

# Biología y Conservación del Urogallo en un hábitat mediterráneo

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## **Biología y conservación del Urogallo en un hábitat mediterráneo**

Biology and conservation of the Capercaillie in  
a Mediterranean environment

Memoria de Tesis Doctoral presentada por

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Licenciado en Biología

para optar al grado de Doctor por la Universidad de León

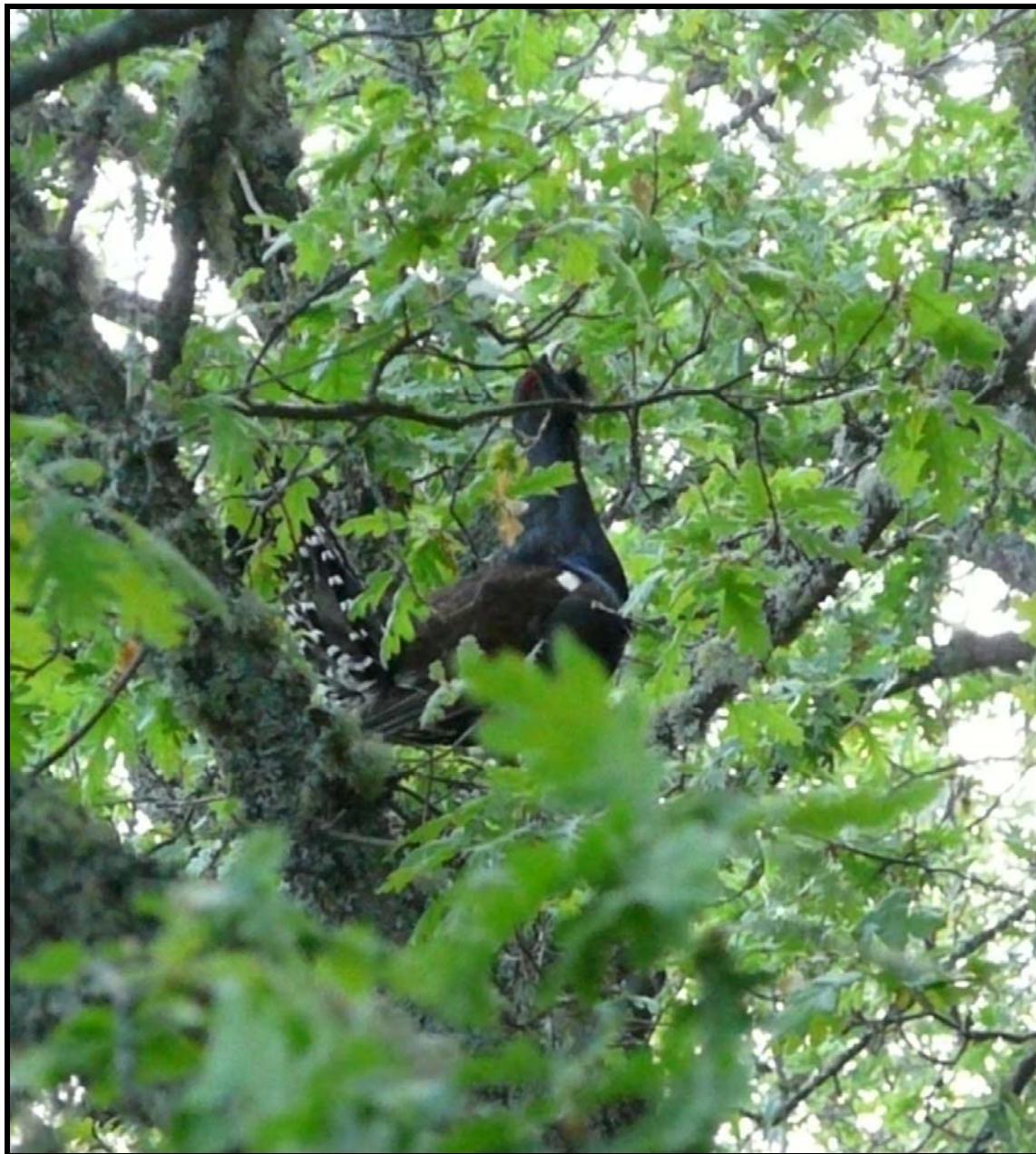
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*A Rafael, a las dos Marías  
y a los que ya no están*



Urogallo cantando al amanecer sobre un roble melojo en el área de estudio (primavera 2011)

*Verde que te quiero verde.  
Verde viento. Verdes ramas.*

*El barco sobre la mar  
y el caballo en la montaña.*

*(F. García Lorca)*

Espero que esta Tesis de Manuel A. González, de Valdelugueros (en cuyos bosques de hoja caduca el Urogallo cantó desde el principio mismo de la creación del mundo) sirva para evitar su desaparición, primero, y para que los profanos en la materia como yo conozcamos más sus características, tan misteriosas y mitificadas, en segundo lugar. Así no diremos que canta al atardecer y en otoño como yo hice en Luna de lobos con mi mejor intención poética, pero con un gran desconocimiento de las costumbres de tan fabulosa ave.

*Julio Llamazares*

Se fue yendo el hombre blanco de esas tierras agrestes y volvió el suelo a latir con sus brezales y robles matojos, a tapar sus vergüenzas de viejo y voraz arado en los panes del centeno. Un espeso matorral cubre el puzzle agrario que ofrecían esos mismos lugares hace cincuenta años. Sobre esa espesura vegetal se tumba ahora la nieve en invierno como si fuera un colchón de muelles para que la primavera se levante vigorosa y conquistando.

Y a su sombra, poco a poco, pitipiti, fue colándose un prodigo: el Urogallo encontró nuevo campeo y se quedó aquí, en el extremo sur de ese corredor de montes que desde los bosques de Ancares y Laciana penetra por el Bierzo hasta las tierras omañesas, tierras que no le son desconocidas al Urogallo, pues de ellas le fue expulsando la intensa y agobiadora repoblación humana que desde hace mil años quemó, aró y explotó cada recurso natural hasta la fatiga... y trampeó, cazó, esquilmó o agotó.

Volvió ayer a estos montes el viejo inquilino, el gallo montés del clocloteo, y de chiripa se ha ido librando de cartuchazos para querenciarse y residir. Es, pues, el Urogallo más meridional de Europa, la nueva rareza que le hace único... y vulnerable. No por haber abandonado el hombre estos parajes de arada pedregosa tiene el Urogallo preservada su casa. Parques eólicos, caza furtiva y la malicia del ignorante que desprecia cuanto ignora le acosan.

Y aquí es donde el trabajo de Manuel A. González (que en estas páginas se sustancia con profusas averiguaciones, campo pateado y estudio tenaz) se antoja una necesidad imperiosa, una desplegada e incontestable razón con la que abolir la agresión o el destierro de la nueva patria de esta especie, cuya supervivencia será también el espejo de la nuestra y del cosmos biológico que confluye en estas tierras donde se concilian lo cantábrico, lo atlántico y lo mediterráneo.

Aquí, pues, está el Urogallo. Tiene tutores en el saber aquí escriturado y en querer aquí prometido. Aquí está el milagro ante el que cualquiera ha de caer de rodillas bendiciendo la esperanza de que no todo está perdido.

El Urogallo ha vuelto. Esta es también su casa. Y este trabajo son ya sus cimientos.

