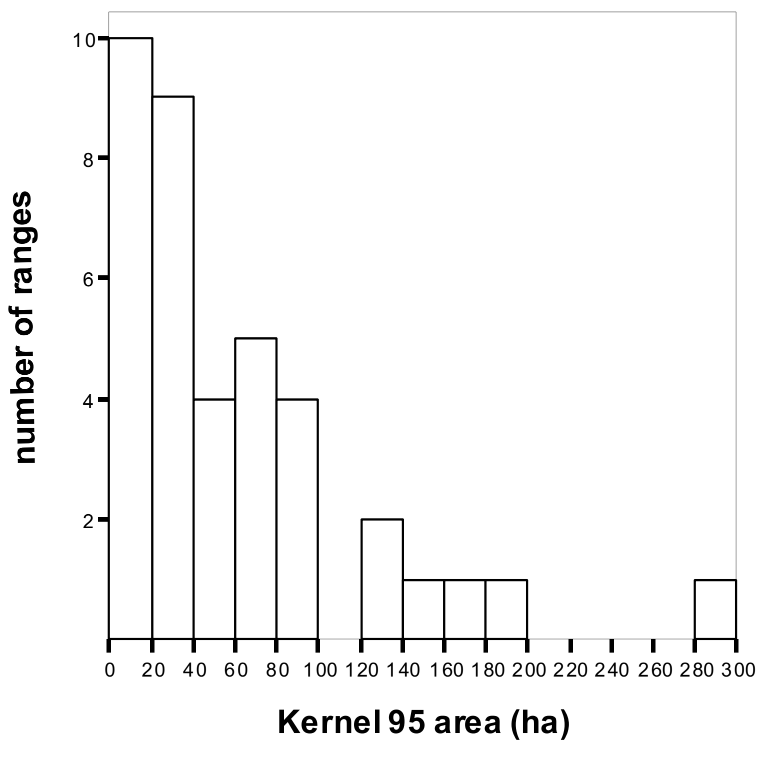

Fig. 2. Frequency distribution of home range sizes of 38 ranges corresponding to 18 little bustard males radio-tracked in the Lleida plains during the breeding season.

differences between ranges composed of 2 units (62.5% ± 8.3%, n = 10) and 3 units (46.7% ± 13.8%, n = 9) (Bonferroni test: P = 0.011), and also between ranges with 2 units in relation to ranges with > 3 units (38.1% ± 7.3%, n = 5) (Bonferroni test: P = 0.001).

3.3 Interannual variation in ranging behaviour

To compare the ranging behaviour of the same individual in two consecutive seasons we monitored 14 birds for several years (resulting in 20 year to year transitions).

When considering together young and young adults, home range size tended to decrease significantly from 77.9 ± 50.1 ha to 29.0 ± 21.2 ha between consecutive years (Paired t-test, t = 2.530; P = 0.039). *Aggregation* increased significantly from −0.12 ± 1.25 to 0.44 ± 0.87 between seasons (Paired t-test, t = −2.484; P = 0.042). In adult males neither home range size (Paired t-test, t = −0.301; P = 0.769) or *Aggregation* (Paired t-test, t = 0.176; P = 0.864) varied significantly between seasons.

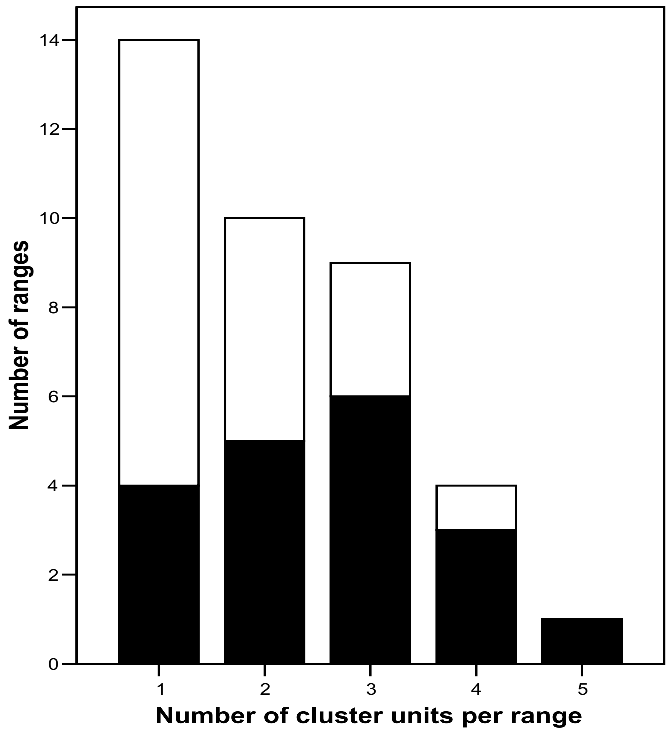

Fig. 3. Frequency distribution of the number of cluster units per range according to study site (black fill: Bellmunt; white fill: Belianes) of 38 ranges corresponding to 18 little bustard males radio-tracked in the Lleida plains during the breeding season.

3.4 Display behaviour

Wing-flash rate was correlated with *Aggregation* (Spearman's rho = 0.683, *P* = 0.030) and *%Habitat C85* (Spearman's rho = 0.717, *P* = 0.020), but not with *Kernel95* (Spearman's rho = −0.471, *P* = 0.169). These results indicated that males with higher wing-flashed display rate held more concentrated ranges with a higher proportion of optimal displaying habitat. Males using a unique cluster area performed the wing-flash display more frequently (0.45 ± 0.26 wing-flashes/min) than males

Table 1. Home range characteristics of little bustard males radio-tracked during the mating season in the Lleida Plains (NE-Spain), according to age categories and study site.

	Age			Study site	
	Young	Young adults	Adult	Bellmunt	Belianes
	n = 4	n = 8	n = 14	n = 8	n = 10
Kernel95 (ha)	88.1 ± 57.9	72.4 ± 40.6	41.4 ± 54.4	72.0 ± 59.9	50.1 ± 42.0
MPC95 (ha)	101.8 ± 58.9	95.5 ± 57.5	46.9 ± 32.7	69.6 ± 28.2	69.9 ± 50.8
Cluster85 (ha)	36.9 ± 28.6	19.8 ± 15.7	9.0 ± 8.7	13.3 ± 8.8	20.0 ± 21.8
Units C85 (nº)*	1.5 (1-3)	2.0 (1-5)	1.7 (1-4)	2.5 (1-5)	1.5 (1-4)
Habitat C85 (ha)	2.7 ± 3.9	1.4 ± 1.0	1.9 ± 1.9	3.0 ± 1.8	1.6 ± 2.5
%Habitat C85	8.2 ± 5.9	10.9 ± 10.8	44.2 ± 29.2	44.3 ± 12.9	18.3 ± 18.3

* Median (range).

using several clusters (0.06 ± 0.15 wing-flashes/min) (Mann–Whitney test, *U* = 1, *P* = 0.015). The wing-flash rate was independent of *age* (between young adults and adults) (Mann–Whitney test, *U* = 4, *P* = 0.239) or *site* (Mann–Whitney test, *U* = 4.5, *P* = 0.123).

The snort call rate was not significantly correlated with *%Habitat C85* (Spearman's rho = 0.491, *P* = 0.150), *Aggregation* (Spearman rho = −0.079, *P* = 0.829) or *Kernel95* (Spearman rho = 0.212, *P* = 0.556). We did not detect significant differences on snort call rate between males using a unique cluster area (1.33 ± 0.60 calls/min) or several ones (2.00 ± 1.58 calls/min) (Mann–Whitney test, *U* = 9, *P* =

0.732). We did not detect significant differences on snore call rate according to *age* (between young adults and adults) (Mann–Whitney test, U = 4, P = 0.296) or *site* (Mann–Whitney test, U = 6, P = 0.305).

4. Discussion

Our home range size estimates fall within the upper values ever reported (Jiguet et al., 2000; Petretti, 1993; Schulz, 1985), which may be associated with methodological differences between studies, but also with habitat or demographic differences between populations. We detected two extremely large ranges, which corresponded to two males that visited the lek for a very short period of time, and subsequently moved outside. This behaviour was consistent with the satellite pattern described by Jiguet et al. (2000) and Jiguet and Bretagnolle (2006), which would correspond to birds switching from one lek site to another during the breeding season or giving up the breeding attempt. The remaining ranges involved birds staying within a single lek during the entire breeding period, and may correspond to the resident pattern of Jiguet et al. (2000). These authors observed a large variation within this pattern, but did not attempt to identify the factors causing such variation. We observed that resident birds held territories with one or several cluster areas, each one probably corresponding to a different displaying arena. In fact, most males held several arenas, and we found that variation in range structure (number of arenas and aggregation of fixes) was as relevant as home range size for explaining the variation in the ranging behaviour of little bustard males during the breeding season.

It has been suggested that little bustard males may defend large territories to assure a higher availability of the females preferred nesting or brooding habitats, in which case we should be talking about a resource-based mating system (Jiguet et al., 2000). Morales et al. (2001) suggested that such strategy may develop in highly intensified agricultural habitats, as a response to a decrease in habitat quality and the increased cost of mate search. In such situations, we would expect higher rank males to own larger territories than lower ranking males. However, we actually detected the reverse: adult and probably higher rank males tended to hold smaller ranges with larger amounts of optimal displaying habitats (fallow fields and scrub-steppe), which are not the habitats used by females to breed in our study area (Lapiedra et al., 2011). These findings are in agreement with Jiguet et al. (2002) who found that male attractiveness was not related to the level of resources used by females within their territories. Hence, our findings support the general opinion that little bustard mates according to an exploded-lek or dispersed polygyny mating system, depending on the degree of male aggregation exhibited in different populations (Jiguet et al., 2000).

Four main hypothesis had been suggested to explain the occurrence of male clustering on leks (Bradbury, 1981): (i) the female preference hypothesis states that females prefer to mate with males that are aggregated; (ii) the black hole model states that male aggregation results from the fact that the probability of males retaining a female is highest if males are clustered; (iii) the hotspot hypothesis states that males cluster in areas were female density is the highest; and finally (iv) the hotshot model, in which the formation of leks results from the aggregation of suboptimal males around more attractive males in order to parasite their attractiveness. Although our study was not primarily aimed to address the issue of lek evolution, the first two hypotheses predict that all males in a lek, irrespective of their social status, should benefit from aggregation, which would result in a small variability in ranging patterns. The large variation observed in the ranging pattern of males in our study area is more consistent with a scenario of social dominance where, while some males may try to monopolize and exclude others from the best displaying sites, others may be obliged to adopt a more itinerant behaviour. This is consistent with the hotspot and the hotshot hypothesis of lek evolution.

Indeed, our results showed a relationship between range size and age, which has also been previously reported in lekking (Alonso and Alonso, 1992; Ballard and Robel, 1974; Healy, 1992; Wegge and Larsen, 1987) and non-lekking species (Badyaev et al., 1996; Nesbitt and Williams, 1990; Thogmartin, 2001). Adult males tended to use smaller ranges than young or young adult males. Besides, adult little bustards tended to use higher percentages of high quality displaying habitats than younger birds. This trend agrees with Jiguet et al. (2000), who found that range size in little bustard males increased with the proportion of unsuitable male displaying habitats. It also agrees with the results of Traba et al. (2008), who showed that little bustard males tend to establish territories in areas with higher food availability. Globally considered, these results indicate that adult males are probably dominant and they occupy the best territories, so that they can fulfil all their requirements with the minimum need to move, which probably increases their mating opportunities. In lekking species, older individuals are usually preferred by females and have a higher mating success (Kirkpatrick, 1987; Ligon, 1999; Manning, 1985) so they are considered to have a higher social rank (Alonso et al., 2010; Ligon, 1999; Pelletier and Festa-Bianchet, 2006). On the contrary, young or young-adult birds used larger ranges with lower proportion of optimal display habitats, perhaps as a result of being displaced from the best places by higher status males or, alternatively, because they move from place to place trying to parasitize more attractive and dominant males, as proposed by the hotshot model of lek evolution.

High rates of display are an indication of health status and ejaculate quality in the houbara bustard (*Chlamydotis undulata*) (Charge et al., 2010). In the little bustard, we found that the frequency of wing-flashes was higher in males occupying the best habitats, which is probably reflecting their highest attractiveness or social status. The wing-flash rate was also higher in males holding more aggregated ranges, which is also an indication of their higher performance and probably social status.

However, social dominance alone cannot explain all the variation observed. Our results show a significant effect of site on both size and patchiness of the ranges. Ranges tended to be larger and more dispersed in Bellmunt than in Belianes. It is difficult to tell whether this difference is simply the consequence of the higher availability and dispersion of displaying habitat in Bellmunt, which would facilitate the movement between displaying sites. However, the fact that displaying rates are higher in males holding a single arena than in males holding several ones might indicate that increased range patchiness is not a facultative option, but rather the consequence of some constraint. We may thus assume that higher range patchiness in Bellmunt is ultimately caused by increased inter-male competition: low female density may force males to move from place to place in an attempt to locate better female sites, in agreement with the hotshot hypothesis. The sequential use of several arenas may reflect such kind of behaviour, while the simultaneous use of them might be more consistent with the presence of males constantly moving from place to place in the attempt to parasitize mating opportunities from more attractive males, in agreement with the hotspot model.

In conclusion, the ranging behaviour of a given little bustard male in a particular year and site may be determined as a result of a combination of different factors: a tendency to reduce the home range in adult males and several finetuning mechanisms adjusting the ranging behaviour to the prevailing environmental or demographic conditions on a given site (particularly the availability of displaying habitats and hens).

Our results also show that males displaying in different, separated arenas are not necessarily different individuals, because the most common ranging pattern was to switch between subsequent arenas. This means that the best estimate of breeding males in a given area is the maximum number of birds seen on a given counting session, rather than considering the accumulated number of arenas observed in several counts.

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Article 2

Comportament espacial i èxit reproductor de les famílies de sisó en ambients cerealístics intensius

Oriol Lapiedra, Anna Ponjoan, Anna Gamero, Gerard Bota, Santi Mañosa

Resum

A Europa, les estepes cerealístiques alberguen la major proporció d'espècies en declivi. Entendre com es produeix aquest declivi és clau per a dissenyar mesures de conservació adequades. El sisó (*Tetrax tetrax*) és un exemple d'espècie amenaçada d'au estepària en regressió tant pel que fa a l'àrea de distribució com en el nombre d'efectius de les seves poblacions. L'escàs èxit reproductor de l'espècie s'ha identificat com a una de les principals amenaces per a la viabilitat de les poblacions de sisó. Malgrat això, sorprèn la manca d'estudis sobre els requeriments ecològics de les femelles amb polls fet que dificulta la implementació de mesures de conservació eficients.

En aquest treball hem estudiat l'ús de l'espai i l'èxit reproductor del sisó mitjançant el radioseguiment de femelles dut a terme durant els períodes reproductors de 2006-2008 a la plana de Lleida. L'èxit reproductor es va estimar en 0.27 polls/femella, i segons els models demogràfics obtinguts en anteriors estudis de sisó aquest seria insuficient per a garantir la viabilitat de la població. S'ha observat que les postes més primerenques tenien més possibilitats d'eclosionar i de tirar els polls endavant. Aquest fet està associat a dos patrons de moviment (i.e. el sedentari versos l'erràtic) que depenen de l'habilitat de la femella i dels polls d'establir-se en determinades àrees on disposin de suficient alimentació i refugi pels polls. Aquests recursos es veuen dràsticament reduïts al llarg de la temporada de cria. En conjunt, els resultats suggereixen que les pràctiques agrícoles, especialment la sega, minven l'èxit reproductor ja sigui directament per la destrucció de nius com indirectament per la reducció dels recursos disponibles per a les famílies. En base a les nostres troballes de les característiques i estructura de l'àrea vital de les femelles amb polls,

recomanem la creació d’una xarxa de parcel·les ocupades permanentment al llarg de la època de cria per vegetació herbàcia, que estiguin connectades entre si per marges herbacis com a mesura de conservació per a incrementar l’èxit reproductor del sisó així com també d’altres espècies d’ocells nidífugs de secà.

Article 2

Brood ranging behaviour and breeding success of the threatened little bustard in an intensified cereal farmland area

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Abstract

Cereal pseudo-steppes hold the largest proportion of declining bird species in Europe. Understanding how this process of decline is driven is essential for designing adequate management practices. The little bustard (*Tetrax tetrax*) is one of such threatened steppe-land bird species, which has suffered recent dramatic range constrictions and population declines. Although low breeding success has been claimed to be the main threat for the viability of future little bustard populations, the surprising lack of studies dealing with ecological requirements of broods hinders the implementation of efficient conservation practices. We studied the ranging behaviour and the reproductive success of a little bustard population by means of female radio-tracking conducted during 2006–2008 breeding seasons in the Ebro basin (NE Spain). We recorded an average breeding success of 0.27 chicks/hen, which is not enough to sustain a viable population according to the demographic models for the species. Early laid clutches showed more probabilities to hatch and to fledge. This was associated to two different ranging patterns (i.e. sedentary versus wandering respectively) which depended on the ability of the hen and its chicks to settle in suitable areas harbouring enough arthropods and shelter for chicks. Such resources decrease drastically as the breeding season progresses. Overall, data suggest that agricultural practices associated to agricultural intensification, particularly early harvest, reduce breeding success both directly by nest destruction and indirectly through a decrease on resource availability for broods. Based on our findings on the characteristics and structure of the home range of little bustard broods, we propose the creation of a network of permanent vegetation plots interconnected by high-quality field margins as a management practice to raise the breeding success of little bustards and other ground-nesting birds on cereal farmland.