*Pedro García-Trapiello*

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# Introducción general



### 1. La importancia de las poblaciones periféricas en latitudes bajas

La abundancia de una especie suele variar a lo largo de su rango de distribución de acuerdo a un patrón descendente del centro a la periferia, aunque los mecanismos implicados son en gran medida desconocidos (Brown 1984; Gaston 2003). Esta hipótesis del centro-periferia asume que en el centro del rango se sitúa el hábitat más favorable para la especie, mientras que en la periferia las condiciones son menos favorables (Brown 1984), por lo que las poblaciones periféricas están frecuentemente aisladas y fragmentadas, y presentan baja diversidad genética intrapoblacional aunque alta entre poblaciones a escala regional (Lawton 1993; Vucetich y Waite 2003). Vivir cerca de los límites de tolerancia de la especie suele implicar que en estas poblaciones periféricas las abundancias sean menores y más variables que en poblaciones centrales, y que su riesgo de extinción sea mayor (Brown 1984; Kark et al. 1999).

En especies en declive existen dos hipótesis para explicar la contracción de sus rangos de distribución. La hipótesis **demográfica**, predice que las primeras en desaparecer serán las pequeñas poblaciones periféricas, mientras que las más grandes poblaciones del centro se mantendrían hasta las etapas finales del declive. Por otro lado, la hipótesis **por contagio** predice la extinción de las poblaciones vecinas a la primera población en la que aparecen los factores del declive, a modo de contagio desde el foco del declive (*sensu* Lomolino y Channell 1995). Sin embargo, los mecanismos implicados en el declive son una mezcla de varios factores y en muchas ocasiones son las áreas periféricas las que mantienen las últimas poblaciones, gracias a su aislamiento y menor influencia de los factores antrópicos causantes del declive (Channell y Lomolino 2000a, b). Así, muchas de esas áreas periféricas proporcionan en la actualidad hábitats y mantienen poblaciones importantes para la conservación de especies amenazadas (ver p.ej. Burbidge y McKenzie 1989; Towns y Daugherty 1994; Naves et al. 2003).

Las áreas en latitudes bajas frecuentemente han actuado como refugios para muchas especies durante los períodos glaciales. De este modo, poblaciones del hemisferio norte que ahora se localizan en el extremo sur del área de distribución de una especie, en otro tiempo pudieron ser centrales o incluso septentrionales. Estas poblaciones periféricas en latitudes bajas o en **retaguardia** (sensu Hampe y Petit 2005) a menudo se han mantenido de forma continuada durante períodos de tiempo más dilatados que las poblaciones de latitudes mayores, más expuestas a cambios climáticos naturales (p.ej. glaciaciones). La presencia continua de estas poblaciones durante períodos más largos hace que a menudo constituyan linajes más antiguos que las poblaciones septentrionales, lo que confiere a estas poblaciones en retaguardia un valor especial como almacenes de diversidad genética (Hampe y Petit 2005; Rodríguez-Muñoz et al. 2007; Bajc et al. 2011).

Ante el actual cambio climático las especies pueden responder mediante selección de los genotipos mejor adaptados a las nuevas condiciones climáticas, o mediante la contracción de su rango de distribución siguiendo las condiciones a las que están adaptadas. Los modelos de distribución de aves europeas predicen una contracción de sus rangos hacia el norte y una reducción del 50-80% de su distribución actual. (Huntley et al. 2006; Huntley et al. 2007). La conservación de las poblaciones en retaguardia es importante a largo plazo para la evolución de las especies (Lesica y Allendorf 1995; Drovetski 2003), y porque a más corto plazo es esperable que sean las más afectadas por el cambio climático (Pearce-Higgins et al. 2011). Para adoptar medidas de conservación eficaces que frenen situaciones de declive es necesario realizar un seguimiento previo de estas poblaciones (Pearce-Higgins et al. 2011).

Mantener la diversidad genética de una especie amenazada puede reducir su riesgo de extinción y para conseguirlo es necesario conservar tanto las poblaciones centrales como el máximo número posible de poblaciones periféricas y en retaguardia, sin importar su tamaño (Hampe y Petit 2005). Las características ecológicas y requerimientos de conservación de estas poblaciones en retaguardia suelen diferir de

las poblaciones centrales por el hecho de ocupar hábitats diferentes. Tratarlas como ecológicamente equivalentes y aplicar medidas de conservación y gestión semejantes a las de poblaciones centrales puede resultar poco adecuado o incluso contraproducente (Lawton 1993; Chase y Leibold 2003). Identificar estas poblaciones en retaguardia, estudiar sus preferencias ecológicas, diversidad genética y factores de amenaza, son requisitos previos a cualquier medida eficaz de gestión y conservación de poblaciones amenazadas (Hampe y Petit 2005).

### 2. Distribución y población mundial de la especie de estudio

El Urogallo Común (*Tetrao urogallus* Linnaeus, 1758) es un ave (Phasianidae: Tetraoninae) forestal de distribución paleártica extensa (Fig. 1).



**Figura 1.** Urogallo macho exhibiéndose (izqda.) y tres hembras en posición receptiva en un cantadero escocés. Autor: Desmond Dugan

La mayor parte de su distribución se concentra entre Siberia y Escandinavia (Fig. 2, Storch 2001; 2007). En las zonas más meridionales de su rango de distribución la especie ha quedado restringida a los bosques más extensos de zonas montanas, igualmente dominados por coníferas (Klaus y Bergmann 1994). La distribución más meridional conocida de *Tetrao urogallus* en tiempos recientes se corresponde con una pequeña población de *T. u. major* (Brehm 1831) en el Monte Athos (Grecia) donde ocupaba bosques de coníferas entre los 1140-1340m s.n.m. (Hölzinger y Rösler 1990) y aunque no está claro si el origen de esta población era natural o introducida allí por monjes (Handrinos y Akriotis 1997), en la actualidad parece haberse extinguido debido a las talas incontroladas y la caza furtiva (Bousbouras 2009).

A nivel global no se considera una especie amenazada, el número total de Urogallos ronda los cinco millones de los cuales Rusia alberga unos cuatro millones (Fig. 2). Sin embargo en las últimas décadas, la mayoría de las poblaciones europeas han sufrido un declive que ha sido especialmente acentuado en las poblaciones periféricas y meridionales del rango de distribución, donde las poblaciones son pequeñas y están aisladas (Moss et al. 2000; Storch 2006).

Actualmente en la península Ibérica viven dos subespecies (Castroviejo 1975; del Hoyo et al. 1994; Martí y Moral 2004). El Urogallo Pirenaico (*T. u. aquitanicus* Inqram, 1915) catalogado en España como Vulnerable (~1500 ejemplares, Real Decreto 139/2011). Y el Urogallo Cantábrico *T. u. cantabricus* (Castroviejo, 1967) (~500 ejemplares, Storch et al. 2006) que está totalmente separado (>300km) de la población más próxima en Pirineos. Esta subespecie, es la población que corre mayor riesgo de desaparición a corto plazo y la única considerada En Peligro de acuerdo a los criterios de la UICN debido a un rápido declive, pequeño tamaño poblacional, aislamiento y hábitat altamente fragmentado (Orden MAM/2231/2005; Robles et al. 2006; Storch et al. 2006; Real Decreto 139/2011).



**Figura 2.** Distribución global del Urogallo Común *Tetrao urogallus*. Adaptado de Storch (2001)

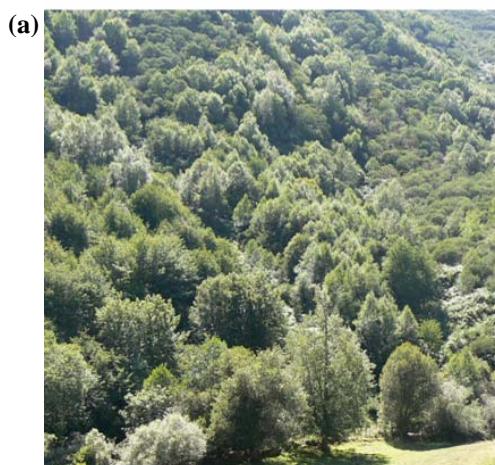
### **3. Selección de hábitat y dieta del Urogallo**

El Urogallo selecciona extensos bosques donde se alternan fragmentos de árboles maduros, etapas seriales y zonas abiertas (Rilstad 1989; Kurki et al. 2000; Wegge et al. 2005). Su hábitat principal y donde se concentra la mayor parte de la población mundial, son los bosques boreales de coníferas o taiga del Paleártico (Storch 2001, 2007).

En Escandinavia y Europa central la presencia del Urogallo está asociada a bosques de coníferas de cobertura forestal abierta (50-60%) y heterogénea. Esta estructura típica de los bosques maduros se traduce en un sotobosque rico en vegetación arbustiva, especialmente en arándano *Vaccinium myrtillus* (Gjerde 1991; Klaus y Bergmann 1994). Este arbusto en general es importante para el Urogallo porque además de proporcionar alimento y cobijo a los adultos (frutos, hojas y tallos), alberga los artrópodos que constituyen el recurso trófico fundamental de los pollos durante sus 3-4 primeras semanas de vida. En consecuencia, la distribución principal del Urogallo se solapa en gran medida con la del arándano (Gjerde y Wegge 1989; Storch 1995b; Selås 2000). Tradicionalmente se ha considerado una especie típica de bosques

maduros (Rolstad y Wegge 1987b; Rolstad y Wegge 1987c; Storch 1993a; Storch 1993c), sin embargo el tamaño del bosque y su heterogeneidad estructural parecen ser las variables más importantes y positivamente correlacionadas con la presencia del Urogallo (Rolstad y Wegge 1987a; Quevedo et al. 2006a, b; Suchant y Braunisch 2008).

En la periferia meridional de su rango de distribución, el Urogallo puede ocupar puntualmente bosques caducifolios siempre que la superficie de bosque sea suficiente (Fig. 3, Obeso y Bañuelos 2003; Quevedo 2006a, b). Así, en lugares concretos de Escocia, Alpes o Pirineos, existen Urogallos en bosques mixtos de coníferas y hayas *Fagus sylvatica*. Pero es únicamente en la cordillera Cantábrica (N-O España) donde una población entera de Urogallo vive todo el año adaptada y casi exclusivamente en bosques caducifolios (Quevedo et al. 2006a, b).





**Figura 3.** (a) Bosque caducifolio cantábrico de abedul *Betula pubescens*; (b) vista interior de un bosque cantábrico de roble orocantábrico *Quercus pyrenaica*; (c) bosque maduro de coníferas *Pinus uncinata* en Pirineos; (d) vista interior de un pinar *Pinus sylvestris* en Escocia. Autora: Beatriz Blanco-Fontao

A pesar de ser una especie sedentaria en la que los adultos muestran una alta fidelidad a los lugares tradicionales de canto o cantaderos, a la vez necesitan amplias áreas vitales de 500ha de media (rango 50-1000ha; Gjerde y Wegge 1987; Leclercq 1987a; Menoni 1991; Storch 1993c). Por tanto, la plasticidad ecológica del Urogallo ante cualquier modificación del hábitat es muy reducida y puede ser utilizado como indicador de calidad de hábitat para otras aves forestales (Pakkala et al. 2003; Laiolo et al. 2011).

El Urogallo es estrictamente vegetariano excepto en las primeras semanas de vida. En invierno, y especialmente si el suelo del bosque está cubierto de nieve, la dieta se restringe casi por completo a acículas de pino silvestre u otras coníferas, con la excepción del Urogallo Cantábrico que presenta una dieta basada en los recursos disponibles de los bosques caducifolios que habita (ver abajo, Storch et al. 1991; Picozzi et al. 1996; Rodríguez y Obeso 2000). A partir de la primavera y con el suelo sin nieve, el acceso a mayor variedad de plantas permite al Urogallo diversificar la dieta incluyendo hojas, brotes, flores, frutos, herbáceas y arbustos, y si el arándano está disponible lo selecciona positivamente (Storch 1995b; Borchtchevski 2009). En

general el alimento del Urogallo, y especialmente la acícula de pino, posee gran cantidad de celulosa y bajo valor energético. Por ello, para sobrevivir con una dieta pobre en energía estas aves han desarrollado ciegos intestinales que ayudan a optimizar la eficiencia metabólica (Andreev 1988; Moss 1989).

### 4. El Urogallo en la cordillera Cantábrica y la población de estudio

La cordillera Cantábrica constituye la retaguardia de *Tetrao urogallus* en su distribución más suroccidental (Obeso y Bañuelos 2003; Quevedo et al. 2006b).

Aunque los datos históricos son muy escasos, la distribución del Urogallo Cantábrico fue mucho más extensa que en la actualidad. En el siglo XVIII y posiblemente hasta principios del XIX, su área de distribución ocupaba la mayor parte de la cordillera Cantábrica (Lugo, Asturias, León, Palencia y Cantabria) y su prolongación meridional (Montes de León y Aquilianos y Sierras del Teleno en León y de la Cabrera entre León y Zamora) donde parece haberse mantenido hasta los años cuarenta del siglo XX (Castroviejo et al. 1974). Ocupó también el norte de Portugal hasta el siglo XVIII en Serra do Gerês (da Gama 1998). Además en el siglo XVII había Urogallos en el Sistema Ibérico (Burgos, Soria y La Rioja) que quizás sobrevivieron hasta mediados del XIX, aunque se desconoce si estos Urogallos estaban comunicados con los Cantábricos o con los Pirenaicos (Madoz 1848; Castroviejo et al. 1974; Martínez 1993).

En la mayor parte de esa distribución antigua, el bosque dominante, al igual que hoy en día, era el melojar (Ramil-Rego et al. 1998). Durante más de 2000 años y de forma masiva a partir de la edad Media, estos bosques han estado sometidos a deforestación por causas antrópicas con el período de máxima deforestación en la mitad del siglo XX (Muñoz-Sobrino et al. 1997; García et al. 2005). Esta reducción masiva del bosque en los últimos siglos parece directamente relacionada con la contracción hacia el norte de la distribución histórica del Urogallo Cantábrico (ver Fig. 4).



**Figura 4.** *Gris oscuro* distribución histórica del Urogallo Cantábrico desde el siglo XVIII (a partir de citas de Madoz 1848 y Castroviejo et al. 1974, recogido en Martínez 1993); *gris claro* distribución en el año 2005 (modificado a partir de Robles et al. 2006)

El Urogallo Cantábrico hoy ocupa unos 2000km<sup>2</sup> en los bosques más extensos y a mayor altitud, entre León y Asturias (Fig. 4, Quevedo et al. 2006a, b). Se mantiene un núcleo residual y en vías de extinción en Cantabria, su presencia es ocasional en Lugo y está extinto en Palencia. En las últimas tres décadas el área de distribución se ha reducido especialmente en los extremos oriental y occidental, y también en la zona central donde la fragmentación del bosque es más acentuada (Robles et al. 2006).