Keywords: ranging behaviour, farmland management, arthropod availability, steppe-bird conservation, agricultural intensification, Lleida plains

1. Introduction

Changes in farming system and agricultural intensification allowed an unprecedented increase in agricultural yields in the last decades (Krebs et al., 1999; Wilson et al.,

2005) but also entailed a dramatic loss of biodiversity (Stoate et al., 2009). Agricultural intensification is a complex process involving increasing levels of mechanization and chemical use, land use transformation, changes in sowing and harvest dates, landscape homogenization and the loss of natural habitats (Benton et al., 2003; Donald et al., 2006; Newton, 2004; Stoate et al., 2001) that may have severe impacts on biodiversity (Grice et al., 2004; Krebs et al., 1999; Robinson and Sutherland, 2002) and has been reported to cause a severe decline in the abundance and diversity of flowering plants (Wilson et al., 2005), arthropods (Sotherton and Self, 2000), mammals (Flowerdew and Kirkwood, 1997) and birds (Bas et al., 2009; Chamberlain et al., 2000; Donald et al., 2006; Tucker and Heath, 1994), where the connection between agricultural intensification and population declines has been identified in a variety of agrarian systems (Brennan and Kuvlesky, 2005; Donald et al., 2001; Fuller, 2000; Semwal et al., 2004; Söderström et al., 2003).

In Europe, farmland is the most widely distributed habitat, representing around 45% of the total area. Consequently, it is of critical importance to the conservation of European biodiversity (Stoate et al., 2009). Among agricultural habitats, cereal pseudo-steppes (i.e. dry extensively farmed areas with low or no forest cover, dominated by mixed rotational crops of winter cereals, fodder and grazed fallows (Suárez et al., 1997)) hold the largest proportion of declining priority bird species in Europe (Birdlife International, 2004; Burfield, 2005). One such species is the little bustard (*Tetrax tetrax*), an endangered ground-nesting sexually dimorphic bird that has suffered rapid population declines and range constrictions throughout Europe during the last decades, mainly attributed to agricultural intensification (BirdLife International, 2004; Del Hoyo et al., 1996; Goriup, 1994). It is ranked as "Near Threatened" at a global scale (IUCN, 2011) and "SPEC 1" and "Vulnerable" in Europe (BirdLife International, 2004). The Iberian cereal pseudo-steppe agro-systems remain as a stronghold for the species, harbouring around 50% of European little bustard population (García de la Morena et al., 2004, 2006), but this habitat is extremely vulnerable to agricultural intensification (Brotons et al., 2004; Stoate et al., 2001; Suárez et al., 1997). Previous research indicates that the demographic viability of declining little bustard populations is seriously compromised by extremely low breeding success (Inchausti and Bretagnolle, 2005; Morales et al., 2005a). However, the vast majority of research on the reproductive biology of little bustards deals with the requirements of males (e.g. Delgado et al., 2010; Delgado and Moreira, 2010; García et al., 2007; Jiguet et al., 2000; Jiguet and Bretagnolle, 2001; Jolivet and Bretagnolle, 2002; Martínez, 1994; Morales et al., 2005b; Petretti, 1993; Schulz, 1985; Silva et al., 2010; Traba et al., 2008; Wolff et al., 2001), which do not take part on parental care (Morales et al., 2001; Schulz, 1985). Low breeding success has been attributed to agricultural intensification, both directly through nest destruction during harvest activities and indirectly through a decrease in the abundance of arthropods (Bretagnolle et al., 2011; Inchausti and Bretagnolle, 2005) that constitute the diet of chicks during the first weeks of life (Jiguet, 2002). Thus, increasing our understanding of the behaviour and ecological requirements of little bustard broods (hen with chicks) is a critical point for the conservation of the species. Although two recent studies have found sexual differences on microhabitat selection regarding vegetation structure (Morales et al., 2008) and habitat preferences (Morales and Traba, 2009), available information on the ecological requirements of broods in this species is very limited (Lett et al., 2000; Schulz, 1985), due to the secretive behaviour of hens and broods. This limitation constitutes a crucial problem hindering the implementation of efficient conservation practices to prevent little bustard population declines.

Non-irrigated cereal crops are a very dynamic habitat in which harvest dramatically changes the landscape and the environmental conditions with which birds must cope with during the rearing period. On the other hand, arthropod availability has been suggested to be determinant to the species' breeding success (Bretagnolle et al., 2011; Inchausti and Bretagnolle, 2005; Morales et al., 2005a; Villers, 2010). In this study, we used female radiotracking to investigate the relationship between agricultural practices in an increasingly intensified cereal farmland habitat and the ranging behaviour and breeding success of the little bustard, with the aim of designing management practices to ensure future population viability. Our specific aims were (i) to investigate the relationship between breeding success and breeding dates; (ii) to determine if the ranging pattern of the broods was associated to breeding success and breeding phenology; (iii) to identify the potential uncoupling between arthropod availability and agricultural practices with breeding phenology;

(iv) to use our findings on the characteristics and structure of the home range of little bustard broods to design a feasible management scheme aimed at raising breeding success.

2. Material and methods

2.1 Study area

We captured little bustard females in the Lleida steppe plains (Catalonia, NE Spain), a 800 km2 strip of pseudo-steppes on the Eastern edge of the river Ebro basin, 400 m above sea level, with an average temperature ranging from 7 ºC in winter to 25 ºC in summer and an average annual rainfall of 300–400 mm (Estrada et al., 2004). This area hosted a little bustard population of 1158 males (95% CI: 898–1418) and 656 females (95% CI: 444–868) in 2002, which is estimated to have experienced a decline of 23% between 2002 and 2009 (unpublished data) presumably as a result of the destruction of high-quality habitat – particularly fallow land and field margins – associated to the agricultural intensification process (Estrada et al., 2004). Within the study area, there was no spatial segregation between displaying males and breeding females. Landscape is dominated by cereal pseudo-steppe, where 79% of land corresponds to non-irrigated herbaceous crops (mainly winter cereal crops), 6% to Mediterranean steppe-scrub vegetation and fallow fields, 6% to almond and olive tree crops, 5% to bare soil, 2% to field margins and 2% to other land uses. The proportion of fallow fields and steppe-scrub vegetation, which are considered to be indicators of a low degree of agricultural intensification (Peco et al., 1999), is one of the lowest among the Iberian breeding range of the species, where it usually represents between 10% and 30% of farmland (Delgado et al., 2009; Silva et al., 2007). Mean cereal yield in the area, which is a good indicator of agricultural intensification (Donald et al., 2001, 2006), is 2.55 t/ha (Cantero-Martínez et al., 2007), higher than the 1.97 t/ha in the Castilla-La Mancha region (http://pagina.jccm.es/agricul/cifras/cereales/cebada), one of the areas with higher little bustard densities in Spain. Landscape changes associated to intensification occurred progressively in the study area throughout the 20th century. For example, the use of herbicides, pesticides, and chemical fertilizers became generalized between 1960 and 1970 (Aldomà, 2004) while the proportion of fallows and setasides decreased from 50% in the mid-thirties (Giralt et al., 2006) to the current 6%. Consequently, annual productivity progressively increased becoming three times higher in 2000 than in 1950 (Aldomà, 2004). The area is still undergoing agricultural intensification through field enlargement and margin elimination, removal of fallow land, and reduced time between cereal harvest and stubble ploughing. Hence, the non-irrigated cereal crops from Lleida plains were an appropriate scenario to investigate the main factors hindering breeding success of a little bustard population in an agricultural intensified area.

2.2. Capture and radio-tracking

We captured 23 little bustard hens between 15th June and 15th July of 2004 (six females), 2005 (seven females), and 2006 (10 females) using funnel traps. This method was specifically designed to capture females and has been reported to perform much better than previous methods both in terms of efficiency and, most importantly, animal welfare (Ponjoan et al., 2010). We tagged females with 2-to-3 year-lasting TWR-1AA backpack transmitters (Biotrack, Dorset, UK) always representing <4% of the individuals' body weight (Kenward, 2001) and both a metal ring and an individual combination of two coloured coiled plastic rings. We radio-tracked the hens during the subsequent 2006–2008 breeding seasons by using a portable scanner-receiver and a 3-element Yaggi antenna and a four-wheel drive car. Radio-tracking started in the pre-laying period (beginning of April) to facilitate the location of the nest and to allow determining laying and hatching dates. We obtained one to four daily locations of each brood at least 5 days per week from hatching until the broods (i.e. females and their chicks) moved to post reproductive foraging areas or until all chicks died. Excluding locations corresponding to pre-laying and laying periods, we obtained a mean ± S.D. of 63.4 ± 34.2 locations per brood. We recorded the habitat type of each radiolocation according to the following categories: cereal crop, cereal stubble,permanent or semi-permanent vegetation (fallow fields, alfalfa, steppe-scrub herbaceous vegetation), field margin (herbaceous strips separating plots), ploughed land, and fruit trees (olive or almond trees).

2.3. Breeding dates and breeding success

Both laying and hatching dates were estimated by means of radio-tracking triangulation, as females do not move during the incubation period and start moving again right after hatching (own unpublished observations). Thus, we estimated laying and hatching dates with a precision of ±2 days, and then we standardized them in relation to the first recorded laying date for each year, so that data from all years could be pooled together (i.e. if a given laying occurred 6 days after the first lay reported for a given year it was given a score of six). Broods were considered to be successful if the chicks reached 30 days. At this age chicks are developed enough to assume that subsequent mortality will be considerably lower than during previous stages of development (Inchausti and Bretagnolle, 2005; Morales et al., 2005a).

2.4. Ranging behaviour and habitat use

To avoid under/overestimation of both mean daily inter-location distance covered and mean daily inter-location speed (see below) we excluded from this analysis locations separated less than three or more than 36 h among each other. This provided 367 locations corresponding to eight broods (Table 1). We located the exact nest position after hatching using location estimations from radiotracking. We used the Minimum Convex Polygon (MCP) as an estimator of the home range area of the broods during the rearing period. Within each MCP, we defined Temporary Settlement Areas (TSA) as 95% cluster areas where the brood remained for an uninterrupted period of at least 5 days (Fig. 1). Thus, in case the brood used simultaneously two separated cluster areas, we pooled them together into a single TSA. When possible, we reported the causes for the abandonment of a TSA (i.e. agronomic activities; human disturbances; unknown), as inferred by direct observation in the field. In order to describe the daily ranging behaviour of each brood, we used three ranging descriptors: accumulated TSA area (MCP encompassing all the locations within the current TSA up to the current day; ha), the mean daily inter-location distance covered (m) and the mean daily inter-location speed (m/h). Although these speed estimations are not accurate, they provided us with a standardized parameter to compare movement patterns in different scenarios (e.g. comparing movement patterns within and between TSAs).

Table 1
Description of the ranges of eight little bustard broods radiotracked in Lleida Plains (NE Spain) between 2006–2008. TSA: "Temporary Settlement Areas". N: "Number of". MCP: "Minimum Convex Polygon".

Female	Year	N chicks >30 days	Age of chicks	Standardized hatching date	N locations	MCP (ha)	N TSAs	TSA area (ha)	Average TSA (ha)	Ranging pattern
Penelope	2006	1	31	2	43	370	1	66.4	66.4	Wandering
Tura	2007	1	41	9	76	431.8	2	101.3	50.7±2.1	Wandering
Mercè	2006	1	35	0	62	43.9	1	13.1	13.1	Sedentary
Manuela	2007	2	43	0	48	72.8	3	9	3.3±1.8	Sedentary
Manuela	2008	1	62	0	66	16.1	3	8.1	2.7±1.9	Sedentary
Mercè	2007	0	26	4	44	15.1	1	3.7	3.7	Sedentary
Minerva	2006	0	13	14	17	135.3	1	106.9	106.9	Wandering
Daria	2007	0	9	27	11	10.0	1	10.0	10.0	Wandering

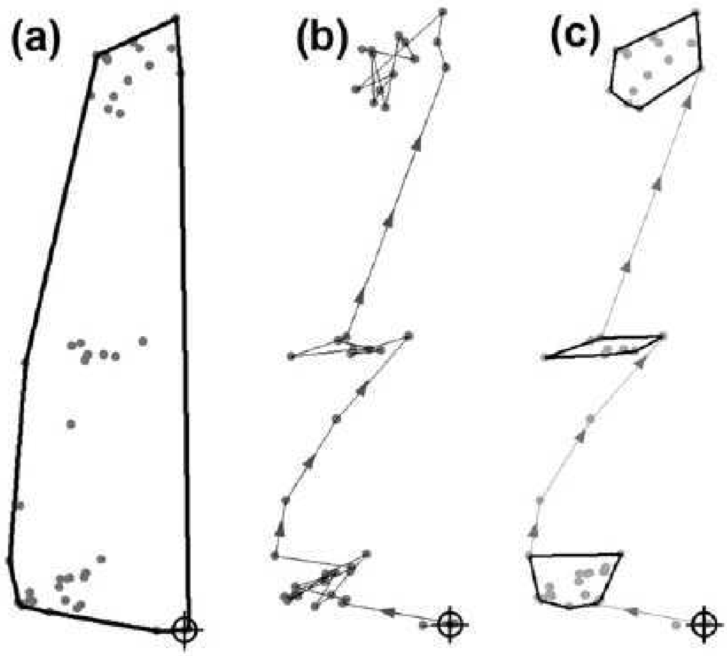


Fig. 1. One example of the movement pattern of a little bustard brood and how movement where analyzed; (a) the MCP encompassing all locations; (b) the trajectory of movement; (c) the Temporal Settlement Areas (TSAs) and movements between TSAs. The cross indicates the location of the nest.

Regarding the analysis of broods' habitat use, we classified brood locations into three broad habitat categories: cereal (cereal crop and cereal stubble), permanent or semi-permanent vegetation (fallow fields, alfalfa, steppe-scrub herbaceous vegetation) and herbaceous field margins (herbaceous strips of vegetation of variable width located between adjacent plots). For analysis of movements in relation to habitat use, we assigned each movement a land use, irrespective from the land-use where these movements were initiated: (i) field margin: movements to a field margin; (ii) herbaceous vegetation: movements performed to a cereal crop or to a permanent or semipermanent vegetation plot; (iii) bare soil: movements performed to a ploughed land or stubble. We calculated ranging variables using the Ranges 7.0 software (Kenward, 2001) and the Animal Movement extensions of ArcView 3.2 (Hooge and Eichenlaub, 2000).

2.5. Arthropod availability

Information on the seasonal and habitat variation in arthropod availability was obtained by using 25 capture sets of pitfall traps from May to July 2003. Sets were distributed in cereal crops (n = 7), field margins (7) and fallow land (11) in the same areas where we captured the females. These habitat categories represented almost

90% of the available habitat and were the most frequently used by the species in the study area. Each capture set consisted on five pitfall traps (separated 1 m from each other) which were emptied weekly. We identified arthropods to order level, and each individual was classified into a body length category. The mean length (in mm) of each category was used to calculate the individual dry biomass (mg) using the potential equation and specific order coefficients given by Hódar (1996). As our interest was focused on food availability for little bustard chicks, taxa unlikely to be consumed by them (i.e. ants and coleopterans larger than 25 mm; see Jiguet, 2002) were excluded from the analyses, although females may feed on large coleopterans (Traba et al.,2008). The biomass/day (in mg) of every capture set was used to evaluate arthropod availability for each considered land-use and fortnight period. Our arthropod availability data were uncoupled with radio-tracking years. However, as our aim was to investigate the phenological association of arthropod abundance to harvest dates and quantifying the relative abundances between habitats, they should be representative of the general pattern of seasonal and habitat variation in arthropod availability.

2.6 Statistical analyses

We evaluated the correlation among ranging descriptors (accumulated TSA area, mean daily inter-location distance, mean daily inter-location speed) by means of the Pearson correlation coefficient. We performed a factorial analysis to integrate these three ranging descriptors into a single factor (called mobility index). Then we conducted a general linear model to examine the relationship between mobility index and the habitat use category towards which every movement took place (included as fixed factor), Julian date (covariate) and individual factor (random factor). The model included main effects and the interactions which were terms of biological interest. For each range, we conducted linear regression analysis between the daily mobility index and Julian date, to determine the changes on individual ranging behaviour along the rearing period. We used Kruskall–Wallis tests to compare means for variables not following a normal distribution and ANOVA tests for variables following a normal distribution. Association between categorical variables was measured with the Pearson χ^2 test. Statistica 8.0 version software was used to conduct these analyses (StatSoft, Inc., 2007). Descriptive statistics in the results section show the mean and standard deviations.

3. Results

3.1. Breeding dates and breeding success

The 23 radio-tagged birds resulted in 22 potential breeding attempts (hens alive on April 1st in the subsequent years). Among these potential breeding hens, five (22.7%) did not lay (one died before and four did not nest). Nine clutches (52.9%) failed during the incubation stage: five failed before harvest (predation was confirmed in three), three were destroyed by harvest operations, and in one case we could not identify the cause and time of failure. Two of the hens that failed at the incubation stage (22%) laid replacement clutches, which also failed during the incubation period (one due to harvest activities and the other unknown). Thus, eight clutches hatched some chicks, but only five of them (62.5%) raised chicks successfully (at least one chick ≥30 days old). Six chicks were raised in total, averaging 0.27 chicks/hen, 0.35 chicks/nest, and 1.2 chicks/successful brood.

All layings occurred between 19th April and 30th May. Laying was earlier (2 ± 4 days, $n = 5$) for hens raising chicks successfully than for those hens that lost all their eggs or chicks (15 ± 10 days, $n = 11$; $t = -3.623$; $p = 0.003$). Hatching occurred from 10th May to 20th June. Hatching date was earlier for successful (2 ± 3 days, $n = 5$) than for failed broods (15 ± 11 days, $n = 3$; $t = -2.614$; $p = 0.040$; Table 1).

3.2. Ranging behaviour

We determined the home range of eight little bustard broods (Fig. 2). Within the MCP, nests were located at 9.7 ± 14.0 m from the MCP boundary, and 75% of them were not included within any TSA. MCP areas were thus normally eccentric in relation to the nest (i.e. the nesting area was not used during the rearing period). After hatching, birds moved at a mean speed of 19.9 ± 25.9 m/h between successive locations. Broods used MCP areas of 136.9 ± 168.9 ha. Five ranges included a single TSA (40.0 ± 45.0 ha), representing 50.3 ± 36.8% of the MCP's total area (114.9 ± 151.2 ha; Table 1). These broods spend 76.1 ± 8.6% of their time within TSAs. On the other hand, three ranges included 2–3 TSA separated by 500 ± 154 m (range

290–676 m) from each other, averaging 14.8 ± 22.2 ha each, which represented the 28.7 ± 19.5% of the MCP's area (173.6 ± 225.4 ha). These broods spent 86.0 ± 6.0% of time within the TSAs. When considering ranges with several TSAs, movements outside TSAs were significantly faster than movements within them (39.8 ± 31.6 m/h, n = 16; and 17.5 ± 21.4 m/h, n = 144; Table 2). Abandonment of a TSA was caused by harvest activities in five occasions, direct human disturbances in two, and was unknown in one case.