La población de Urogallo Cantábrico ha sufrido un declive entre el 25 y el 50% en los últimos 15 años y actualmente es estima en torno a los 500 ejemplares (Robles et al. 2006; Storch et al. 2006). Esta cifra se considera la población mínima viable (riesgo de extinción <1% en 100 años) para poblaciones aisladas de la especie (Storch 1997b;

Grimm y Storch 2000), aunque incluso dentro de la misma especie la población mínima viable dependerá de la historia natural y las condiciones ambientales de la población, por lo que su extrapolación al Urogallo Cantábrico puede no ser válida (ver Flather et al. 2011).

La peculiaridad ecológica más exclusiva del Urogallo Cantábrico consiste en vivir en bosques caducifolios en la retaguardia de la especie (Fig. 5). Ocupa boques caducifolios de la cordillera Cantábrica, tanto hayedos, como abedulares *Betula pubescens* y diferentes robledales *Quercus orocantabrica*, *Q. petraea* y *Q. pyrenaica* (Obeso 2005; Suárez-Seoane y García-Rovés 2004). En la actualidad la subespecie se mantiene en los bosques más extensos y a mayor altitud que aparentemente sufren menos molestias que otros bosques cantábricos y presentan una mayor cobertura de arándano (Quevedo 2006a, b). A lo largo del año los Urogallos Cantábricos en general y las hembras con pollos en particular, utilizan diferentes micro-hábitats fuera del bosque, como pastizales, piornales y zonas de matorral por encima de la orla supra-forestal (Quevedo et al. 2006b; Bañuelos et al. 2008).

Para una especie básicamente folívora como el Urogallo pasar el invierno en los bosques sin hojas de la cordillera Cantábrica conlleva implicaciones ecológicas. Unas de las más importantes son el mayor uso de recursos del sotobosque en comparación con el resto de poblaciones europeas, y el consumo en invierno del acebo *Ilex aquifolium*, que es una de los pocos árboles cantábricos que mantienen sus hojas en invierno (Rodríguez y Obeso 2000; Blanco-Fontao et al. 2010).



Figura 5. Urogallo Cantábrico *Tetrao urogallus cantabricus* macho exhibiéndose en un abedular. Autor: Héctor Ruiz

#### *Genética del Urogallo Cantábrico*

Las penínsulas del sur de Europa, como la Ibérica o la Balcánica, han actuado de refugios glaciales y en ellas el Urogallo ha mantenido su distribución más estable y meridional. Tras un largo período de aislamiento, hoy existe una marcada diferenciación genética entre las poblaciones ibéricas y las demás poblaciones de Urogallo (Rodríguez-Muñoz et al. 2007; Bajc et al. 2011). Se han diferenciado dos linajes de Urogallo, el linaje meridional y el boreal (Duriez et al. 2007). El linaje meridional se encuentra distribuido en las penínsulas Ibérica y Balcánica, y se considera el linaje evolutivo más antiguo (Rodríguez-Muñoz et al. 2007). En Pirineos existen haplotipos de ambos linajes (meridional y boreal) lo que sugiere que esa cordillera actuó en algún momento como zona de contacto entre los Urogallos Ibéricos y el resto de Urogallos. Una situación semejante a la de Pirineos existe en la península Balcánica, donde aparecen en simpatría los dos linajes de Urogallo (Bajc et al. 2011). Pero es sólo en la cordillera Cantábrica donde se encuentra únicamente linaje

meridional. Este linaje está considerado una Unidad Evolutiva Significativa (ESU; Moritz 2002) y por tanto requiere ser conservado por su singularidad y variabilidad genética mediante medidas específicas de conservación (Rodríguez-Muñoz et al. 2007).

El Urogallo Cantábrico presenta la diversidad genética más baja entre las poblaciones de Urogallo. Esto es probablemente debido al largo aislamiento de la población Cantábrica y al reciente cuello de botella sufrido entre los siglos XIX-XX que provocaron deriva genética y endogamia (Duriez et al. 2007; Rodríguez-Muñoz et al. 2007). Además, ser la única población en la que únicamente aparece el linaje meridional, vivir en bosques caducifolios en la retaguardia de la distribución de la especie y presentar la diversidad genética más baja de todas las poblaciones de Urogallo, hacen que la subespecie cantábrica esté considerada dentro de la ESU como una MU (Unidad de Manejo) que por su divergencia genética y ecológica debe ser conservada a corto plazo de manera independiente del resto de Urogallos, incluso del resto de la ESU (Moritz 2002; Duriez et al. 2007; Rodríguez-Muñoz et al. 2007; Alda et al. 2011; Bajc et al. 2011).

Hoy existen dos núcleos principales de Urogallo Cantábrico (occidental y oriental; Robles et al. 2006) separados por una zona con muy baja población de la especie y restringida a la vertiente norte de la cordillera (Asturias) por donde aún parece existir un reducido flujo génico que conecta la zona occidental y la oriental (ver Fig. 8, Alda et al. 2011).

### *Factores del declive del Urogallo Cantábrico*

El declive documentado del Urogallo Cantábrico es producto de factores globales (declive generalizado de la especie), regionales (peculiaridades ecológicas en la retaguardia de la especie) y locales (competencia con ungulados, predación, etc...) que probablemente actúan sinérgicamente. Los factores más importantes de este declive son la pérdida y fragmentación del hábitat (Obeso 2005).

Una de las causas históricas de pérdida y fragmentación de bosque en la cordillera Cantábrica ha sido el uso del fuego por el hombre para la obtención de pastos (Luis-Calabuig et al. 2000; Suárez-Seoane y Garcia-Rovés 2004; Ezquerra y Rey 2011). En general la fragmentación del bosque aumenta la densidad de bordes forestales y las posibilidades de que los cantaderos queden abandonados (Obeso et al. 2001, Obeso 2005), puede aumentar la depredación (Angelstam 1992; Storaas et al. 1999), la competencia con otros herbívoros y las molestias humanas (Blanco-Fontao y Quevedo 2006; Blanco-Fontao et al. 2011). Esta última hipótesis de competencia con otros herbívoros se apoya en las correlaciones detectadas entre el declive del Urogallo y el aumento de ganado doméstico y ungulados silvestres en la cordillera Cantábrica (Pollo et al. 2003; Blanco-Fontao et al. 2011), en la superposición de nicho trófico existente entre el Urogallo Cantábrico con el corzo *Capreolus capreolus*, el ciervo *Cervus elaphus* y la vaca *Bos taurus*, y en una reducción significativa de la disponibilidad del arándano cuando las densidades de estos ungulados son elevadas (Blanco-Fontao et al. enviado). También apoya esta hipótesis que los mejores efectivos de Urogallo Cantábrico se mantengan en el occidente de la cordillera, donde no existe el ciervo y las densidades de vaca son menores que en el oriente, donde el Urogallo está prácticamente extinto (Rodríguez-Muñoz et al. 2011).

A nivel de paisaje los parques eólicos, minas a cielo abierto, autopistas, tendidos eléctricos o pistas forestales son causas directas de pérdida y fragmentación del hábitat, y de molestias para la especie en la cordillera Cantábrica (MMA 2004). También la degradación del micro-hábitat no visible a nivel de paisaje (p.ej. zonas del bosque excesivamente ramoneadas o degradadas por una elevada presión de herbívoros o de humanos, mallas ganaderas, etc...) que no necesariamente afecta a nivel de población (p.ej. dispersión entre poblaciones), sí puede afectar al área vital de los Urogallos (p.ej. reduciendo supervivencia individual y reproducción, ver Franklin et al. 2002). Un ejemplo de este tipo de degradación del hábitat puede ser una pista en el bosque, frecuentemente utilizada por vehículos y/o personas, cuyo entorno los

Urogallos evitan, pero que no constituye ninguna barrera para la dispersión de juveniles.

A todos estos factores de declive referentes al hábitat, hay que añadir la baja diversidad genética del Urogallo Cantábrico que por efecto de la deriva genética puede suponer otro factor hacia la extinción (Storch et al. 2006; Rodríguez-Muñoz et al. 2007). La abundancia de parásitos, que puede contribuir al declive de especies amenazadas, no parece ser una causa del declive del Urogallo Cantábrico, aunque la baja diversidad y abundancia de parásitos internos encontrados en sus excrementos podría ser un reflejo del declive (Obeso et al. 2000; Millán et al. 2008).

Finalmente, la influencia del cambio climático sobre las lluvias y temperaturas de Mayo-Junio puede disminuir el éxito reproductor del Urogallo, lo cual constituye otra amenaza, especialmente para las poblaciones periféricas y meridionales (Moss et al. 2001). Aunque los modelos predicen la extinción total de las poblaciones ibéricas y balcánicas para finales de este siglo (Huntley et al. 2007), el futuro del Urogallo Cantábrico es incierto. La subespecie podría adaptarse por selección natural y/o modificando su distribución, pero con el escaso conocimiento actual de la biología del Urogallo Cantábrico, la dirección con la que puede responder al cambio climático es impredecible.

La conservación del Urogallo Cantábrico en el escenario de cambio global y paisaje altamente fragmentado de la cordillera Cantábrica (García et al. 2005) pasa por mitigar los factores de amenaza mediante la conservación estricta del hábitat para mantener la conectividad funcional y el flujo génico de toda la metapoblación (Quevedo et al. 2006a, b; Alda et al. 2011). Para conseguirlo se ha propuesto la prohibición de las prácticas silvícolas, mallas ganaderas, instalación de tendidos eléctricos, parques eólicos y explotaciones mineras en los bosques con Urogallo y en su orla de matorral supra-forestal, la limitación de la construcción y uso de pistas, el control de las poblaciones de ciervos y jabalíes en el hábitat del Urogallo, la restricción del pastoreo

en zonas con Urogallo, el incremento de la vigilancia de los cantaderos en la época de celo, el seguimiento de las poblaciones y la sensibilización social (MMA 2004; Obeso 2005).

### *El melajar mediterráneo: un “nuevo” hábitat para el Urogallo Cantábrico*

El Urogallo en la cordillera Cantábrica es un caso de especie adaptada al frío en un refugio glacial al sur de su distribución (Duriez et al. 2007; Rodríguez-Muñoz et al. 2007).

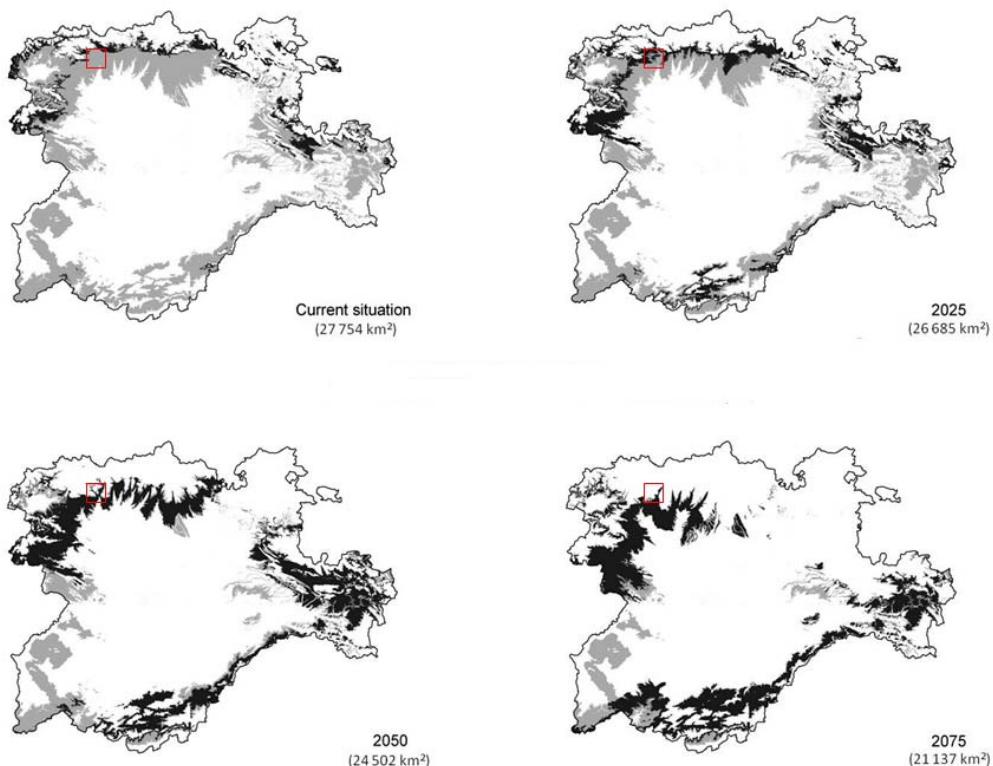
Hasta ahora los estudios que han abordado la biología del Urogallo Cantábrico se han desarrollado en abedulares, hayedos o robledales eurosiberianos, donde tradicionalmente era conocida la presencia de la especie (Castroviejo 1975; Obeso y Bañuelos 2003). La aparición en Mayo de 1998 de un Urogallo con comportamiento “loco” permitió constatar la presencia del Urogallo Cantábrico en melojares mediterráneos del sur de la cordillera Cantábrica (Pollo 2001; Pollo et al. 2004), y estudios posteriores entre los que se incluyen los de esta Tesis confirmaron la presencia de una población de Urogallo viviendo en melojares mediterráneos. En estos bosques tan diferentes a los eurosiberianos (p.ej. sequía estival y práctica ausencia de acebo y arándano) el Urogallo podría haberse adaptado a estas diferentes condiciones ambientales. La cordillera Cantábrica constituye la retaguardia actual de *Tetrao urogallus* y estos melojares mediterráneos son la distribución actual más meridional del Urogallo Cantábrico, por lo que podemos considerar los Urogallos de estos melojares en “la retaguardia de la retaguardia”.

De cumplirse lo que los modelos predicen para aves adaptadas al frío (Huntley et al. 2006, 2007), estos Urogallos en “la retaguardia de la retaguardia” serían los primeros de su especie en desaparecer por causas climáticas. Sin embargo, especies relictas tienen más posibilidades de adaptarse al cambio global en regiones con diversidad de climas y orografía compleja, porque en ellas podrían encontrar condiciones favorables realizando dispersiones más cortas que si estuvieran en regiones de clima homogéneo

(Ohlemüller et al. 2008). Por tanto, el Urogallo Cantábrico que ocupa una zona de transición entre las regiones biogeográficas Eurosiberiana y Mediterránea (ver Cap. 1) con orografía compleja podría parcialmente mitigar los efectos del cambio mediante dispersiones locales entre ambientes diferentes.