We integrated three positively correlated ranging variables (accumulated TSA area, mean daily inter-location distance, mean daily inter-location speed) into a single variable we called "mobility index", which explained 80.1% of the variance. The values of the component matrix correlation between the original variables and the new PC coordinates were 0.925 for mean daily distance, 0.921 for mean daily speed and 0.835 for TSA area size. Thus, low scores of the mobility index indicated that

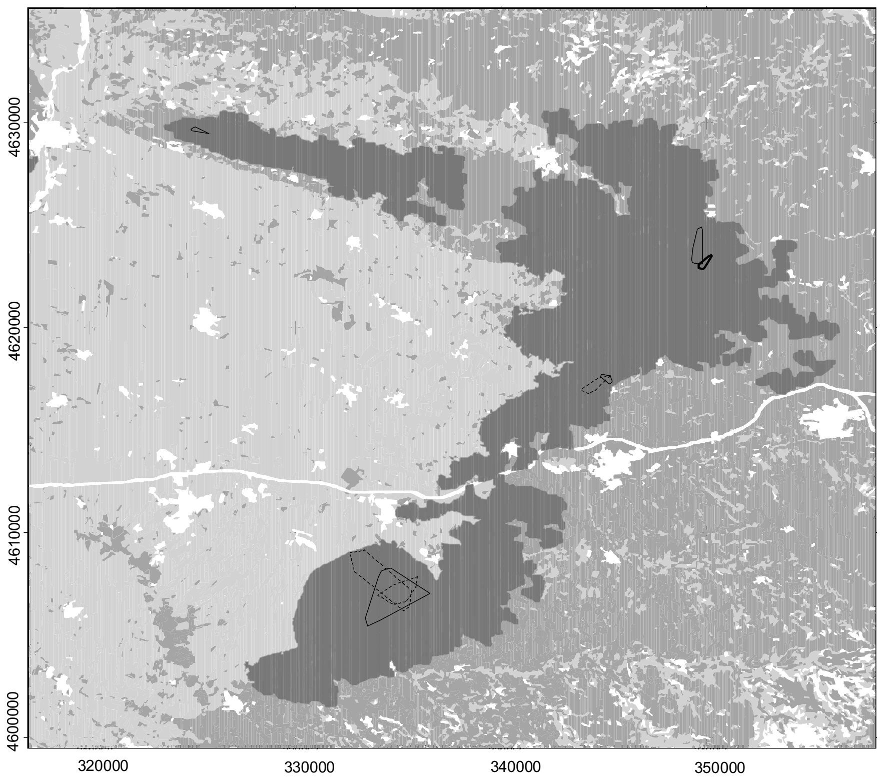


Fig. 2. Location of the eight brood's ranges in the study area. Dark grey area corresponds to pseudo-steppe dry cereal farmland, grey to other non-irrigated herbaceous or fruit tree crops, and light grey to irrigated crops. Line designs correspond to different breeding years: dotted line, 2006; grey line, 2007, and black line, 2008 seasons respectively.

Table 2
General linear model analyzing the effect of movement type (fixed factor; within/outside Temporal Settlement Areas) on movement speed (m/h) of broods of little bustard (random factor) conducting both sorts of movements during the rearing period.

Source of variation	d.f.	*F*	*P*
Intecept	1	10.330	0.067
Movement type	1	10.946	0.001
Brood identity	2	20.126	<0.001

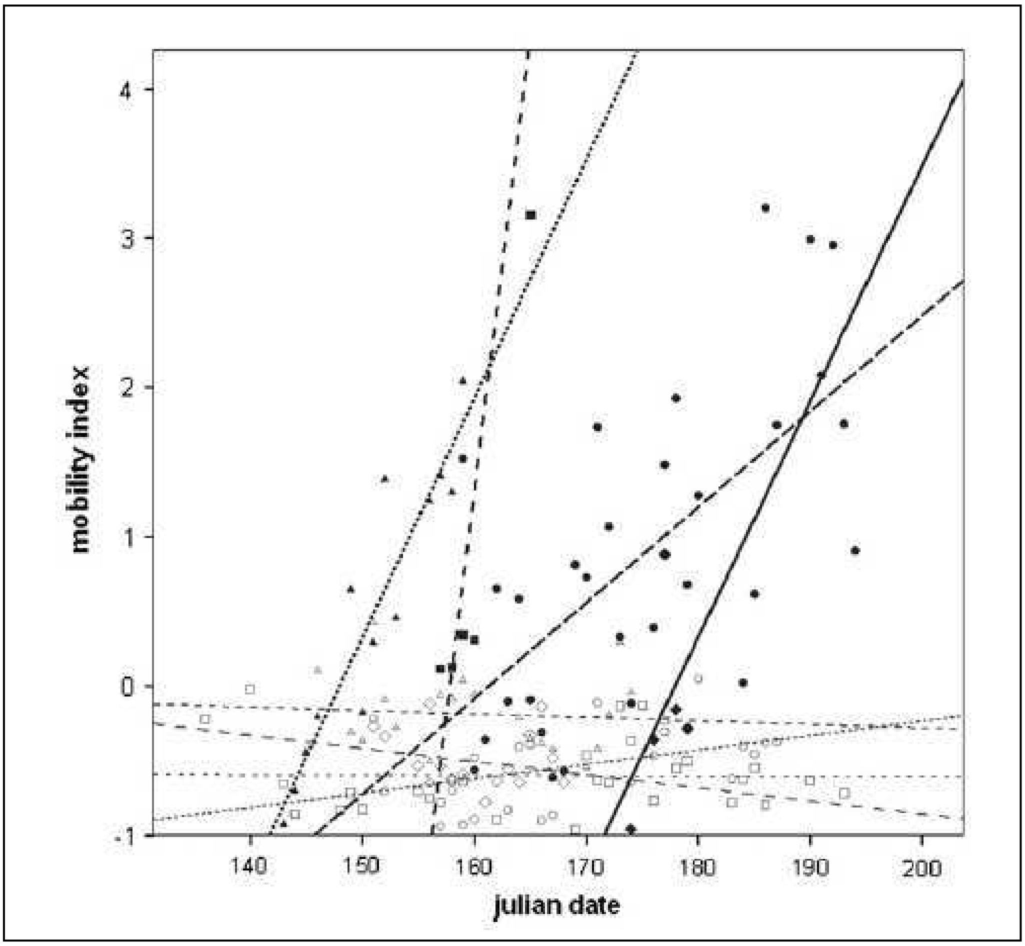
birds moved slowly and through short movements within a small TSA area, while high mobility index scores corresponded to a more erratic ranging behaviour, with longer and faster movements and larger TSA areas. Between brood variation in the mobility index was explained by the effects of land use, Julian date, and individual factor (Table 3). Mobility index was significantly lower in herbaceous vegetation (-0.372 ± 0.489, n = 91) than in bare soil (0.688 ± 1.071, n = 18) or in field margins (0.669 ± 1.421, n = 33) (Kruskall–Wallis test, $\chi^2 = 37.559$, df = 2, $P < 0.001$). Movement speed registered in field margins (28.2 ± 26.8 m/h) or bare terrain (22.7 ± 17.8 m/h) was higher than the speed in herbaceous vegetation (10.9 ± 11.4 m/h) (Kruskall–Wallis test, $\chi^2 = 30.072$, df = 2, $P < 0.001$). Mobility index tended to increase through the rearing period, but when the individual factor was considered, this relation became very strong for four hens and disappeared in the

Table 3
General linear model analyzing the effect of different land uses (fixed factor), Julian date (covariable) and individual variability (random factor) on the mobility index describing the ranging behaviour of little bustard broods radio-tracked during the rearing period.

Source of variation	d.f.	*F*	*P*
Intercept	1	3.977	0.050
Land use	2	3.623	0.049
Brood identity	7	9.952	<0.001
Julian date	1	4.767	0.031
Brood identity * julian date	7	11.703	<0.001
Land use * brood identity	12	3.147	<0.001

other four, who maintained a constant mobility index score through the entire rearing period (Table 3, Fig. 3). These results reflect the existence of two main ranging patterns: first, a sedentary pattern consisting on movements within a small area during the whole rearing period; and second, a wandering pattern corresponding to faster and longer movements that cause a progressive increase on the area used through the rearing period. Sedentary females successfully reared twice as much young than wandering females, which also tended to lay smaller clutches (Table 4). This could be partially explained by phenological differences, as hatching occurred on average 12 days earlier in sedentary hens (Table 4).

Fig. 3. Relationship between the mobility index factor (see main text for details) and the Julian date for each little bustard brood. Each line corresponds to a different brood. Light grey lines and open symbols correspond to sedentary females while dark grey lines and filled symbols represent wandering females.



3.3. Habitat use and arthropod availability

Irrespective of the ranging pattern displayed, all females laid their eggs on cereal fields and mainly used herbaceous crops from hatching to harvest time, which took place on average in June 16th ± 8 days. Before harvest, females used the habitats more or less in proportion to their availability, and were mainly found in cereal crops (87% of locations), fallows (10%) and field margins (3%), while non-irrigated fruit trees plots and ploughed land were not used at all. After harvest, the proportion of locations in field margins increased to 20% and the use of fallows increased slightly to 15%. The proportions of locations of broods on cereal crops decreased to 62%, while 3% of locations corresponded to fruit trees and ploughed land. Habitat use differed between ranging patterns (χ^2 = 23.24, df = 2, P < 0.001; Table 4). After harvest, wandering females mainly shifted to increasing use of field margins and bare terrain, while sedentary females tended to remain in herbaceous vegetation (fallow fields or unharvested leguminous crops; Fig. 4).

Table 4
Characteristics of the two ranging patterns (wandering/sedentary) observed in little bustard broods radio-tracked during the rearing period.

		Wandering	Sedentary	*P*
Use of space	Mobility index	0.70 ± 0.75	-0.46 ± 0.19	0.024[a]
	TSA area (ha)	71.2 ± 44.5	8.5 ± 3.9	0.031[a]
	Mean daily distance (m)	245 ± 74	95 ± 15	0.007[a]
	Mean daily speed (ms)	28.6 ± 12.5	9.1 ± 2.9	0.023[a]
Breeding	Nº chicks >30 days	0.5 ± 0.6	1.0 ± 0.8	0.356[a]
	Clutch size	2 ± 1	3 ± 1	0.304[a]
	Hatching date (days)	13 ± 11	1 ± 2	0.067[a]
	Hatching period	11-28 May	20 May -20 June	-
Habitat use (% locations)	Unharvested crops	48.1 %	74.5 %	<0.001[b]
	Field margins	36.1 %	16.8 %	
	Bare soil	15.8 %	8.7 %	

[a] Anova test.
[b] χ^2 test.

Arthropod availability increased during May and early June - matching the hatching period – and declined afterwards matching with the beginning of harvest activities at the end of June (Fig. 5). Broods moved mainly within cereal crops, although arthropod availability was lower than in other land uses (Fig. 5).

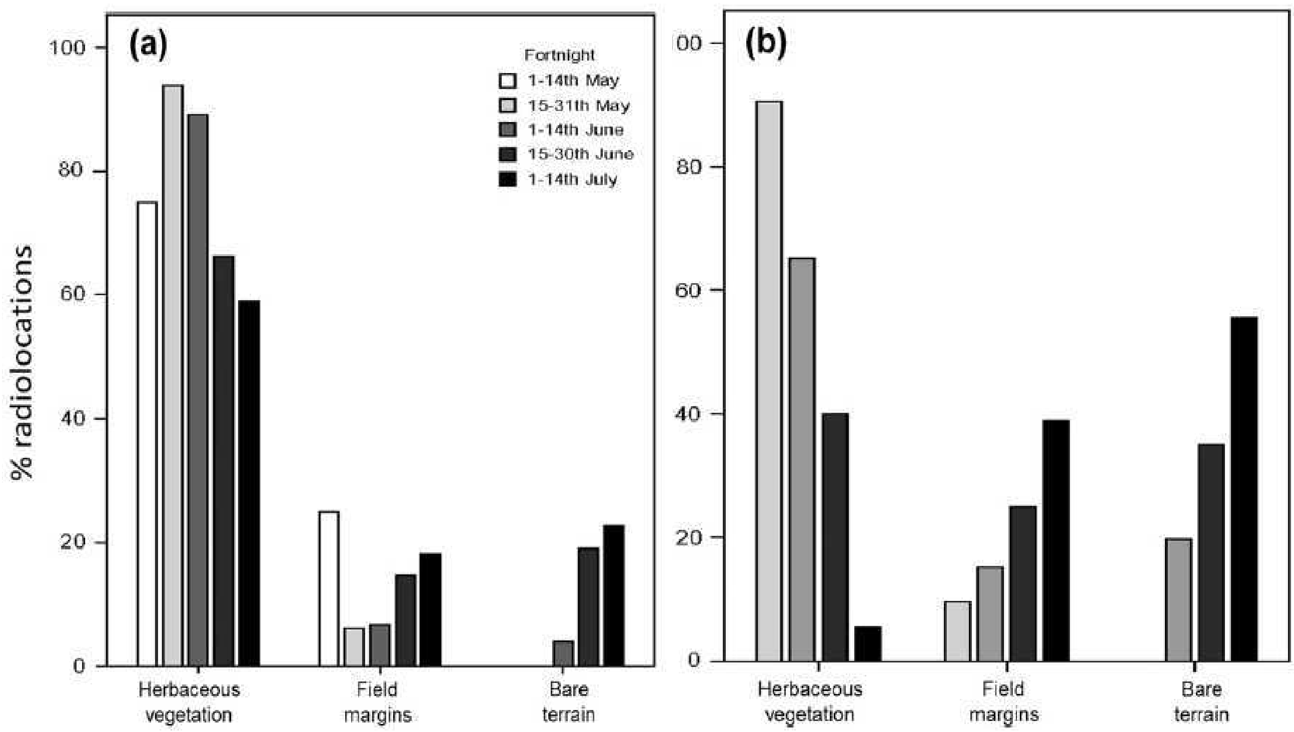


Fig. 4. Habitat use of (a) sedentary and (b) wandering little bustard broods radio-tracked during the rearing period (fortnightly from 1st May to 15th July).

4. Discussion

The breeding success reported in the little bustard population in the Lleida plains is similar to the lowest estimations for the endangered population in France (0.39 chicks/female, Inchausti and Bretagnolle, 2005; 0.51 chicks/female, Morales et al., 2005a; 0.26 chicks/breeding female, Bretagnolle et al., 2011) and is not enough to guarantee the long term viability of the population (Morales et al., 2005a). Low breeding success has been found to be responsable of the severe decline of the little bustard population in Western France (80% between 1978 and 2002, Bretagnolle et al., 2011; Inchausti and Bretagnolle, 2005; Jolivet and Bretagnolle, 2002; Morales et al., 2005a), so a similar discouraging scenario can be envisaged for the little bustard

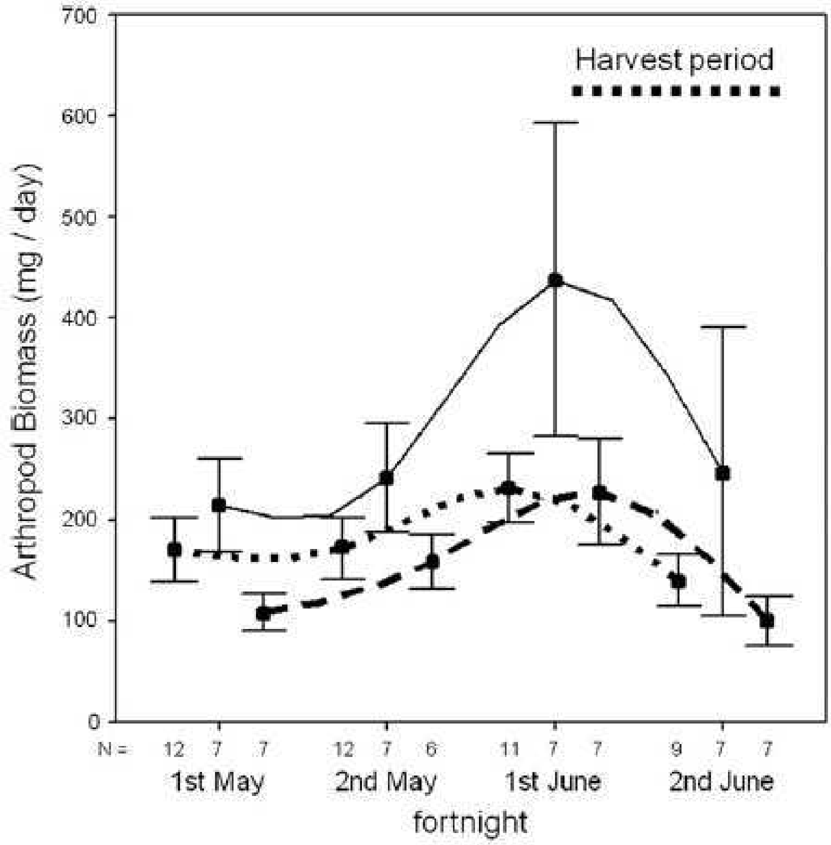


Fig. 5. Evolution of arthropod biomass captured in pit-fall traps during the breeding season in cereal crops (dashed line), field margins (bold line) and fallow land (dotted line) represented as mean mg/day ± SD.

Catalan population, which has already declined about 23% between 2002 and 2009 (unpublished data). Females were captured and tagged at the end of a given breeding season and tracked the subsequent seasons. Thus, they survived winter and bred the subsequent year with the tags so there is no sign that make us believe handling during capture did have any effect on breeding success the following year. We identified several causes for the reported low breeding success. On one hand, we found a considerable number of females that did not even attempt to breed. In the great bustard (*Otis tarda*), this has been attributed to the lack of experience of young females (Glutz et al., 1973). However, the females followed in our study had previous breeding experience (they were captured when rearing chicks). Alternatively, some females may have refused to breed because they were in bad condition after the winter or because they were unable to find satisfactory conditions to do so. Further studies should be conducted on this respect, especially considering the costs of reproduction for a long-lived bird such the little bustard. On the other hand, the percentage of nests which failed to hatch (53%) was higher in our study area than in Western France (36%; Bretagnolle et al., 2011). However, this higher rate of nest failure does not seem to be attributable to farming practices: unlike in Western France, where little bustard nest in alfalfa plots and most nest failures were attributed to harvest operations (70%), in our study area females nest on cereal crops, and farming practices accounted only for a maximum of 42.8% of the nesting failures. The remaining failures during the incubation stage in our case were attributed to predation (minimum 42.8%) or to other causes apparently not related with harvest operations. Differences in crop types, agricultural practices and predator communities between our study area and Western France may explain these differences. Understanding the high rate of nest losses due to causes other than harvest in our study area remains a key issue to be investigated.

Losses during the chick rearing period were also important (37.5%). Although we were unable to obtain information on the ultimate cause of dead of chicks, the investigation of the ranging behaviour of broods provided us some cues. Broods concentrated their activity on a relatively small area of their range, the Temporary Settlement Areas (TSA). Most nests were not included within a TSA and all were on the edge of the brood range. This suggests that the ecological conditions required for nesting females were different from those needed to rear chicks. Females may nest in patches well shaded from predators and harsh weather conditions, which may not correspond to the most suitable areas to find food for small chicks. Habitat heterogeneity may thus be a crucial requirement for breeding little bustard females, as for farmland biodiversity in general (Benton et al., 2003). The fact that broods tended to move more slowly within TSAs than between them may indicate that movements within TSAs correspond to their usual foraging activity while movements between them probably correspond to unusual movements induced by disturbances of any kind. Indeed, we found that disturbances associated to farming or other human activities were the main cause of movement between settlement areas. Such movements may lead to an important increase of the total home range size compared to seminatural or natural steppe areas, where these human disturbances would be less frequent or even absent, as reported in other ground-nesting farmland species (Buenestado et al., 2008). This may explain why brood home ranges obtained in the Lleida plains were considerably larger than those obtained by Lett et al. (2000) for two broods (17–25 ha) and by Schulz (1985) for a single one (3.1 ha) in natural or semi-natural areas. Moreover, such natural areas, including large proportions of natural meadows and fallow land plots, may offer habitats of higher quality compared to arable farmland, allowing the birds to fulfil their ecological requirements within a smaller range (Fisher and Owens, 2000; Nesbitt and Williams,1990; Wegge and Rolstad, 1986).

However, not all broods ranged in a similar way. Early broods tended to show a constant mobility index through the rearing period, and consequently their ranging area remained stable below a certain threshold. This sedentary pattern indicates that these broods showed a strong tendency to stay within certain presumably optimal vegetation patches. Late broods, however, tended to exhibit a wandering pattern (i.e. longer movements and larger ranging areas), presumably reflecting that they were unable to find such optimal patches to stay. Sedentary and wandering patterns were highly associated to high and low brood surviving probabilities respectively. Harvest occurs earlier in the Lleida plains than in other areas in Spain (Rodríguez-Teijeiro et al., 2009), and at the end of June most of the little bustard's breeding habitat in our study area turns into stubble or bare soil (fields may be ploughed within few days after being harvested) within only 7–10 days. Consequently, late broods face very harsh conditions (i.e. a strong reduction on arthropod availability, lack of cover to hide from both aerial or mammalian predators, and the lack of protection from strong sun or rain) that force them to continuously move to find adequate vegetation cover. This generates the observed wandering pattern, which may ultimately increase energetic expenditure of chicks and the risk of starvation, which has been found to be the main cause of chick death in Western France (Bretagnolle et al., 2011). A similar relationship between chick survival and ranging patterns has been described in other farmland birds (Hill and Robertson, 1988; Warner, 1984), and may be the explanation for the low breeding success of late little bustard broods. We cannot preclude that a lower individual quality of late breeding females may partially explain their lower breeding success (Kosicki and Indykiewicz, 2011). However, evidence suggest that the effect of harvest and the associated reduction of food and shelter may, at least to an important degree, be the direct causes of the reported seasonal decline in breeding success rather than differences between early and late breeders in terms of territory or individual quality (Svensson, 1997; Lepage et al., 1999).

Our results indicate that field margins harbour high arthropod populations. However, they represent only a small proportion of the study area, and were only intensively used by wandering broods after harvest, probably because they were the only suitable patches of vegetation remaining on their ranges. In fact, the wandering pattern may arise in part as a result of the particular spatial configuration of field margins, which are narrow strips of permanent vegetation. Although harbouring a slightly smaller density of arthropod prey than field margins, cereal crops and stubbles provide a more extensive and probably more adequate substrate for detecting, chasing and catching prey. For that reason, the use of field margins may not be enough to fully compensate for the destruction of the cereal crop habitat and the overall decrease of arthropod prey availability after harvest, and broods continue to use cereal stubble, which may increases the risk of detection by aerial predators. Moreover, the use of field margins may represent some extra costs for broods. Predation risk may be higher near linear corridors or field boundaries compared to surrounding agricultural matrix (Wilson et al., 2001), because mammal predators use these vegetated strips to move around (Sharpe, 2006). Together with dogs, red foxes (*Vulpes vulpes*) are known to be the main predator of great bustard chicks (Ena et al., 1987; Morales et al., 2002), and may probably also kill little bustard chicks or hens. Red fox densities in our study area in 2006, estimated by nocturnal transects using a distance sampling approach (López-Martín, 2006) ranged from 0.79 to 1.3 individuals/km^2 (Àrea d'Activitats Cinegètiques, Generalitat de Catalunya, unpublished data) which was higher than the 0.5 foxes/km^2 threshold considered to allow fox population control in game estates (López-Martín et al., 2007). Hence, broods exhibiting a wandering pattern – which are more usually found using field margins – may not only have higher difficulties in obtaining enough food, but also be more vulnerable to mammalian predation (Storaas et al., 1999).

5. Conclusions and conservation applications

The viability of little bustard populations has been shown to be particularly sensitive to breeding success rates (Morales et al., 2005a) and the value found in our population is largely below the threshold of 0.8–1.0 chicks/hen suggested by the models developed by these authors for a viable population. Consequently, increasing the breeding success of our population should be a management priority. Although some caution is required in the interpretation of our results, because of the limited sample size, they are based on intensively collected radio-tracking data, which provided high-quality information on reproductive parameters and ranging behaviour. The overlap between harvest time and breeding phenology appears to be a key factor decreasing the opportunities of little bustard broods to find adequate food and shelter, which is reflected on their ranging behaviour and subsequent breeding success. We found that late broods had reduced survival chances, and that this was related to the alteration of the ranging behaviour of the broods, which ultimately may increase their energetic expenditure and increase the risk of starvation and predation. These results can be used to design conservation measures based on ecological findings, which is crucial for maximizing the benefits of agri-environmental schemes for endangered species (Kleijn et al., 2006; Vickery et al., 2004). Our results suggest that rearing success of little bustards inhabiting cereal pseudo-steppes is the result of a complex balance. On one hand, breeding time of the species overlaps with harvest of cereal crops and arthropod abundance is highest right before harvest. Paradoxically, broods overlapping with the highest food availability period are also more likely to encounter a sudden drastic decrease in the availability of food and shelter caused by harvest. On the other hand, although field margins may provide high arthropod availability and shelter after harvest, they do not seem able to fully compensate for the loss of cover in the crops. Frequently, management efforts to reduce the impact of agricultural intensification in declining farmland bird populations have been focused on the improvement and conservation of field margins, which undoubtedly play an important role on the preservation of farmland biodiversity (Tattersall et al., 2002; Vickery et al., 2002, 2009). However, little bustard provides us an example where field margins conservation and management may not be enough to compensate for the intensification within the field matrix. Hence, in this case, management practices should adopt a broader landscape and plot perspective. Here, based on ecological findings on the ranging behaviour of little bustard broods, we propose the creation of a network of 5–10 ha green cover plots – the size of the observed TSAs – where vegetal cover is maintained throughout the little bustard breeding season to provide shelter and food for little bustard broods, particularly after harvest. These plots should be situated approximately 500 m from each other – the mean distance between TSAs – and connected by wide high-quality herbaceous field margins to facilitate movements between them. They may consist on natural fallows (Ewald et al., 2010; Jiguet, 2002; Robinson and Sutherland, 2002), herbaceous or alfalfa crops which should not be harvested, or simply be created by delaying cereal harvest until the chicks are fully grown (i.e. at least until July 15th). These plots would generate a heterogeneous landscape where little bustard hens would be able to fulfil all their variable needs from nesting to fledging.

Agri-environmental schemes may be useful for reversing the decline of farmland birds (Vickery et al., 2004). Although in a different agrarian landscape, Bretagnolle et al. (2011) have shown that the implementation of agri-environmental schemes aimed at reducing nest destruction and improving chick survival may be an effective tool to stop the decline of little bustard populations. The proposed network would involve around 15% of the study area, and may also be beneficial for other farmland and steppe-land birds as delayed harvest and the creation of fallows or legume plots has been found to be a suitable agri-environtmental measure for little bustard and other steppe birds (Astraín and Zaragüeta, 2006; Casas and Viñuela,2010; De la Concha et al., 2007; Moreno et al., 2010). Most importantly, the proposed measures could be funded under Axis 2 (Environment) of the current European Agricultural Fund for Rural Development (EAFRD) of the Rural Development Regulations, as we estimate that their overall cost would be well below the maximum 600 €/ha threshold allowed for annual crops.

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La sega del cereal i l'ús de l'hàbitat de les famílies de sisó en pseudoestepes cerealístiques

Anna Ponjoan, Oriol Lapiedra, Gerard Bota , Santi Mañosa

Resum

El sisó (*Tetrax tetrax*) és un ocell estepari les poblacions del qual estan en regressió a causa principalment de la intensificació agrícola. Malgrat que el baix èxit reproductor és un dels factors determinants en la viabilitat de les poblacions de sisó, els requeriments d'hàbitat de les famílies resta encara gairebé desconegut. En aquest estudi s'investiga l'ús de l'hàbitat de 10 famílies de sisó que van ser monitorades a mitjançant de radioseguiment a la plana de Lleida (Catalunya). A través d'un anàlisi composicional s'ha detectat que les famílies seleccionen positivament els marges herbacis. Un model lineal mixt ha revelat que les famílies prefereixen camps de mida mitjana (2-3 ha) i els guarets o els camps de lleguminoses en relació als camps de cereal. També prefereixen parcel·les amb alta disponibilitat de marges herbacis o adjacents a guarets o camps de lleguminoses. Entre els camps de cereal sense segar, les famílies usen principalment camps amb una baixa activitat fotosintètica i alta disponibilitat de marges herbacis, així com aquells camps envoltats per diferents usos del sòl especialment els que tenen guarets o lleguminoses en parcel·les adjacents. Després de la sega, les famílies incrementen l'ús dels marges, i entre els rostolls tendeixen a utilitzar aquells més propers a guarets o camps de lleguminoses. Els resultats obtinguts confirmen que les parcel·les amb vegetació semi-permanent o els marges herbacis són seleccionats positivament per les famílies de sisó, probablement perquè actuen com a font d'alimentació i refugi. En estepes cerealístiques, la gestió per a la conservació hauria de promoure la presència de parcel·les amb vegetació herbàcia semi-permanent (ja siguin guarets o lleguminoses) i l'abundància de marges herbacis durant el període de cria, per tal d'incrementar l'èxit reproductor del sisó.

Article 3

Cereal harvest and habitat-use of little bustard broods in a cereal pseudo-steppe

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Per enviar a *Biological Conservation*

Abstract

The little bustard (*Tetrax tetrax*) is a threatened steppe-land bird suffering strong population declines mainly due to agricultural intensification. Although low breeding success is one of the main factors explaining the low viability of little bustard populations, the habitat requirements of broods remain almost unknown. We investigated the habitat use of ten little bustard broods radio-tracked during the rearing season in a pseudo-steppe area of NE-Spain. Compositional analysis revealed that broods positively selected field margins. A Generalized Linear Mixed Model revealed that broods selected medium-sized (2-3 ha) fallow or leguminous plots over cereal plots, as well as plots with higher availability of herbaceous margins or adjacent to fallow or leguminous plots. Among noncropped cereal fields, broods selected fields with lower photosynthetic activity and high availability of herbaceous margins, surrounded by different herbaceous land uses specially fallow or leguminous plots. After harvest, broods increased the use of field margins and among stubbles they selected those adjacent to fallow or leguminous plots. Our findings confirm that, when available, permanent and semi-permanent vegetation plots or field margins are preferentially used by little bustard broods, probably because they may maximize food availability and concealment. In cereal pseudo-steppes, conservation management should promote the presence of semi-permanent herbaceous vegetation and high field margin availability through the entire rearing season, to increase breeding success of little bustard as well as other ground-nesting medium-size birds.

Keywords: farmland bird conservation, habitat selection, field margins, agricultural intensification, fallow

1. Introduction

During the second half of the 20th century, worldwide agricultural intensification allowed an unprecedented increase in crop production (Krebs et al., 1999; Wilson et al., 2005), but has also brought to a simultaneous dramatic loss of biodiversity. Farmland birds have suffered a significant general decline in many parts of the world, particularly in areas where farmland habitats are a fundamental part of the landscape, such as in Europe (Stoate et al., 2009). Indeed, agricultural environments in Europe are of critical importance for the conservation of biodiversity, as they cover 45% of the European Union area and host 50 % of all European bird species (Pain and Pienkowski, 1997).

To reduce the loss of biodiversity in these European areas, numerous agri-environment schemes (AES) have been implemented, specially devised to support farming practices that are compatible and benefit the environment and wildlife conservation (Kleijn and Sutherland, 2003). However, their effectiveness remains controversial, as they have often turned out to be less ecologically effective than initially expected (Kleijn et al., 2001, 2006; Kleijn and Sutherland, 2003). AES have proven to be generally effective only when their objectives are well-defined and their prescriptions are based on a precise knowledge of the requirements of the target species (Kleijn et al., 2006). Indeed, it is crucial to understand the mechanisms involved in the population decline (Donald et al., 2006; Kleijn et al., 2006; Whittingham, 2006; Concepción and Díaz, 2011). Hence, identifying the ecological requirements and the causes of decline of farmland bird populations is crucial to design effective management practices.

The Little bustard (*Tetrax tetrax*) used to occur in farmland and grassland landscapes across Europe. Their populations declined dramatically during the last decades, becoming extinct from Central and Eastern Europe by the mid-20th century (Goriup, 1994). Consequently, this ground-nesting steppe bird is ranked as "Near Threatened" at a global scale (IUCN, 2012), and as "SPEC 1" and "Vulnerable" in Europe (Birdlife International, 2004). Such population declines and extinctions have been attributed to agricultural intensification, which leads to habitat loss and degradation (Martínez, 2002; Morales et al., 2005a; Morales et al., 2005b; Garcia et al., 2007). In Western Europe, the little bustard is still found in the Iberian Peninsula, France and Sardinia (Iñigo and Barov, 2010). More than half of its worldwide population inhabits the Iberian cereal pseudo-steppes (García de la Morena et al., 2006), dry extensively farmed areas with low or no forest cover, dominated by mixed rotational crops of winter cereal, fodder and grazed fallows (Suárez et al., 1997). These farmland areas are currently subject to a rapid process of agricultural intensification (Suárez et al., 1997; Stoate et al., 2001; Brotons et al., 2004), seriously compromising the viability of little bustard populations, as a result of an extreme reduction of breeding success. Hence, raising productivity should be one of the main goals of any conservation program of the species (Bretagnolle and Inchausti, 2005; Inchausti and Bretagnolle, 2005; Morales et al., 2005a; Bretagnolle et al., 2011). Although it has been shown that the ecological requirements of breeding little bustards differ between sexes (Morales et al., 2008; Morales and Traba, 2009), our current knowledge on the females breeding biology and the ecological requirements of broods (i.e. hens with chicks) remains surprisingly limited (Schulz, 1985; Lett et al., 2000; Lapiedra et al., 2011; Faria et al., 2012). Nest destruction by harvesting operation and chick starvation have been found as the main causes entailing low breeding success in an intensive agricultural area in Western France (Villers, 2010). The implementation of AES based on these previously identified limiting factors reverted the little bustard population's decline in such French population (Bretagnolle et al., 2011; Berthet et al., 2012). However, factors explaining the low breeding success of little bustards in cereal pseudo-steppes are still poorly understood. A combination of high clutch failure rates due to nest predation and harvest operations and decreasing availability of shelter and feeding habitat after harvest have been suggested to be driving a very low breeding success in the Catalan cereal pseudo-steppes (Lapiedra et al., 2011). In this area, cereal harvesting involves the elimination of the vegetation cover of over 80% of the study area in only 7-10 days (Lapiedra et al., 2011). This dramatic alteration takes place during the species' breeding period and may decrease reproductive output both directly through nest destruction during harvest activities and indirectly through a decrease in food and shelter availability for chicks (Inchausti and Bretagnolle, 2005; Bretagnolle et al., 2011; Lapiedra et al., 2011). However, the impact of harvesting operations on the breeding success of the species may depend on the presence of alternative habitats within the agricultural matrix, where broods could cope with all their ecological requirements. Hence, understanding the requirements of little bustard broods is essential to design efficient conservation practices to revert little bustard population declines in cereal pseudo-steppes.

Our aim here was to investigate the habitat use and preferences of little bustard broods in a cereal pseudo-steppe, to establish the guidelines that should allow for the design of AES aimed to increase little bustard reproductive success in such habitats. Provided that the vegetation cover experiences a dramatic seasonal change during the reproductive period of little bustards in cereal farmland, we hypothesized that habitat preferences of broods may be affected by cereal harvest. Hence, we adopted a plot-based, multi-temporal approach to identify differential habitat use of cereal plots by little bustard broods before and after harvest.

2. Material and methods

2.1 Study area

The Lleida plains, on the easternmost edge of the river Ebro basin (Catalonia, NE Spain), lay 400 m above the sea level and are characterized by low annual rainfall (300–400 mm) and a contrasted continental climate (Bosch, 2004). Regional landscape combines a central irrigated area surrounded by a belt of cereal pseudo-steppe areas.