En relación con lo anterior, el modelo local de cambio climático propuesto para Castilla y León por del Río y Penas (2006) no coincide con el propuesto para la península Ibérica (IPCC 2001). El modelo local sugiere un aumento en la precipitación estival en zonas mediterráneas junto con una tendencia hacia unidades bioclimáticas templadas, con temperaturas anuales más altas y precipitaciones distribuidas a lo largo de todo el año. Esto conllevaría un retroceso de los melojares hacia el sur impulsado por el abandono rural que ya lo está permitiendo (ver Fig. 6, del Río y Penas 2006; Morán-Ordoñez et al 2011), lo que para el Urogallo por un lado podría suponer ventajas (aumento del hábitat potencial hacia el sur en forma de melojares mediterráneos) y/o por otro lado desventajas (cambios en la precipitación y temperaturas en Mayo-Junio que podrían disminuir la tasa de reproducción, ver Moss et al. 2011).

Ante el cambio climático el futuro del Urogallo en general y de la subespecie Cantábrica en particular, es incierto. Por su situación geográfica y el hábitat que ocupa, la población de Urogallo de los bosques mediterráneos del sur de la cordillera Cantábrica es idónea para estudiar la respuesta de la especie ante el cambio climático a medio plazo. De modo que el seguimiento de esta población en la retaguardia de la distribución sería de gran interés científico y de conservación.



**Figura 6.** *Gris* distribución potencial del melojar mediterráneo para la actualidad y para los años 2025, 2050 y 2075 en León y Castilla; *negro* distribución potencial del melojar templado para la actualidad y para los años 2025, 2050 y 2075 (extraído a partir de del Río y Peñas 2006); *recuadro rojo* localización del área de estudio

## 5. Objetivos y estructura de la Tesis Doctoral

La conservación de cualquier especie amenazada requiere la elaboración de medidas de gestión adaptadas a sus requerimientos (Yoccoz et al. 2001). A lo largo de la distribución de la especie estos requerimientos pueden variar, especialmente en poblaciones alejadas de la zona central (Brown 1984; Lawton 1993). Por tanto,

conocer los requerimientos locales y el estado actual de las poblaciones es fundamental y anterior a cualquier medida de conservación (Marsh y Trenham 2008).

El conocimiento actual del Urogallo en los melojares mediterráneos se restringe a su existencia casi anecdótica en este tipo de hábitat (ver Pollo 2001; Pollo et al. 2004). A menudo cuando no existe una base científica las medidas de gestión fallan (CEBC 2009), producen una enorme pérdida de recursos, o tienen incluso consecuencias negativas sobre la biodiversidad de los ecosistemas gestionados (Olea et al. 2009). Por tanto, antes de aplicar medidas de gestión eficaces de conservación del Urogallo Cantábrico, se requiere un mayor conocimiento de la ecología de esta población en melojares mediterráneos. Conocer su situación genética, selección de hábitat, dieta y amenazas respecto al resto de la (sub)especie, permitirá mejorar las medidas de gestión del Urogallo Cantábrico y de todos los ecosistemas que habita.

El objetivo fundamental de esta Tesis es el estudio de la ecología y conservación del amenazado Urogallo Cantábrico en los bosques mediterráneos en la retaguardia de su distribución actual (Fig. 8, 9 y 10). La estructura de esta Tesis se compone de capítulos independientes, cada uno de ellos con objetivos específicos comentados brevemente a continuación, y detalladamente explicados en cada capítulo:

**Capítulo 1.** Los censos suelen ser el paso previo a cualquier investigación más específica (Yoccoz et al. 2001). Ya que la localización de Urogallos en nuestra área de estudio es muy reciente, no existe aún un censo global de la especie en su distribución mediterránea. *Objetivos:* en este capítulo se establecen las bases para el resto del estudio. Para ello se localizan y describen los cantaderos de Urogallo, y se realiza una estimación de la población de machos por cantadero para toda el área de estudio.

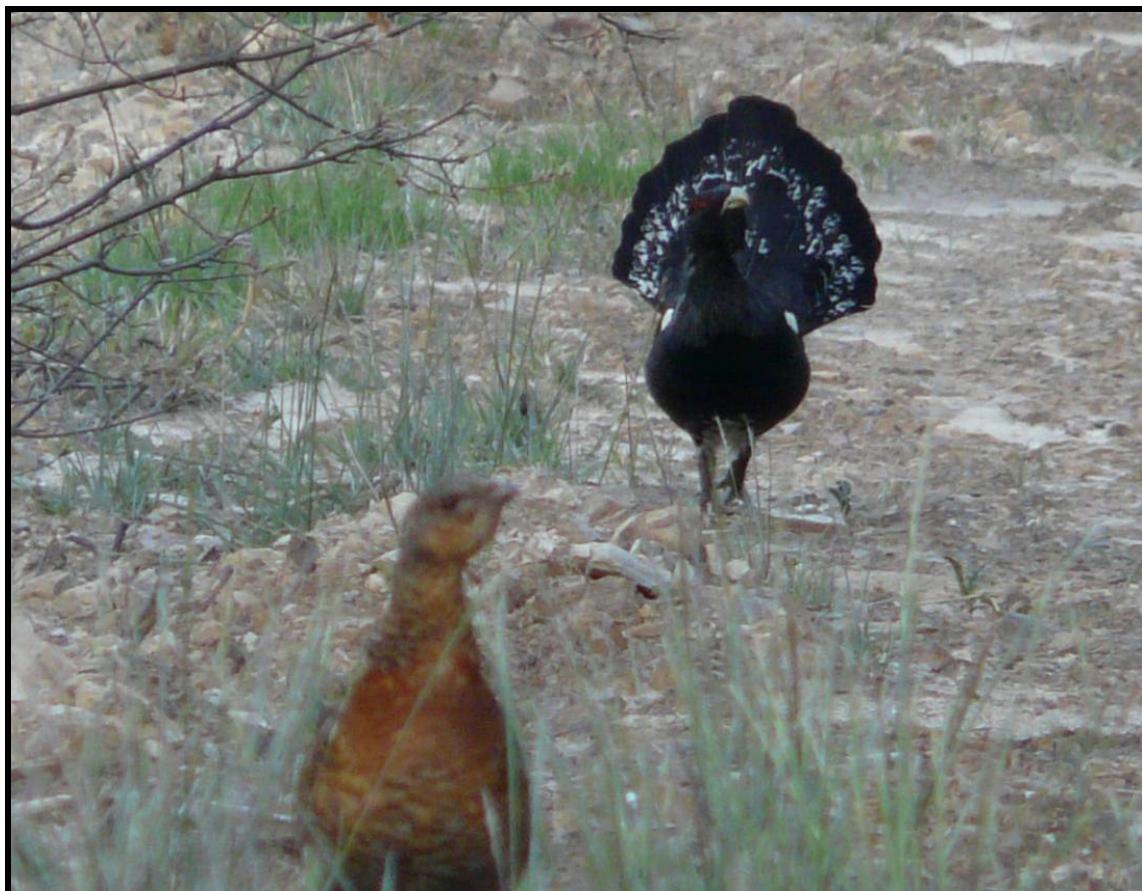
**Capítulo 2.** La selección de hábitat y dieta son dos aspectos clave para comprender los requerimientos ecológicos de una especie en un hábitat determinado (Sutherland 1998). En el caso del Urogallo Cantábrico existen estudios que abordan estos aspectos en la distribución eurosiberiana de la subespecie (Rodríguez y Obeso 2000;

Quevedo et al. 2006b; Blanco-Fontao et al. 2010), pero no en el área mediterránea que se estudia en esta Tesis. Estos trabajos aportan interesantes recomendaciones de conservación para las áreas donde fueron realizados. Sin embargo, debido a las diferentes condiciones ambientales de aquellas áreas, probablemente no reflejen la realidad local en nuestra área de estudio, siendo en estos casos recomendable realizar estudios a nivel local o regional (ver McAlpine et al. 2008, Quevedo et al. 2006a). *Objetivos:* en este contexto se describe la selección de hábitat del Urogallo en el área de estudio y su dieta comparada con la población central de Urogallo Cantábrico.