This area hosted a little bustard population of 1158 males (95% CI: 898–1418) and 656 females (95% CI: 444–868) in 2002, which is estimated to have experienced a decline of 23% between 2002 and 2009 (unpublished data). We captured and monitored hens in the cereal pseudo-steppe, where landscape was dominated by a mosaic of cereal crops (ca.79 %), mainly barley (*Hordeum vulgare*), with interspersed olive and almond groves (ca. 6%), patches of fallows and steppe-scrub vegetation (ca. 6%), ploughed land (ca. 5%), field margins (ca. 2%) and other land uses (ca. 2%). Throughout the 20th century, landscape and agricultural practices changes associated to intensification (i.e. reducing fallow availability; increasing levels of mechanisation, chemical use and cereal yield) occurred progressively in the study area (Aldomà, 2004). For example, the proportion of fallows and steppe-scrub vegetation has decreased from 50% in the mid-thirties (Giralt et al., 2006) to the current 6%, which is one of the lowest among the Iberian breeding range of the species, where it usually represents between 10% and 30% of farmland (Silva et al., 2007; Delgado et al., 2009).

2.2 Field work

In 2001-2006 we captured 8 little bustard hens using funnel traps, which had been proven more efficient and safe than alternative capture techniques (Ponjoan et al., 2008, 2010). We tagged the hens with either 2 or 3 year-lasting TW3-2/3AA and TW3-AA backpack transmitters (Biotrack, Dorset, U.K.) weighting 28 g and 32 g respectively (< 4% of the individuals' body weight). During the subsequent breeding seasons (2002-2008) we radio-tracked 10 broods corresponding to the 8 hens (two hens were monitored during 2 consecutive seasons). We used a four-wheel drive car and a portable scanner-receiver and a 3-element Yaggi antenna. Each brood was located 1-4 times a day, at least 5 days per week from hatching until the familiar group moved to post-breeding areas or until all chicks died. We obtained 407 locations corresponding to 40.7 ± 23.1 locations/brood. We recorded the land use from 402 radiolocations (98.8 %), according to the following categories: cereal crop, cereal stubble, herbaceous field margin (herbaceous strips separating plots), arboreal field margin (strips separating plots covered by trees), ploughed land, fruit trees (olive or almond trees), steppe-scrub vegetation, tracks, urban patches (buildings or roads), and semi-permanent herbaceous vegetation (fallow fields or leguminous crops). All spatial information was imported into a geographic information system, using ortho-rectified aerial photographs and 1:5000 digital maps (Institut Cartogràfic de Catalunya) as a base map.

2.3 Habitat use analysis

First, we analyzed the general habitat preferences of little bustard broods during the entire rearing period (from hatching until all chicks from the brood abandoned the breeding area or died) by considering all land uses of the study area (both agricultural plots and non-cropped patches). Second, due to the high percentage of locations situated in cropland fields (90%), we also adopted a plot-level approach to assess habitat preferences among agricultural plots during the entire rearing period, providing biologically relevant information for management at a plot level. We used such an approach because plot is the management unit of most of agri-environment schemes (AES). We used plot as synonymous of field and we use both terms indistinctly through the text. Third, as 77 % of all locations were concentrated on cereal and stubble fields, we were also interested in investigating which factors made some of these fields more attractive for the broods than others. Based on a previous study focused on ranging behaviour (Lapiedra et al., 2011), we hypothesized that cereal harvest might affect the habitat use of broods. Thus, we used a sequential approach to assess habitat use and selection of cereal plots at two different periods: before and after harvest. Because broods inhabit different areas and harvest phenology varies significantly among areas and years, these periods were individually defined for each brood. The before-harvest period for a given brood encompasses the time from hatching until the date of the first radiolocation on stubble; the after-harvest period for a given brood encompasses the time from the 7th day after the first radiolocation in stubble until all chicks from the brood abandoned the breeding area or died. For each brood and period we calculated the area of its Minimum Convex Polygon (MCP; Mohr, 1947). We built a database for each period by including all field plots partially or completely included in the MCP of each brood. From all of these plots we obtained several variables related to plot shape and size, topography, photosynthetic activity, characteristics of the field margins, and adjacent land uses (Table 1), which have been suggested to be relevant for both distribution and breeding success of little bustard broods (Jiguet, 2002; Morales et al., 2008; Bretagnolle et al., 2011; Lapiedra et al., 2011). We defined habitat DIVERSITY as the number of agronomical land uses present in the neighbouring plots (considering cereal, ploughed land, semi-permanent herbaceous vegetation, fruit trees and scrub-steppe vegetation). We used the range of altitude within each plot as indicator of the SLOPE. Values were obtained from a digital terrain model (DTM) with a spatial resolution of 30 m (Institut Cartogràfic de Catalunya 2000). To avoid including pixels from adjacent fields due to spatial resolution differences, pixels situated in the 5 m inner buffer of each plot were excluded from the calculation. The Normalized difference vegetation index (NDVI) is a spectral index calculated from earth surface reflectance patterns in the red and near-infrared regions of the electromagnetic spectrum and enhances the detection of plant properties (Tucker, 1979). Low NDVI

Table 1. Description and statistical descriptors (mean ± sd or median and range (minimum, maximum)) of variables considered (Dep: dependent variable; Ind: independent; Rand: random factor) in the Generalized Mixed Models assessing habitat selection of Little Bustard broods in three datasets (Cropland plots during the entire rearing period; cereal plots before harvest; cereal plots after harvest). Hyphen indicates variable not included in the model.

Variable			Model		
Name	Description	Type	Cropland plots	Cereal plots Before harvest	Cereal plots After harvest
LOCATIONS	Number of brood locations in the plot	Dep	0 (0-27)	0 (0-19)	0 (0-5)
SIZE	Size (ha) of the plot	Ind	1.3±1.2 (0.0-10.9)	1.5±1.5 (0.1-10.5)	1.4±1.3 (0.3-8.7)
PERIMETER	Perimeter (m) of the plot	Ind	-	-	-
MARGIN	Area (ha) of herbaceous margins bordering the plot	Ind	0.02±0.03 (0-0.2)	0.03±0.04 (0-0.2)	0.02±0.01 (0-0.2)
TREE MARGIN	Area (ha) of arboreal margins bordering the plot	Ind	0.01±0.02 (0-0.2)	0.02±0.04 (0-0.2)	>0.00±0.03 (0-0.2)
SLOPE	Maximum – minimum altitude within the plot (m)	Ind	1.9±2.0 (0-17)	2.8±2.0 (0-16.0)	2.2±1.9 (0-13)
NDVI BEFORE	Average of NDVI values in the cereal plot during the before-harvest period	Ind	-	0.643±0.130 (0.260-.870)	-
NDVI AFTER	Average of NDVI values in the cereal plot during the after-harvest period	Ind	-	-	0.236±0.031 (0.136-0.360)
DIVERSITY	Number of different land uses in the bordering plots	Ind	-	2 (0-5)	2 (0-4)
NEXT TREE	Number of almond and olive groves in the bordering plots	Ind	0 (0-3)	0 (0-3)	0 (0-3)
NEXT HERBACEOUS	Number of bordering plots covered by semi-permanent herbaceous vegetation	Ind	0 (0-4)	0 (0-3)	0 (0-3)
NEXTURBAN	Number of bordering patches of urban land	Ind	0 (0-3)	0 (0-1)	0 (0-2)
LAND USE	Land use category of the field	Ind	4 categories	-	-
ID	Identity of each monitored brood	Rand	10 broods	6 broods	5 broods

values indicate predominance of bare ground or dry vegetation, while higher positive values indicate a photosynthetically more active substrate. NDVI has shown a reasonable correlation with vegetation abundance and other important ecological parameters, such as leaf area index (LAI), and thus continues to be a commonly used indicator of vegetation parameters in remotely sensed data (Elmore et al., 2000). NDVI has successfully been employed to interpret animal preferences regarding vegetation characteristics (Willems et al., 2009; Pettorelli et al., 2011; Sardà-Palomera et al., 2012). We used NDVI to assess differences on photosynthetic activity and biomass of both cereal and stubble plots (Myneni et al., 1995; Aparicio et al., 2002). NDVI was calculated from LANDSAT remote sensor images supplied fortnightly and with a spatial resolution of 30 m (Image source: USGS Global Visualization Viewer). We calculated the NDVI mean pixel values for all cereal plots included in all MCPs using the closer LANDSAT image on date to such period (Table 1). These images were previously geographically and radiometrically calibrated and cereal plots with presence of clouds in the image were excluded from the analysis. To avoid including pixels from adjacent fields due to spatial resolution differences, NDVI pixels situated in the 10 m inner buffer of each plot were excluded from the calculation. To calculate the MCP areas and to obtain these variables we used the Animal Movement (Hooge and Eichenlaub, 2000) and the X-tools extensions (DeLaune, 2000) for Arcview 3.2, and the Spatial Analysis extension for ArcGIS Desktop 9.0.

2.3.1 Habitat selection during the entire rearing period

To investigate if some habitat types were in general preferred over others, we conducted a compositional analysis (Aebischer et al., 1993), using the Resource Selection software (Leban, 1999). In this analysis we considered 5 land use categories: cereal crops (cereal or stubble), semi-permanent herbaceous vegetation (fallow or leguminous fields), field margins (herbaceous or arboreal field margins and tracks), fruit trees (olive or almond), and other uses. We used the third order selection approach (Millspaugh and Marzluff, 2001) considering the number of locations in each of the land uses as the used resources, and habitat availability as the proportion of each land use types within the MPC encompassing all the radiolocations of the entire rearing period of each brood. Cereal crops were chosen as the denominator in the log ratios because this habitat category was present in all home ranges. Zero values were replaced by 0.003 (Aebischer et al., 1993; Bingham and Brennan, 2004). If selection was significantly non-random ($p < 0.05$) habitat types were ranked from the most to least selected, using a matrix of mean and standard deviations of log ratio differences for all habitat types.

2.3.2 Selection of crop fields during the entire rearing period

Here we were interested in sorting out why broods concentrated on some crop fields but not in other. We generated a database including 1343 agricultural plots located partially or completely within an MCP encompassing all locations of the entire rearing season for each brood. The MCP considered in this analysis corresponded to all 10 broods having on average 40 ± 23 locations/brood (Table 2). We included in this analysis cropland plots (i.e. those containing cereal -cereal crop or stubble-, semi-permanent vegetation -fallow fields or leguminous-, ploughed land, and fruit trees -olive or almond trees-), and excluded field margins, tracks, urban or scrub-steppe patches. We built a Generalized Linear Mixed Model (GLMM) to identify which factors determine the amount of use of field plots by little bustard broods. The number of locations within each agricultural plot was the dependent variable. Eight independent variables were included as fixed factors, and INDIVIDUAL was considered to be a random factor (Table 1). We log-transformed non-normal continuous variables. We assessed colinearity among variables using Spearman & Kendall's Tau correlations. No variables with correlations > 0.7 were included in the same model. PERIMETER and field SIZE were the only variables correlated above this level, so we used SIZE because of its easier estimation for designing conservation implementations. We used a zero-inflated distribution approach to model the amount of locations in each plot. This corresponded to a Poisson distribution with an important proportion of zero scores. It is built by overlapping a binomial distribution with a logit link identity that divides the sample between presences and absences, and additionally applying a Poisson distribution with log link identity taking into account that each used plot differs in the amount of locations. We selected the Minimum adequate model (MAM), based on stepwise AIC selection to choose the best model to fit data in each case.

2.3.3 Selection of cereal fields before harvest

We built a dataset including 197 cereal plots located partially or completely within a MCP encompassing all locations obtained during the before-harvest period for each brood. The MCP included in this analysis corresponded to 6 broods having in average 32 ± 12 locations/brood (Table 2) We conducted a GLMM following the same procedure as described above. In this case, we considered the number of locations within each plot during the before-harvest period as the dependent variable.

To build the model, we introduced 9 independent variables, together with INDIVIDUAL as a random factor (Table 1). As this model was focused exclusively on cereal plots we excluded the LAND USE variable from the analysis. However, as we hypothesized that the use of a cereal plot may be influenced by the degree of landscape heterogeneity around it, we included a variable defining habitat DIVERSITY in the model (Table 1). Finally, we hypothesized that females may prefer cereal crops with a certain vegetation density cover or structure while rearing chicks (e.g. broods may have some difficulties to range within high-density plots). Therefore, we considered the NDVI BEFORE as an indicator of photosynthetic activity and biomass on cereal crops before harvest (Table 1).

2.3.4 Selection of cereal fields after harvest

We built a database including 351 cereal plots located partially or completely within a MCP encompassing locations obtained after harvest for each brood. The MCP included in this analysis corresponded to 5 broods having in average 20 ± 11 locations/brood (Table 2). We conducted a GLMM following the same procedure explained above, considering the number of after-harvest locations on each plot as the dependent variable, 9 independent variables and INDIVIDUAL as a random factor (Table 1).

All statistical analyses were conducted in R (version 2.13.1, R Development Core Team, 2009).

Table 2. Number of locations and size of the Minimum Convex Polygons (MCP) of 10 little bustard hens radiotracked in Lleida plains (Catalonia, Spain) during the entire rearing period, the before-harvest (from hatching until the date of the first radiolocation on stubble, for each individual) and the after-harvest (for a given brood, from on the 7th day after the first radiolocation in stubble until all chicks from the brood abandoned the breeding area or died) periods.

Individual	Periods					
	Before-harvest		After - harvest		Entire Rearing	
	Nº fixes	MPC (ha)	Nº fixes	MPC (ha)	Nº fixes	MPC (ha)
Cuca	-	-	8	183.9	14	183.9
Bilbo	-	-	26	38.0	26	38.0
Daria	-	-	11	10.0	11	10.0
Manuela 2007	21	5.1	17	21.4	48	72.8
Manuela 2008	52	15.3	-	-	66	16.1
Merce 2006	41	42.3	9	2.3	12	43.9
Merce 2007	26	3.2	-	-	44	15.1
Minerva	-	-	-	-	17	135.3
Penelope	27	26.5	-	-	43	370
Tura	24	73.7	35	160.6	76	431.8

3. Results

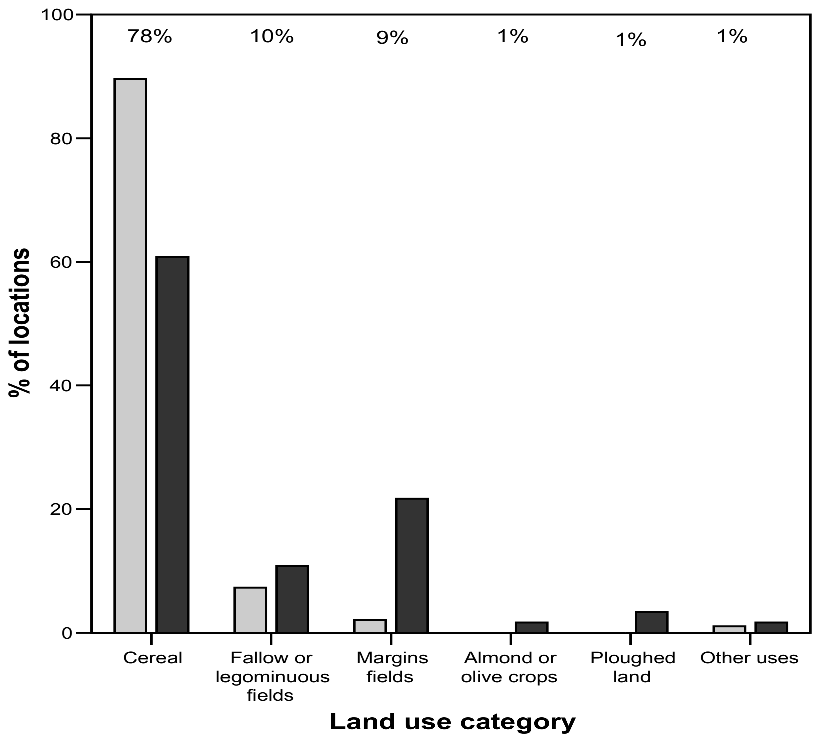
3.1 Habitat preferences throughout the entire rearing period

Compositional analysis revealed that habitat selection of broods differs significantly from random (Wilks $\lambda = 0.0594$, $p < 0.001$, $n = 10$). Field margins were significantly preferred over any other habitat (t-test; $t = -4.6719$, $p = 0.001$) but there was no difference in the use of the other four categories (Cereal crops > Semi-permanent herbaceous vegetation > Other land uses > Fruit trees).

3.2 Selection of crop fields during the rearing period

Although field margins were the most preferred habitat, only 9 % of the 407 radiolocations were found there, and 90% of locations corresponded to agricultural fields (Fig. 1). The GLMM identified SIZE, MARGIN, NEXT HERBACEOUS and

Fig. 1. Proportion of locations of 10 little bustard broods radio-tracked in the Lleida Plains (NE-Spain) according to land use categories, during the entire breeding period (top figures), before harvest (light grey bars) or after harvest (dark grey bars).



LAND USE as the factors determining the use of a given agricultural field during the rearing period (Table 3). First, fields of 2-3 ha were more frequently used than expected (χ^2–test; G = 58.682, d.f. = 3, p < 0.001, Fig. 2). Second, the area of herbaceous margins was significantly higher in fields where the species was detected (0.041 ± 0.044 ha, n = 153 versus 0.022±0.025 ha, n=1184) (Mann-Whitney U = 64528.0; Z = -5.802; P< 0.001). We also observed that the number of locations in a given plot increased with the presence of semi-permanent herbaceous vegetated nearby. On average, the number of locations was 0.28 ± 1.43 in cereal plots without adjacent semi-permanent herbaceous vegetated plots (n = 1020), while it increased to 0.43 ± 2.22 for plots surrounded by 2 or more semi-permanent herbaceous vegetated plots (n = 80). Finally, when having cereal plots as the reference category, the model revealed a preference for fields of semi-permanent herbaceous vegetation and a negative selection of fruit tree fields (Table 3). Semi-permanent herbaceous vegetation plots were present within eight out of ten home ranges, encompassing 8.4 ha ± 12.9 ha and representing a 7 % ± 7 % of the individual MPC area.

Table 3. Values of coefficients and p-values for the variables included in the final generalized linear mixed model, assessing habitat use of cropland plots through the entire rearing period.

Factor	Coefficient	p-value
MARGIN	4.745	>0.001
SIZE	9.194	>0.001
NEXT HERBACEOUS	2.921	0.003
LAND USE		
Fruit tree	-2.355	0.012
Bare terrain	0.219	0.827
Herbaceous vegetation	2.489	0.013

3.3 Selection of cereal plots before harvest

From the 195 radiolocations obtained before cereal harvest, 88 % were found within cereal plots. Thus, we focused on the analysis of the characteristics that made some cereal fields to be more visited than others. The GLMM revealed that DIVERSITY, SIZE, NEXT HERBACEOUS, NDVI BEFORE, NEXT TREE and MARGIN were the main contributing factors explaining brood presence in cereal crops before harvest (Table 4). The model indicated that the presence of broods within a plot was affected by habitat diversity around the cereal crop. The number of locations per plot was 0.4 ± 0.9 in cereal fields surrounded by a single land use (n = 72), 1.0 ± 2.3 in cereal fields surrounded by two different land uses (n = 95), and 1.4 ± 3.6 for fields surrounded by ≥ 3 land uses (n = 28). The number of locations per cereal field tended to decrease with the presence of adjacent tree crops and increased with the frequency of semi-permanent herbaceous vegetated plots around the field. Although the small sample size due to the scarcity of fallow fields in the study area, we observed that the number of locations was 0.9 ± 2.3 in cereal plots without adjacent semi-permanent herbaceous vegetated plots (n=159), and increased to 3.7 ± 3.5 for plots surrounded by 2 or 3 semi-permanent herbaceous vegetated plots (n = 38). Radiolocations were more frequently situated in fields of 2-3 ha than we expected (χ^2–test; G = 119.023, df = 3, p < 0.001) (Fig. 2). NDVI was significantly lower in cereal plots used by broods (0.610 ± 0.122, n = 48) than non-used plots (0.657 ±

0.131, *n* = 109) (Mann-Whitney U = 1910.0; Z = -2.692; *p* = 0.007). Cereal crops used before harvest had more herbaceous field margins (0.043 ± 0.039 ha, *n* = 62) than non-used plots (0.028 ± 0.034 ha, *n* = 135) (Mann-Whitney U = 3192.5; Z = -2.674; *p* = 0.008).

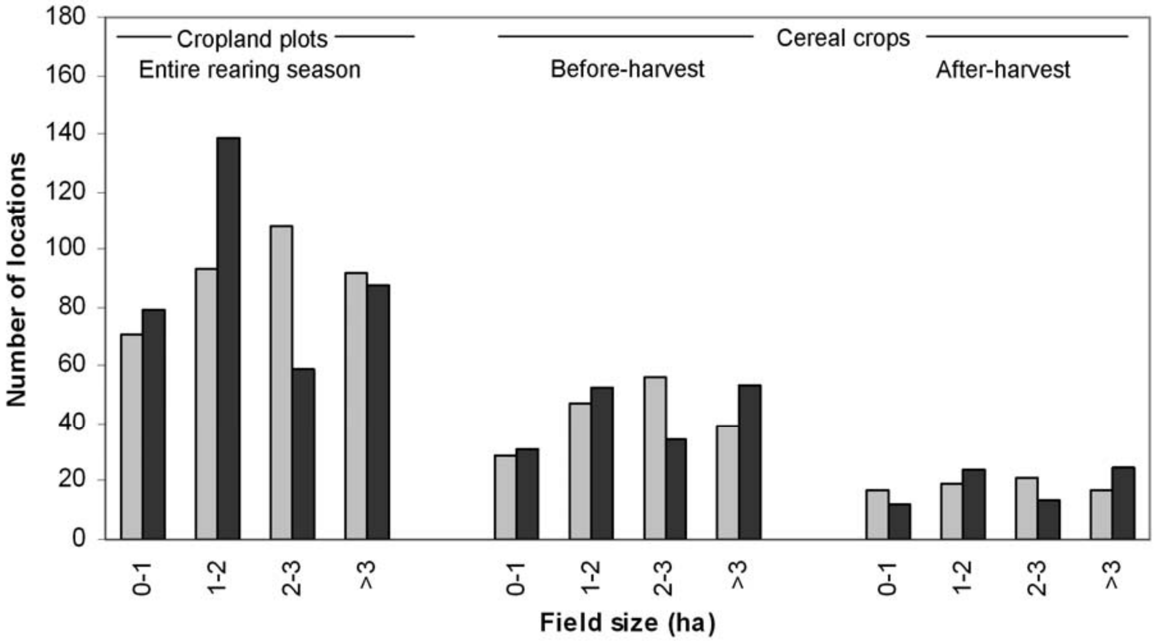
3.4 Selection of cereal plots after harvest

The proportion of locations situated in field margins increased from 2 % before harvest to a remarkable 22% after harvest (Fig. 1). However, most family locations (60 %) were found within stubbles. The best model to explain the probability of a stubble plot being used by little bustard broods included plot SIZE and NEXT HERBACEOUS (Table 4). Radiolocations were again more frequent in fields of 2-3 ha and in 0-1 ha (χ^2–test; G = 10.194, df = 3, *p*=0.017; Fig. 2). Broods tended to use cereal stubbles contiguous to fallow or leguminous plots. On average, the number of locations was 0.15 ± 0.55 in cereal plots without adjacent semi-permanent herbaceous vegetated plots (*n* = 318) and 0.33 ± 0.65 for plots with adjacent semi-permanent herbaceous vegetated plots (*n* = 33) (Mann-Whitney U = 4383.0; Z = 55104.0; *p*= 0.006).

Table 4. Values of coefficients and p-values for the variables included in the final generalized linear mixed models, assessing habitat use in cereal crops according to two temporal approaches.

Period	Factor	Coefficient	p-value
Before-harvest	MARGIN	2.111	0.034
	SIZE	3.554	>0.001
	NEXT HERBACEOUS	2.669	0.007
	NEXT TREE	-2.000	0.046
	DIVERSITY	3.628	>0.001
	NDVI BEFORE	-2.251	0.024
After-harvest	SIZE	5.921	>0.001
	NEXT HERBACEOUS	1.907	0.056

Fig. 2. Distribution of observed (light grey) and expected (dark grey) number of radiolocations of 10 little bustard broods radio-tracked in Lleida Plains (NE-Spain) in relation to field size categories i) all agronomical land uses during the entire breeding period; ii) cereal crops before harvest; iii) cereal crops after harvest.



4. Discussion

Our findings highlight that habitat use of little bustard broods in a cereal pseudo-steppe is mainly driven by the presence of semi-permanent herbaceous vegetation, either herbaceous field margins or fallow or leguminous fields, as these land uses offered both concealment and food availability.First, our results showed the importance of herbaceous margins for little bustard broods during the rearing period, in agreement with previous results (Lapiedra et al., 2011). Although the significant positive selection towards margins detected by the compositional analysis may be partially explained by the reduced extension of margins, these findings were confirmed by the GLMM results. The positive effects of field margins on bird populations as a source of food have been widely documented (Benton et al., 2003; Vickery et al., 2009; Casas and Viñuela, 2010). This may be particularly important in the case of little bustards because the diet of the chicks is based exclusively on arthropods during the first weeks of life (Jiguet, 2002), and in our study area arthropod abundance was maximum in herbaceous field margins (Lapiedra et al., 2011). Second, our results showed that broods preferred semi-permanent vegetation plots, such as fallow fields or leguminous crops, which are important food and shelter sources not only for little bustards (Morales et al., 2008) but also for other farmland birds (Douglas et al., 2010). Fallow fields typically offer a more heterogeneous vegetation cover than dense monoculture cereal crops, with greater vegetation complexity and higher insect availability (Henderson et al., 2000; Pépin et al., 2007; Rodríguez and Bustamante, 2008; Douglas et al., 2010). In fact, arthropod abundance was higher in fallow fields than in cereal crops in our study area (Lapiedra et al., 2011), and arthropod availability is a crucial factor to explain the little bustard presence (Traba et al, 2008; Faria et al., 2012). Leguminous crops were intensively used in our study area by one of the tracked broods (25 % of its locations), despite occupying a small extension within the study area (< 5 ha). Although there may be individual differences in little bustard habitat-use preferences, such crops may provide with the availability of green plants until the end of the rearing period that are consumed by females and large chicks. Provided that arthropod abundances are low due to the widespread use of herbicides and insecticides in crop fields (Aebischer, 1990), broods using margins or semi-permanent vegetation plots may thus benefit from increased food abundance. Fallow fields and leguminous crops are usually covered by vegetation throughout the whole rearing period and thus they represent a shelter against predation or hot temperatures (Morales et al., 2008; Douglas et al., 2010) compared to stubble plots. Broods also seem to minimize predation by occupying plots away from almond and olive tree crops. Tree crops may act as a screen obstructing hen's visibility against predators and this may expose broods to a higher predation risk (Morales et al., 2008; Magaña et al., 2010), although other bustard species inhabiting cereal pseudo-steppes use tree crops as shading areas during the hottest hours of the day (Alonso et al., 2009). The use of field margins as refuge source is controversial. After harvest, when most of the study area has no vegetation cover, broods using herbaceous margins could benefit from refuge against hot temperature or predation. However, before harvest, predation risk may be higher in field boundaries (Wilson et al., 2001; Sharpe, 2006), as carnivores tended to use field margin due to the easier mobility and the elevated abundance of potential prey compared to surrounding agricultural matrix (Vickery et al., 2002). Our results highlight that little bustard broods prefer medium sized fields, on the range of 2-3 ha, rather than smaller or larger fields. In intensified agro-systems, like our study area, little bustard broods may limit their use of larger cereal fields or stubbles due to the positive selection they also make for field margins, as a source of food or shelter, as in some galliformes (Casas and Viñuela, 2010). Hence, the selection of medium sized fields of little bustard broods may be the result of a trade-off between being close of field margins as a source of food and shelter against raptor predation or harsh environmental conditions, but far enough to reduce the predation risk associated to linear habitats (Casas and Viñuela, 2010; Lapiedra et al., 2011). Hence, fallow or leguminous fields covered by herbaceous vegetation may represent high-quality rearing habitats as they may offer both food and concealment resources. Furthermore, herbaceous field margins might be a crucial habitat mainly in terms of food resource availablity and also as a shelter after harvest. Promotion of semi-permanent vegetation patches may contribute to reduce starvation and predation of chicks which have been described as main causes of chick's mortality in the little bustard (Villers, 2010; Bretagnolle et al., 2011). Thus, conservation management should promote the presence of semi-permanent vegetation in order to raise the low breeding success, the major cause of the low viability of little bustard populations (Bretagnolle and Inchausti, 2005; Inchausti and Bretagnolle, 2005).

Despite of the importance of field margins or semi-permanent vegetated plots, its presence is so limited in our study area that most of locations (78 %) were in cereal crops, the dominant habitat. Our results pointed out that habitat use of cereal crops by little bustard broods changes after harvest, suggesting that bird's habitat preferences may be affected by agricultural practices. Before harvest, broods positively selected medium sized cereal plots with high availability of herbaceous margins and next to other habitat patches, particularly fallow fields. Although unharvested cereal might supply a suitable and abundant shelter, broods may benefit from the higher availability of insects and plant diversity typically documented in field margins and fallow land in comparison to cereal crops (Rodríguez and Bustamante, 2008; Lapiedra et al., 2011).

In extensive agro-systems, where high quality habitat is abundant, little bustard tended to avoid diverse land mosaics (Moreira et al., 2012). However, in more intensified agro-systems, like our study area, high land cover diversity is a main factor explaining species' abundance (Campos and López, 1996; Salamolard and Moreau, 1999). In intensified agro-systems, where resources are scarcer, little bustard may benefit from an increased landscape heterogeneity to fulfil all its ecological requirements. In addition, broods also tended to select cereal plots with lower NDVI values within its range. It is plausible that lower NDVI values occur in less vigorous vegetated cereal crops with less biomass and cover. Sparse and less dense vegetation may facilitate the mobility of hens with small chicks and accessibility to food items (Atkinson et al., 2004).

After harvest, the only factor that may be driving the use of a stubble apart from field size is the presence of surrounding semi-permanent herbaceous plots, that may allow them to hide in case of a disturbance. Indeed, the lack of vegetation cover together with the dry conditions after harvest may result in a more homogeneous landscape in which differences between stubbles may be weaker. In this context, preferences of broods seem to focus on other habitats surrounding them, such as herbaceous field margins and semi-permanent herbaceous vegetation patches, which offer comparatively higher shelter and food availability than stubbles. However, we need to acknowldege that the absence of other determining factors of habitat use after harvest may alternatively be explained by the limited sample size or by the possible effect of unconsidered factors such as stubble height, which have been found to determine the use of stubble in some ground-nesting birds (Whittingham, 2006).

5. Conclusions and conservation applications

Habitat use of little bustard broods in cereal pseudo-steppe is mainly driven by the presence of semi-permanent vegetation which provided both food and shelter. In such agro-systems, habitat use of broods varied through the rearing season, as a result of dramatic changes in the landscape due to agronomical practices and drier environmental conditions as the season advances. Before harvest, habitat use of broods is determined both by factors at a plot level (crop type, plot size, NDVI mean value and presence of field margins) and at a landscape level (diversity of land uses, absence of tree crops and presence of fallow fields around the plots), while selection after harvest appears to be mainly determined by the presence of semi-permanent vegetation plots and field size.

Our findings have several implications for the conservation of the species. They provide inedit information about the habitat requirements of little bustard broods that are essential for the design of management guidelines in cereal pseudo-steppes. According to our results, conservation management aiming to raise breeding success, which is a management priority for little bustard populations (Morales et al., 2005a; Bretagnolle et al., 2011; Lapiedra et al., 2011), should include practices both at the landscape and plot level. Agri-environmental schemes could help to improve rearing habitat quality for little bustard broods. These would greatly benefit from the implementation of measures at a landscape level (for example, increasing the diversity or presence of fallows in adjacent fields). Hence, for a global improvement of habitat quality for little bustard broods, we suggest that conservation efforts in this species should combine both agri-environmental schemes and conservation programs. Management practices must be both biologically meaningful and technically feasible for existing farms, to encourage the voluntary participation of farmers on the conservation programs, which is central to achieve conservation objectives (Barreiro-Hurlé et al., 2010).

In cereal pseudo-steppes, management guidelines should promote the presence of semi-permanent vegetation to provide shelter and food throughout the entire breeding season. We suggest at least an average of 0.04 ha of herbaceous field margins per plot (i.e. in a plot of 1 ha, this would represent a 1-meter wide herbaceous margin), which is the mean margin availability of the plots positively selected by broods in our study area. We also recommend promoting 2-3 ha plots covered by natural fallows fields (Jiguet, 2002; Robinson and Sutherland, 2002; Ewald et al., 2010) or leguminous crops (Bretagnolle et al., 2011). Creation of leguminous crops had been successfully implemented in agri-environmental measures in the French (Bretagnolle et al., 2011) and the Catalan (Bota et al., 2007) little bustard populations. Semi-permanent herbaceous vegetation (either margins or plots) should not be mowed, ploughed or treated with herbicide until the chicks are fully grown (end of July in our study area) (Lapiedra et al. 2011). We suggest to promote a less vigorous vegetation cover in AES cereal fields by means of promoting cereal varieties with lax structure (like promoting barley instead of wheat), reducing the seed dose when sowing, or avoiding any kind of irrigation. In these fields, harvest should be delayed and stubbles not polughed until the end of the rearing season to increase breeding success (Lapiedra et al., 2011). General management guidelines should also limit the proliferation of new tree crops and promote landscape heterogeneity. All these measures are feasible from an agronomic point of view, as they basically represent a return to traditional agronomic practices in cereal pseudo-steppe areas and can be funded by European Agricultural Fund for Rural Development (EAFRD).

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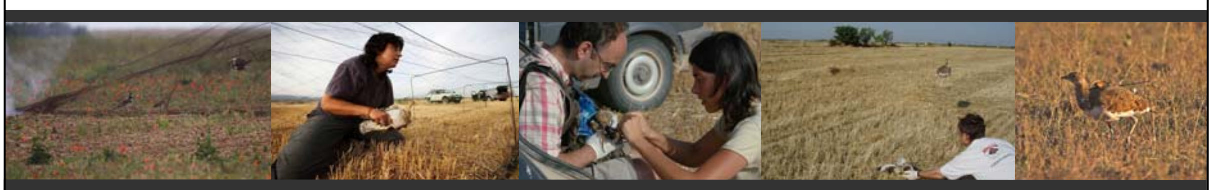
Capítol 2

Aportacions metodològiques per la captura i manipulació de sisons



Chapter 2

Methodological aspects of capturing and handling birds

Tècniques de captura en el sisó *Tetrax tetrax* segons l'edat, el sexe i el període de captura

Anna Ponjoan, Gerard Bota, Santi Mañosa

Resum

Molts projectes de recerca en l'àmbit de la biologia de la conservació es basen en la captura d'animals salvatges, per tant, l'èxit d'aquests estudis depèn en bona part del resultat de les captures. L'adequació del mètode de captura a l'espècie objectiu és determinant per a l'èxit de les captures. En el cas d'algunes espècies com ara les formadores de leks, donada la complexitat de la seva biologia reproductiva i de l'estructura social, l'adequació de la tècnica de captura pot variar fins i tot entre individus d'una mateixa espècie. En aquest treball es descriuen una sèrie de tècniques de captura per tal de facilitar l'elecció del mètode més adequat per als objectius de futurs projectes de recerca, en funció de l'edat, el sexe, el període de l'any.

En el transcurs d'un projecte de recerca emmarcat en la biologia de la conservació, s'han capturat 147 sisons (*Tetrax tetrax*) de diferents edats, sexes i durant varis períodes del cicle anual de l'espècie, mitjançant 4 tècniques de captura diferents. Segons els resultats obtinguts, la trampa de llaços és el mètode més adequat per a capturar mascles reproductors, mentre que per atrapar femelles amb polls el millor mètode entre els estudiats és la trampa d'embut. Els polls, encara petits, es poden capturar fàcilment mitjançant salabres amb mànec telescòpic. La captura d'exemplars en grups no-reproductors mitjançant una trampa de llaços és força ineficient. Aquests mètodes de captura poden ser també útils per a capturar exemplars d'altres espècies d'ocells precocials formadores de leks o d'ambients oberts.