**Capítulo 3.** El Urogallo Cantábrico muestra la diversidad genética más baja entre las poblaciones de Urogallo y está considerado una MU (Unidad de Manejo) que a corto plazo debe ser conservada independientemente (Moritz 2002; Duriez et al. 2007; Rodríguez-Muñoz et al. 2007; Alda et al. 2011; Bajc et al. 2011). Para reducir el riesgo de extinción de una especie amenazada es necesario mantener la diversidad genética, y se contribuiría a ello conservando las poblaciones periféricas y en retaguardia, sin importar su tamaño (Hampe y Petit 2005). Al igual que sucede con los estudios que han abordado la ecología del Urogallo Cantábrico, los que hasta ahora han estudiado aspectos genéticos se han centrado en los bosques eurosiberianos (ver Duriez et al. 2007; Rodríguez-Muñoz et al. 2007; Alda et al. 2011). *Objetivos:* estudiar mediante técnicas no invasivas la estructura genética de los Urogallos mediterráneos (Fig. 7) y su posible contacto con la población principal de Urogallo Cantábrico.

**Capítulo 4.** Planificar la gestión de las especies amenazadas es una obligación legal y una herramienta básica para asegurar su conservación (Calzada et al. 2011; Real Decreto 139/2011). Las actividades humanas de explotación de los recursos naturales que conllevan pérdida y/o fragmentación del hábitat suponen una amenaza para la conservación del Urogallo Cantábrico y los ecosistemas naturales que ocupa (MMA 2005; Obeso 2005). El área de estudio está fundamentalmente desprotegida, por lo que a las amenazas generales del Urogallo Cantábrico pueden sumarse aquí otras

específicas del área de estudio. *Objetivos:* en este último capítulo se describen las principales amenazas contemporáneas causantes de fragmentación y destrucción del bosque, se analiza el efecto potencial de la construcción de parques eólicos e incendios, y se discuten las implicaciones que pueden tener para la conservación del Urogallo Cantábrico en la retaguardia de la distribución de la especie.

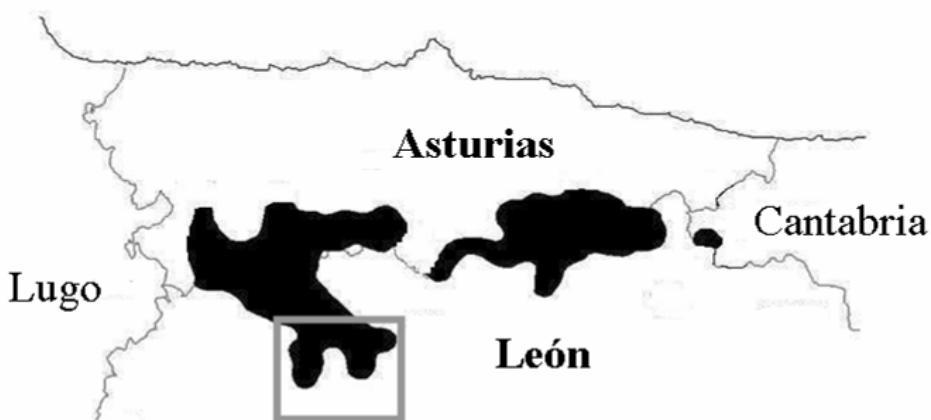


**Figura 7.** Urogallina Cantábrica cortejada por un macho adulto en el área de estudio.

Autor: Fernando Gonzalo

## 6. Área de estudio

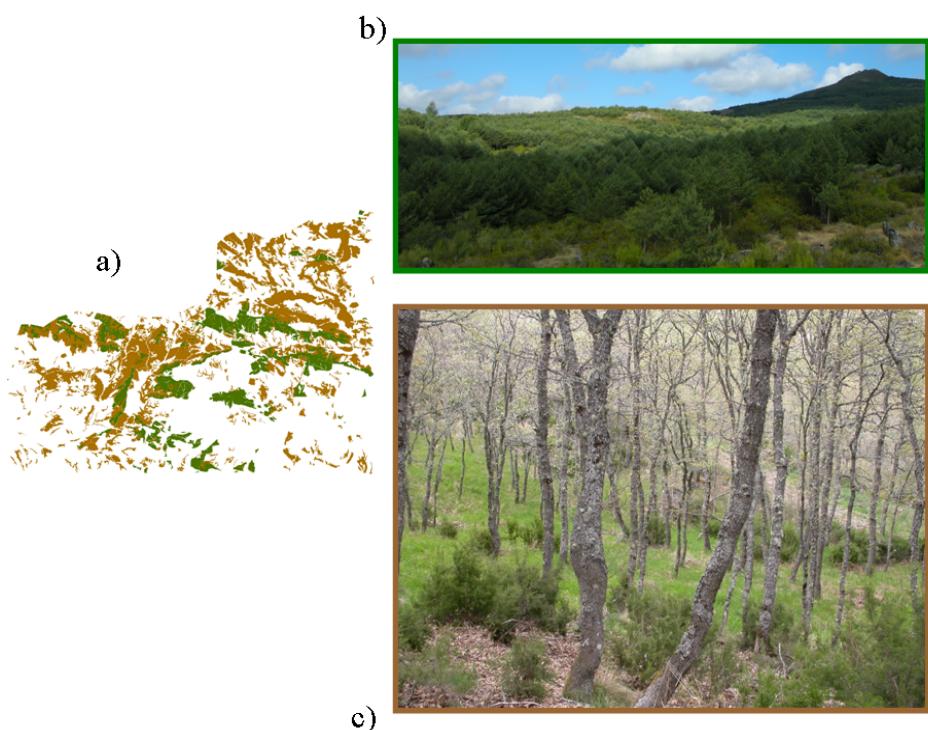
Situada en el noroeste de la península Ibérica, en las estribaciones sur del sector occidental de la cordillera Cantábrica, centro-oeste de la provincia de León. Pertenece a la zona de transición entre la vertiente sur de la cordillera Cantábrica y los Montes de León. (Fig. 8 y 9). Se trata de un área de unos 1500km<sup>2</sup> en la región biogeográfica Mediterránea. Al norte limita con la región Eurosiberiana donde los bosques predominantes son los abedulares y los robledales albares y orocantábricos (Rivas-Martínez et al. 2004; EEA 2008). Bioclimáticamente el área de estudio pertenece al piso supramediterráneo (Penas 1995; del Rio et al. 2007). El paisaje es cuarcítico y ligeramente montañoso con elevaciones entre 800 y 1600m s.n.m. Se encuentra en la divisoria entre las cuencas hidrográficas del Sil (hacia el oeste: ríos Boeza y Rodrigatos) y del Duero (hacia el este: ríos Omaña y Valdesamario).