Trapping techniques for little bustard *Tetrax tetrax* according to age, gender and season

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Capsule

We describe four techniques for the capture of Little Bustards according to their age, sex and season, and discuss their adequacy for different research objectives.

Marking or radiotagging animals are common practices in ecological and wildlife research (Bub 1991, Kenward 2001). The success of these studies relies on the ability of researchers to devise safe and effective means to trap and release wild animals uninjured. Capture success depends on the adaptation of the trapping technique to the characteristics, habitat and biology of each species, and may differ between individuals within a species. Little Bustards *Tetrax tetrax* are steppe-land birds exhibiting an exploded lek mating system (Morales et al. 2001). Displaying males exhibit strong territorial behaviour, while females have a discrete plumage and secretive behaviour (Johnsgard 1991). Chicks fledge 28–32 days after hatching, and they are fully grown at the age of 50–55 days (Johnsgard 1991). Outside the breeding season, Little Bustards are gregarious (Jiguet & Wolff 2000). Several capture techniques have been used to trap Little Bustards: cannon nets, snares, clapnets, or spotlighting (Otero 1985a, Schulz 1985, Wolff 2001). However, literature about capture success, trap design and techniques is almost non-existent for Little Bustards, and scarce for bustards in general (Taylor 1985, Launay et al. 1999, Seddon et al. 1999). Incorrect trapping techniques or management can lead to capture myopathy (Williams & Thorne 1996), especially in Little Bustards (Marco et al. 2006, Ponjoan et al. 2008).

Here, we provide information on the design, use and success of four trapping techniques designed to take account of the behaviour and habitat requirements of Little Bustards according to age, sex and season.

We captured 147 birds using four techniques: snares for single birds, snares for groups, funnel traps and hand-held nets. Sex determination of juvenile or adult birds was based on plumage characteristics (Johnsgard 1991) or genetic analyses. Age determination was based on Otero (1985b) and Jiguet & Wolff

(2000). We used wing length to estimate the age of chicks (in days) based on growth curves (Attié 2002). We fitted 87 birds with different radiotag models, weighing <3 % of the bird's mass (Kenward 2001) and we monitored them daily after release. When familial groups were caught, we tagged one bird per family. The occurrence of capture-associated disorders was evaluated during the handling process by checking for signs of physical injuries, or during the hours following release, by checking for signs of abnormal behaviour or mobility (Ponjoan *et al*. 2008). We recorded capture effort and capture success in some years and at some study sites for each method, excluding handheld captures (Table 1). For each trapping method we recorded: capture session length (hours), people needed, and the assembly time (minutes). We conducted Mann–Whitney *U* -tests to evaluate possible differences in the age of chicks caught with respect to year and trapping technique.

SNARES FOR SINGLE BIRDS

We modified the Schulz (1985) and Wolff (2001) snare trap to catch Little Bustards. Traps consisted of a set of 12 welded wire grilles (15 cm × 100 cm); along each grille we fixed a 1-m pneumatic strip attached to both ends, where we tied 10–12 nylon slipknots (diameter = 5–10 cm) at 10-cm intervals. The pneumatic strip worked as cushioning to avoid injuries when the captured bird tried to escape. We fixed the grille to the ground 1–4 m around a bustard decoy, by means of three metal picks and we set the loops upright. Our trap design contributed to make the assembly easier and quicker than the previous designs based on individual fixation of snares (Wolff 2001). We placed four grilles forming a square around a decoy (stuffed male and/or female), four more forming a rhombus outside the square and the last four grilles in a second square outside the rhombus. In that way, we ensured that the wild bird would cross two noose lines in order to reach the decoy. Three people assembled traps (40 minutes) in fallows or ploughed fields where Little Bustards had been previously seen. We used this trap between 15 April and 31 May at two sites on the eastern edge of the Ebro river basin (northeast Spain): in Lleida Plains (Catalonia) (41°41′ N, 0°58′ E) from 2002 to 2005, and in Monegros-Bajo Cinca (Aragón) (41°36′ N, 0°16′ W) from 2005 to 2007. We captured 27 adult males, but only 6 juvenile males, probably because they do not exhibit territorial behaviour (Johnsgard 1991), and no females, which were not attracted to the lures. This technique is useful to catch displaying males as they were strongly attracted by decoys owing to their territorial behaviour. Capture success of snares for single birds was similar between study areas (Table 1), in spite of the strong variation in male densities between them (Lleida Plains: 1.91 males/km 2; Monegros-Bajo Cinca: 0.93 males/km 2) (García de la Morena *et al.* 2006), which suggests that it is independent of male densities. Based on our experience, territorial males fiercely attacked male decoys placed on their arena, while female decoys may also attract neighbouring males. The use of female decoys could be useful when the exact situation of the arena is not known, or to increase capture probability of juvenile males. We did not observe physical injuries following capture, but 2 of the 30 radiotagged males developed capture stress disorders. However, reduction of handling time may eliminate this problem (Ponjoan *et al* . 2008).

SNARES FOR GROUPS

Five people placed the described grilles within an area 7 × 5 m (50 minutes) around two to six decoys (male and female), where a flock was previously observed. We used this method in Lleida Plains during the post-mating period (July 2002) and the pre-mating period (March 2004). We captured one female in a pre-mating group, and two juvenile males, one female and one fullgrown chick in post-mating groups.

Although captures in Little Bustard flocks were successful in previous studies using snare traps (Wolff 2001) and cannon nets (Otero 1985a), our results discourage use of these techniques for several reasons. First, these techniques had the lowest success rate compared with other techniques (Table 1), probably because flocks were little attracted by decoys. Secondly, this technique resulted in disturbance to the entire flock to catch only one or a few individuals. Finally, we observed a high occurrence of capture stress disorders (two of the four radiotagged birds were affected), which could be related to hyperthermia promoted by high environmental temperatures prevailing during the postmating season in the study area (Williams & Thorne 1996).

Table 1. Capture effort and success rate of three trapping techniques used to catch Little Bustards at two sites (Lleida: Lleida plains; Mon: Monegros-Bajo Cinca) in the Ebro river basin (northeast Spain) during different seasons (Mat: mating; Pre:premating; Post: postmating), 2002–2006.

Technique	Site	Year/ season	Effort		Success rate		
			Hours	Sessions	Birds/h	Birds/ session	% Successful sessions
Snare single	Lleida	2004/Mat	90	18	0.08	0.39	33
	Mon.	2006/Mat	15	3	0.20	1	100
	Mon.	2007/Mat	45	9	0.04	0.22	20
	Total		150	30	0.08	0.40	40
Snare group	Lleida	2002/Pre	130	10	0.03	0.40	30
	Lleida	2003/Post	169	13	0.01	0.08	8
	Total		299	23	0.02	0.22	17
Funnel	Lleida	2006/Post	60	20	0.55	1.65	75
	Lleida	2007/Post	42	14	0.33	1	50
	Total		102	34	0.46	1.38	65

FUNNEL TRAP

We adapted the funnel trap described by Bub (1991). Our design consisted of a wide-net blind tunnel (10 m long, 1 m high and 1 m wide) with a single entrance from which a plastic mesh barrier fence (25 m long × 1 m high) spread out from both sides. The tunnel consisted of six metal square wickets, placed in a line and separated by 1.5 m covered by a mist net, excluding the tunnel entrance. We used metal bars with one pick at each extremity to secure the mist net to the ground. When a female with chicks was detected in a flat area devoid of vegetation, a team of four people set the trap (30 minutes) >200 m from the familial group and then they drove the birds towards the tunnel with two vehicles. Two teams of two people simultaneously handled the female and the chicks. Catching took place in the three-hour period after sunrise or before sunset. We used this trap in Lleida Plains from the end of June to mid-July between 2004 and 2007, and we caught 26 breeding females and 52 chicks, corresponding to 38 familial groups. This trap was useful to capture females and/or large chicks and gave the highest capture success among all methods (Table 1). The success rate was higher in 2006 (Table 1), when chicks were younger (42 ± 14 days, n = 17) than in 2007 (50 ± 13 days, n = 7) (although this difference was not significant (U = 39.000, P = 0.209)). Chick size affected capture rate and was higher when chicks were grown enough to walk easily, but not prone to flush. An important constraint in cereal steppe landscapes is that capturing has to be delayed until most cereal had been harvested, which may result in few families being still available or the chicks being too large. However, our design had several main advantages: certainty that the adult bird would be female; quick assembly time, which allowed the settlement of the trap close to the family, increasing capture probabilities; ability to catch complete families; the capture of chicks that were half-grown or larger, which may be necessary for radiotagging purposes. No capture related diseases were observed, which could be explained by the fixed structure of the trap, thus avoiding entanglement, a contributing factor to such disorders (Williams & Thorne 1996).

HAND-HELD NET

We use an extended handle net to capture chicks from a moving vehicle. During the three hours after sunrise or three hours before sunset, we worked in pairs with one person driving the car and the other in charge of capturing. We used this technique in Lleida Plains between 15 June and 31 July from 2002 to 2007. We captured 31 chicks, which were significantly younger (26 ± 10 days, n = 19) than those captured using the funnel trap (40 ± 14 days, n = 38) (U = 148.0, P = 0.000). The hand-held net was useful for catching chicks that were less than half-grown, that were reluctant to walk and difficult to drive into the funnel trap. We did not detect any signs of abnormal mobility or behaviour among radiotagged chicks, so we did not attribute subsequent deaths to capture-related disorders.

CONCLUSIONS

Our results show that a combination of trapping methods and strategies are needed to address the specific biological characteristics of Little Bustards, and that no single capture technique can fulfil all research objectives. We recommend the use of snares to capture displaying males, funnel traps to capture females or medium-sized to large chicks, and hand-held nets to catch small chicks. We do not recommend capturing in pre-mating or post-mating flocks owing to the high occurrence of capture-related disorders. The described techniques could also be adapted to capture other medium-sized lekking or ground-nesting species in open habitats, especially other species of bustards.

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Efectes adversos de la captura i manipulació en el sisó

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Resum

En l'àmbit de la biologia de la conservació, molts projectes de recerca es basen en l'aplicació de tècniques de seguiment o marcatge que requereixen la captura i manipulació d'animals salvatges. Aquestes tècniques permeten obtenir dades ecològiques, demogràfiques o etològiques bàsiques per al disseny de directrius de gestió per a la conservació i que difícilment s'aconseguirien mitjançant altres mètodes. Ara bé, la captura i manipulació dels animals pot causar efectes adversos importants com la reducció de la probabilitat de supervivència a causa de ferides, traumes o alteracions en el comportament, o fins i tot, la mort. Per tant, l'aplicació d'aquestes tècniques tan sols seria acceptable si els beneficis per a la conservació de l'espècie són majors que els efectes adversos provocats, que en qualsevol cas haurien de ser mínims.

En el transcurs de tres estudis sobre la biologia i l'ecologia del sisó (*Tetrax tetrax*) duts a terme La Crau (França), la Meseta Central (Espanya) i la plana de Lleida (Catalunya), es van capturar i radiomarcar 151 exemplars, 23 (15'2 %) dels quals van mostrar alteracions en la mobilitat i la coordinació després de l'alliberament, fet que va causar la mort directa o indirectament de 10 ocells (43'5 % dels animals afectats; 6'6 % dels exemplars capturats). La simptomatologia d'aquestes alteracions és compatible amb la miopatia de captura i aquesta es va diagnosticar en 4 dels ocells afectats. Es tracta d'una patologia degenerativa del teixit muscular que resulta de l'intens esforç muscular associat a l'estrès de la captura i el captiveri. Una regressió logística ha permès identificar d'entre els factors de risc considerats (gènere, període de l'any, edat, mètode de captura, temps de manipulació, temps de retenció)

els 4 darrers com els factors que més contribueixen a incrementar el risc de desenvolupar símptomes compatibles amb la miopatia de captura en el sisó. El risc s'incrementa quan s'allarga el temps de manipulació o de retenció, quan s'utilitzen xarxes canó en relació a les altres trampes, i quan es capturen exemplars joves. No s'ha trobat cap temps llindar per sota del qual desaparegui la miopatia de captura, però la incidència és menor quan el temps des de la captura fins a l'alliberament no supera els 10 o 20 minuts.
Aquests resultats indiquen que el sisó és especialment susceptible a patir alteracions en la mobilitat compatibles amb la miopatia de captura. Com a conclusió, en futurs estudis de sisó i altres espècies pròximes, la tècnica del radioseguiment tan sols s'hauria d'aplicar quan sigui estrictament necessari, i en cas d'utilitzar-la es recomana dissenyar prèviament un protocol de captura i manipulació que tingui en compte els principals factors de riscs per tal de reduir al màxim l'aparició d'efectes adversos relacionats amb la miopatia de captura.

Adverse Effects of Capture and Handling Little Bustard

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ABSTRACT

Capturing wild animals for research or conservation purposes may cause some adverse effects, which is only acceptable if these are outweighed by conservation benefits. We used information from 3 on-going telemetry studies on the endangered little bustard (*Tetrax tetrax*) in Western Europe to evaluate the risk factors associated with capture and handling. Of 151 telemetered birds, 23 (15.2%) exhibited impaired mobility and coordination after release, probably related to the occurrence of capture myopathy. Among the 23 impaired birds, 10 (43.5%) died before recovering normal mobility (6.6% of all birds captured). Logistic regression analyses identified longer handling time, longer restraint time, use of cannon nets, and capture of juveniles as inducing factors for these disorders. We conclude that little bustard is fairly susceptible to suffering ataxia and paresia after release as a result of restraint associated with capture and manipulation. Researchers can reduce this risk by keeping handling and restraint time below 10–20 minutes, particularly when using cannon nets or when capturing juveniles.

KEY WORDS: capture myopathy, little bustard, mortality, radiotagging, *Tetrax tetrax*, trapping.

The little bustard (*Tetrax tetrax*) is a globally near-threatened species distributed from Central Asia, where population trends are unknown, to Western Europe, where populations have declined rapidly as a consequence of agricultural intensification and habitat transformation (Tucker and Heath 1994, BirdLife International 2004). Capture and radiotagging of little bustards is necessary to obtain ecological and demographic data needed to implement conservation practices in an increasingly fragmented habitat.

Capturing and handling any wild animals for research and conservation purposes may cause some mortality or reduction in survival probability due to postrelease shock, trauma, and possible behavioral alterations (Basson and Hofmeyr 1973, Cox and Afton 1998, Nicholson et al. 2000). It has been suggested that handling protocols involving >2% mortality need careful reevaluation (Spraker 1993).

We evaluated the incidence of adverse effects due to capture and radiotagging of little bustards from 3 on-going studies in Western Europe. Our objectives were to 1) evaluate the frequency of occurrence of mobility disorders in little bustards after capture, handling, and radiotagging, 2) identify factors associated with the occurrence of mobility disorders, and 3) show how an analysis of capture and handling protocols can give relevant cues on how to reduce the incidence of mobility disorders in sensitive species.

STUDY AREA

From 1998 to 2004, 3 independent research projects involving the capture of little bustards were conducted in La Crau (southeast France), Lleida plains (northeast Spain),and the Meseta central (central Spain; Fig. 1). La Crau was a 600-km2 plain between the delta of the river Rhone and the Alpilles Mountains. La Crau was covered by a mosaic of land uses, including the original semi-arid steppe dominated by perennial grass (*Brachypodium*

Figure 1. Location of the 3 research projects on little bustards in Spain and France (1998 to 2004) from which we compiled capture and handling data.

retusum), and arable land, comprising hay fields, fallow lands, improved pastures, peach orchards, and intensive grain crops. Sheep grazing was a dominant activity in La Crau. The Lleida plain was a 900-km^2 strip of steppes and pseudo-steppes on the eastern edge of the river Ebro basin. Lleida plain was covered by low-intensive cereal crops and small remains of the original dry-shrub vegetation. The Meseta central study area included a 300-km2 sub-area of extensive cereal crops (i.e.,wheat, barley) interspersed with fallows and wastelands in Madrid province and a 30-km2 irrigated sub-area in Toledo province, mainly devoted to alfalfa crops. Little bustard populations were estimated at 473–650 breeding males and 1,700–1,800 wintering birds at La Crau (Wolff 2005), 847–2,688 breeding males and about 1,500 wintering birds on the Lleida plains (Bota et al. 2004, García de la Morena et al. 2006), 500 breeding males in the Madrid sub-area (García de la Morena et al. 2004), and up to 2,000 wintering birds in the Toledo sub-area (E. L. García de la Morena,Universidad Autónoma de Madrid, unpublished data).

METHODS

We captured little bustards during the mating (Mar–Jun) and nonmating season (Jul–Feb) using 3 techniques: leg nooses, cannon nets, or funnel traps (Bub 1991). Each 1 captured bird was handled by 2–4 persons and fitted with a backpack transmitter model TW3 with a 3-year lifespan AA battery (Biotrack, Dorset, United Kingdom). In all cases, the transmitter weighed ≤4% of the weight of the bird (Kenward 2001). We determined sex from plumage characteristics and, if required, by genetic analyses from blood samples. We defined age following Otero (1985) and Jiguet and Wolff (2000). We considered females to be adult from the first spring after hatching and males from the beginning of their second spring (Wolff 2001). At each capture, we recorded total time (TT, min from capture until release), handling time (HT, min during which the handler was manipulating the bird in some way), and restraint time (RT, min during which the bird was retained but not being handled; RT = TT - HT).

We established the occurrence of mobility disorders in birds by following their movements and behavior at least once every 3 days and recording any sign of abnormal mobility on release or during the following hours, days, or weeks. According to intensity, we established 3 categories of altered mobility: minor alterations, in which the bird was able to fly and walk but showed some transient difficulty in coordination; strong alterations, in which the bird was unable to fly but able to walk; and severe alterations, in which a bird was unable to fly and unable to walk. We considered that a previously affected bird recovered when we observed it flying and walking with no difficulty.

To analyze the factors associated with the occurrence of such disorders, we conducted a forward stepwise logistic regression analysis relating the occurrence or absence of alterations as a dependent dichotomous variable and HT and RT as independent continuous variables (Hair et al. 1999). We also incorporated the following independent categorical variables as dummy variables: origin (La Crau, Lleida plains, Meseta central), sex (M, F), age (juv, ad), trapping method (leg nooses, cannon net), time of year (mating, nonmating), and time of day (hr; 0600–1100, 1100–1800, 1800–2300). We set the first category of each of these variables as the reference level. We excluded birds captured in funnel traps from this analysis, due to small sample size. We evaluated the performance of the model by constructing receiver operator characteristic (ROC) plots and calculating the corresponding area under the curve (AUC) values (Fielding and Bell 1997). Performance varied from 0.5 to 0.7 (random classification), 0.7 to 0.8 (fair classification), 0.8 to 0.9 (good classification), or 0.9 to 1 (excellent classification). We calculated all statistics, ROC graphs, and AUC calculations with SPSS 11.5 statistical package (SPSS Inc., Chicago, IL).

RESULTS

We captured 151 little bustards, 81 at La Crau, 37 on the Lleida plains, and 33 on the Meseta central. During the nonmating period we captured both sexes in similar proportions, but during the mating season capture was selective toward males (χ^2_1 = 21.879, $P \leq 0.001$) and against juveniles (χ^2_1 =

4.289, *P* = 0.043; Table 1). Our sample contained a disproportionately low number of juvenile females (χ^2_1 = 5.019, *P* = 0.027).

After release, 23 (15.2 %) birds had mobility alterations, which were minor in 3 birds (13%) and strong or severe in 20 birds (87%; Table 2). Within the latter, 4 birds had strong alterations and 6 had severe alterations; the exact level could not be determined for 10 birds. Of the 23 affected birds, 13

Table 1. Sex (M, F, unknown), age (ad, juv, unknown), trapping method (leg nooses, cannon net, funnel trap), and capture period (mating, nonmating) of little bustards captured in La Crau (France), Lleida plains, and Meseta central (Spain), 1998 to 2004.

		Leg nooses		**Cannon net**		**Funnel**	
Sex	**Age**	**Mating**	**Non-mating**	**Mating**	**Non-mating**	**Non-mating**	**Total**
M	Juv	9	10	0	1	0	20
	Ad	27	16	7	2	0	52
	Unknown	4	1	5	2	0	12
F	Juv	0	5	0	1	0	6
	Ad	12	24	2	3	6	47
	Unknown	0	0	0	1	0	1
Unkown	Juv	0	6	0	0	0	6
	Ad	1	0	0	0	0	1
	Unknown	3	3	0	0	0	6
Total		56	65	14	10	6	151

subsequently recovered normal mobility and 10 (43%; 6.6% of all birds captured) died without recovering. All deaths took place after release, and we found carcasses depredated 2–11 days later. Among the 128 nonaffected birds that we tracked, only one died during the same 11-day period, from a power line strike. The mortality rate was lower for birds with minor alterations (33%, *n* = 3) than for birds with strong or severe alterations (45%, *n* = 20). Among the latter, the mortality rate was 50% for birds with strong alterations (*n* = 4) and 83% for birds with severe alterations (*n* = 6). For affected birds that survived, time to recover ranged from <1 day to 11 days (*n* = 8; Table 2).

The logistic regression analysis showed that the variables that significantly affected the probability of occurrence of time, and trapping method were accounted for, we detected no effect of sex, study area, time of year, or time of day. For a given handling and restraint time, the probability of occurrence of mobility alterations after capture were handling time, restraint time, trapping method, and age, with regression coefficients 6 standard errors of 0.11 ± 0.036, 0.02 ± 0.006, 3.00 ± 0.948, and -1.78 ± 0.725, respectively. Once the effects of age, handling time, restraint time, and trapping method were accounted for, we detected no effect of sex, study area, time of year, or time of day. For a given handling and restraint time, the probability of occurrence of mobility disorders increased by a factor of about 10 when we used cannon nets and by a factor of about 5 when we caught juvenile birds (Fig. 2). The model explained 41% of the variance in the probability of occurrence of mobility disorders. The ROC analysis yielded an AUC value of 0.852 (95% CI = 0.762–0.943; $P \leq 0.001$).

Juvenile birds suffered from postcapture mobility disorders more often than adults (31%, n = 32 vs. 10%, n = 100; $\chi^2 = 8.515$, df = 1, $P = 0.004$).

Table 2. Estimated days to recover or die in relation to the intensity of the mobility alterations (severe: incapable of flying or walking; strong: bird walks but does not fly; minor: ataxia) of little bustards in La Crau (France), Lleida plains and Meseta central (Spain), 1998 to 2004.

		Recovery time (d)				Time to death (d)			
Intensity	**n**	**1**	**2-5**	**>5**	**Unkown**	**1**	**2-5**	**>5**	**Unknown**
Severe	6	0	0	1	0	0	2	2	1
Strong	4	1	1	0	0	0	0	2	0
Severe or strong	10	2	1	0	5	0	1	1	0
Minor	3	2	0	0	0	0	1	0	0

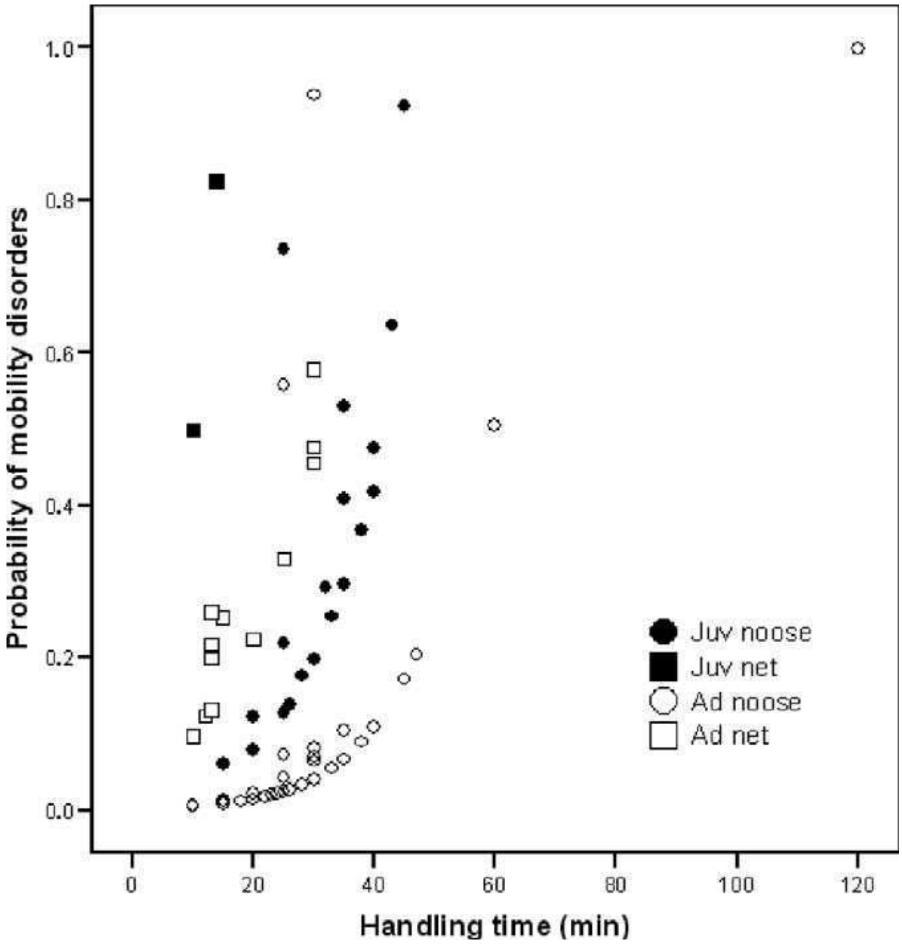

Figure 2. Predicted probability of occurrence of mobility disorders after release in little bustards captured between 1998 and 2004 in La Crau (France), Lleida plains, and Meseta central (Spain), in relation to handling time (min during which the handler was manipulating the bird in some way), age (juv and ad) and trapping method (leg nooses and cannon net).

However, we observed no differences in the frequencies of occurrence among birds caught in leg nooses (14%, n = 121) or cannon nets (25%, n = 24; χ^2 = 1.799, df =1, P = 0.219). Handling time (10–120 min; 27.2 ± 12.5 min; n = 142) was longer for birds captured with leg nooses (Table 3). Total time (10–390 min; 43.7 ± 46.6 min; n = 142) was longer during the nonmating season and shorter in funnel traps than for other methods (Table 3). Both handling time and total time were shorter in birds with no mobility disorders. Among birds that had some level of mobility alteration, handling time was longer in birds with severe alterations than in birds with only minor or strong alterations (Table 3).

Table 3. Handling time (min during which the handler was manipulating the bird) and total time (min from capture until release) of captured little bustards at La Crau (France), Lleida plains and Meseta central (Spain), 1998 to 2004.

		Handling time (min)				Total time (min)			
		$\bar{x}$	SD	*n*	*P*	$\bar{x}$	SD	*n*	*P*
Origin	Lleida Plains	30.03	10.5	35	0.085	31.4	12.2	35	0.01
	Meseta central	23.29	10.62	31		45.8	26.9	30	
	La Crau	27.57	13.68	76		34.5	19.7	72	
Period	Mating	28	15.37	62	0.524	31.3	16.2	62	0.011
	Nonmating	26.65	9.7	80		40.2	22.8	75	
Trap	Noose	29.28	12.69	113	0.000	35.8	18.7	108	0.033
	Net	19.43	8.23	23		42.7	27.7	23	
	Funnel	18.67	3.38	6		18.7	3.9	6	
Age	Juv	28.9	8.3	31	0.340	57.2	51.8	31	0.080
	Ad	26.3	13.8	92		39.3	47.9	92	
Sex	M	27	14.6	78	0.128	35.5	21	78	0.128
	F	26.04	9.02	52		49.9	65.0	52	
Alterations	Yes	36.2	21.4	23	0.027	52.8	29.2	20	0.009
	No	25.5	9.04	119		33.4	17.3	117	
Intensity	Minor or strong	27.6	5.4	7	0.046	41.6	21.8	5	0.961
	Severe	37.2	9.8	6		42.2	12.6	6	
Death[a]	Yes	37.1	12.6	10	0.867	40.1	14.1	10	0.056
	No	35.5	26.8	13		65.5	35.1	10	

[a] Only for birds showing mobility disorders after release.

DISCUSSION

Our results indicate that the little bustard is highly susceptible to developing mobility alterations after capture and handling. Frequencies of occurrence ranged between 12% and 21% in 3 research projects, and the overall associated mortality was 6.6%, similar to values found in other studies with sensitive species (Cox and Afton 1998, Nicholson et al. 2000). We did not determine the immediate cause of death of some of the affected birds, as we found all carcasses depredated, but that death occurred much more often in birds with mobility alterations links the likelihood of mortality to the observed disorders. Death occurred more often in birds with the strongest alterations, which could be the direct result of the disorder or of an increased vulnerability to depredation due to ataxia or paresia (Spraker et al. 1987, Cox and Afton 1998).

The exact origin of the disorders was not certain in most cases, but capture myopathy was histologically diagnosed in all the carcasses that were necropsied (n = 4; Marco et al. 2006). Because all affected birds showed similar signs compatible with capture myopathy and because we detected no evidence of trauma, shock, or transmitter misfit, we concluded capture myopathy as the most probable origin of the disorders observed (Spraker et al. 1987, Williams and Thorne 1996). The importance of handling and restraint time, as well as of age and trapping method, has also been reported by other studies that inferred capture myopathy related mortalities (Spraker et al. 1987, Williams and Thorne 1996, Nicholson et al. 2000, Hölfe et al. 2004).

The aim of our model was not to predict when mobility alterations are going to occur, but to identify some risk factors that may promote occurrence of alterations. The AUC value of the ROC analysis indicated that our model predicted with acceptable accuracy the occurrence of myopathy. However the model only explained 41% of total variance in the probability of occurrence of mobility disorders, indicating that other factors, such as environmental temperatures, relative humidity, or body condition may also be involved (Williams and Thorne 1996, Bro et al.1999, Nicholson et al. 2000, Hölfe et al. 2004).

We conclude that long handling time and restraint time, the use of cannon nets, and capturing juveniles increased the risk of occurrence of mobility alterations in little bustards after capture. Nicholson et al. (2000) showed that processing time was a significant factor in capture mortality in eastern wild turkey females (*Meleagris gallopavo*). Although less important, restraint time also seemed to increase the risk, so the time that birds spend caught in traps or inside boxes must be minimized. When handling time is <20 minutes, the probability of occurrence of mobility disorders for adult little bustards caught in nooses remains fairly low (Table 3, Fig. 2). Nets appear to increase the risk of occurrence of alterations after release more than other methods, as found in other bird species, but the increased risk may not be associated with differences in handling times, which in fact were shorter for birds captured with nets (Table 3; Spraker et al.

1987, Williams and Thorne 1996, Hölfe et al. 2004). Unnatural positions under the net and large numbers of birds caught at the same time might be the underlying source of the negative effect of using cannon nets (Cox and Afton 1998). Juvenile birds were more susceptible to developing postrelease alterations, which were not related to differences in handling time or total time between young and adult birds (Table 3). Age-biased effects have been observed elsewhere for other bird species (Spraker et al. 1987, Hölfe et al. 2004). However, the effect of age in our study must be treated with some caution, because age was not independent of sex or trapping period (Table 1).

MANAGEMENT IMPLICATIONS

Our results highlight the importance of reducing the total time of handling and restraint to minimize the risk of occurrence of adverse effects when capturing and handling sensitive species such as the little bustard. Staff awareness and teaming during capture and handling are crucial to achieving this goal. Small nets that allow only individual captures and adequate mesh size that reduces entanglements also may help to reduce restraint time (Dabbert and Powell 1993). In the case of the little bustard, we recommend not to exceed 20 minutes of total time of handling and restraint, to keep the risk of occurrence of mobility alterations to a minimum. Caution must be extreme when capturing juvenile birds or when using cannon nets. Under these circumstances, we recommend to keep the total time of handling and restraint below 10 minutes.

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Agraïments

Aquest periple va començar un bon dia a la facultat, quan l'empenta i entusiasme de joventut ens van dur a emprendre el primer treball ornitològic. El primer agraïment va per vosaltres, la Montse i la Tresa, mireu en què s'ha convertit el musclo!!! Seguint en el temps, la següent persona que em vaig creuar en el camí ornitològic va ser en Santi, el qui després seria el meu director de tesi. Santi, un gràcies enorme, per tot el què m'has ensenyat durant aquests anys i sobretot pel teu suport incondicional, que em vas donar des del primer dia, i que ha estat decisiu per a tirar endavant.

Part d'aquesta tesis es va coure al Centre Tecnològic Forestal de Catalunya, a qui agraeixo el suport rebut durant tot el temps que hi vaig treballar. També agrair als companys de l'Àrea de Biodiversitat, en Gerard, els Davids i en Campro totes les coses que n'he après. També a l'Oriol Lapiedra; moltes gràcies Uri, ha estat un plaer compartir amb tu les penes i glòries de la vida científica. Als companys de fatigues de temporades de camp (en Pau, en Sergi Ricart, l'Eli Montserrat, la Núria Pocino, Juan Bécares, en Ferran Broto, l'Enric Ortega...) amb els qui he compartit moooltes hores de feina, postes de sol, sortides de sol, gloriosos entrepans de can Busqueta, estones a l'Avenç, sopars de nevera buida, entrepans de xoriço congelats, radiadors col·lapsats d'espigues, conquestes de turons pel radioseguiment, etc. Gràcies per llevar-vos cada dia ben d'hora, ben d'hora per treballar per la conservació dels secans. Als companys del Departament, moltes gràcies pel suport i per aguantar les meves visites fugiceres! Una menció especial a tots aquells que m'heu donat aixopluc en les meves constants anades i vingudes, sobretot a la pensió del Rei Planelles, a la 3A i en Xevi, a la Bori (avui vindré...) i a la Maia.

Voldria agrair el finançament rebut de la Fundació Catalana per a la Recerca, i a l'Agencia de Gestió d'Ajuts Universitaris i de Recerca (AGAUR) per la concessió d'una beca FI i una BE-2011 per a estades a l'estranger. També expressar el meu agraïment al Dr. Tim Benton de la Universitat de Leeds, per acollir-me al seu grup de recerca, així com a tots els membres que en formen part, per la seva calorosa acollida. Un altre grup que m'ha rebut amb els braços oberts és la ètnia Maluquer, a qui vull agrair el recolzament constant, sobretot a en Rafel Ramos. Gràcies també a aquells que desinteressadament heu embellit aquesta tesi amb les vostres fotos i el vostre art, especialment a en Jordi Bas, en José Antonio Martínez, en Martí Franch i la Momo.

Finalment, voldria disculpar-me a la família i als amics que heu patit en algun moment els efectes secundaris (i espero que transitoris!) propis del doctorat. Una abraçada per al E.L.N.D., per fer que la vida sigui molt millor!!! i un gràcies personalitzat a la Pecu (pdh connexions), a en Jordi (sempre a punt!) i a la Fanlo (per fer-me sentir com a casa!). Un gràcies a l'aire pels oblidats (perdoneu, la memòria no és el meu fort) i pels creadors dels petits grans plaers: la delicadesa de l'Albert Puig i l'encert d'August Kuentzmann Damm i la ironia del Senyor Marcelí.

A la família, sobretot als meus pares de qui sempre he rebut un suport incondicional, gràcies pel suport i la paciència! Pepita, que he acabat! I tal i com bé deia en Lluc, ara toca fer festa!

Ús de l'espai i de l'hàbitat en el sisó *Tetrax tetrax* durant el període reproductor: aspectes aplicats a la conservació en hàbitats agraris

1. Comportament espacial dels mascles de sisó, *Tetrax tetrax*, en el lek

2. Comportament espacial i èxit reproductor de les famílies de sisó en ambients cerealístics intensius

3. Ús de l'hàbitat de les famílies de sisó en pseudo-estepes cerealístiques en relació a la fenologia de sega

4. Tècniques de captura en el sisó segons l'edat, el sexe i el període

5. Efectes adversos de la captura i manipulació en el sisó