**Figura 8.** *Negro* distribución actual del Urogallo Cantábrico (modificado a partir de Robles et al. 2006 y datos propios); *cuadro gris* localización del área de estudio

El bosque dominante en el área de estudio es el melojar maduro (más de 50 años) y sus etapas sucesionales post-fuego, y las plantaciones de pino silvestre de menos de

cincuenta años que aparecen frecuentemente intercaladas con el bosque autóctono (Fig. 9, Penas 1995). Tanto los robledales como las plantaciones de pino son monoespecíficas, cubriendo el robledal unas 27000ha (19% del área de estudio) y las plantaciones de pino alrededor de 11000ha (8%). El arándano y el acebo en estos melojares se pueden encontrar en zonas húmedas del interior de los bosques más maduros, pero las dos especies son muy escasas y su presencia se puede considerar anecdótica en el área de estudio. El sotobosque está compuesto principalmente por brezos *Erica arborea* y piornos *Cytisus scoparius*, zarzas *Rubus* sp., pardalina *Halimium lasianthum* ssp. *alyssoides*, escaramujos *Rosa* sp. y gramíneas *Festuca* sp. (Fig. 9 y 10).



**Figura 9.** a) Hábitat potencial del Urogallo en el área de estudio: *verde* plantaciones de pinos, *marrón* bosques de roble melojo; b) apariencia primaveral del exterior de una plantación de pinos; c) apariencia primaveral del interior de un melojar en el área de estudio

Al norte se alcanzan las cotas máximas (Cueto Rosales: 1566m s.n.m.), mientras, al sur, el relieve se suaviza. El resto del área de estudio la conforman plantaciones de chopos *Populus* sp. o fresnedas *Fraxinus excelsior* en las riberas, brezales monoespecíficos de *Erica australis* y escobales de *Genista* sp. en antiguas laderas cultivadas, minas a cielo abierto, carreteras y en los fondos de valle cultivos y pueblos. La densidad de población humana es baja (0.6 habitantes/km<sup>2</sup>) y desde los años 50's del siglo pasado se ha producido un declive del 85% (INE 2008) que está permitiendo la recolonización del bosque (Morán-Ordoñez et al. 2011). Las principales actividades económicas son minería subterránea de carbón, ganadería extensiva, agricultura, aprovechamientos forestales y caza (Penas 1995), aunque en la actualidad el abandono rural y el envejecimiento de la población residente son la tónica general. La parte norte (~5% del área de estudio) está declarada como Zona Especial de Protección para las Aves (ZEPAs de las Omañas y Sierras de Gistreo y Coto). El resto del área (~95%) la forman cotos de caza y carece de cualquier figura de protección.

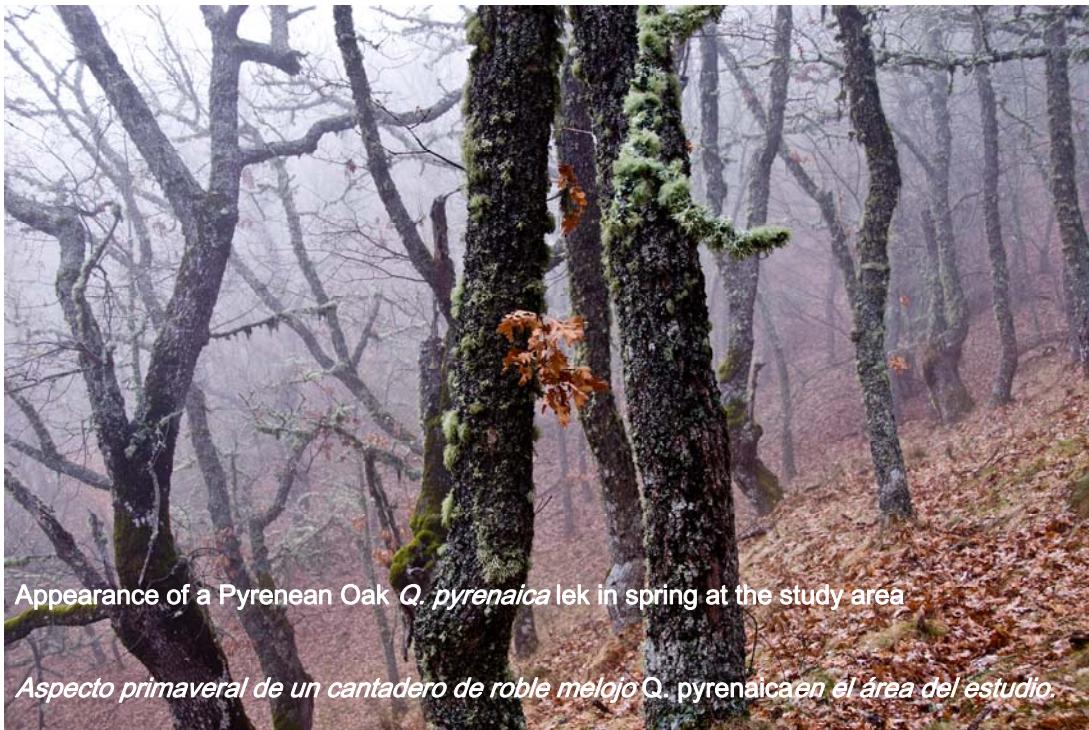


**Figura 10.** Panorámica del área de estudio en invierno: melojar autóctono intercalado con plantaciones de pino y brezales sobre suelos silíceos, y al norte las cumbres Cantábricas



# Chapter I / Capítulo I





Appearance of a Pyrenean Oak *Q. pyrenaica* lek in spring at the study area

*Aspecto primaveral de un cantadero de roble melojo Q. pyrenaica en el área del estudio.*

## The Mediterranean *Quercus pyrenaica* oak forest: a new habitat for the Capercaillie?

*El bosque mediterráneo de roble melojo Quercus pyrenaica: ¿un hábitat nuevo para el Urogallo?*

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En un área y habitat atípico para la especie se describe una zona de distribución del Urogallo Cantábrico *Tetrao urogallus cantabricus* contigua al rango conocido. Se detectaron nueve cantaderos de Urogallo y 14 machos adultos en 2009 en bosques mediterráneos de roble melojo *Quercus pyrenaica*, en un área de 1500km<sup>2</sup> de los cuales se prospectaron 4500ha de bosque. Hasta el momento esta población de Urogallo constituye tanto la distribución más meridional para la especie como la única que habita en bosques mediterráneos de roble melojo, lo que sugiere mayor adaptabilidad de la que antes se había considerado para esta (sub)especie. Esta población y su hábitat requieren estudios más profundos e incluirse dentro de las medidas de conservación para el Urogallo Cantábrico.

### **Abstract**

We described an extension of the known distribution range of the Cantabrian Capercaillie *Tetrao urogallus cantabricus* into an atypical area and habitat for the species. Nine Capercaillie leks and 14 cocks were registered in 2009 in Mediterranean *Quercus pyrenaica* forests in an area of 1500 km<sup>2</sup>, of which 4500 forest hectares were surveyed. At present, this population represents both the southern-most distribution for Capercaillie and the only one inhabiting Mediterranean *Q. pyrenaica* forests, what suggests a wider adaptation of this (sub)species than previously thought. This population and its habitat need to be better studied, as well as to be considered in conservation planning for Cantabrian Capercaillie.

## Introduction

Populations across distribution ranges show different adaptations to local conditions from the core areas to the periphery of their distribution (Guo et al. 2005). In the case of the Capercaillie *Tetrao urogallus*, the vast majority of populations inhabit boreal and montane coniferous forests with abundant bilberry *Vaccinium myrtillus* understory (Storch 1995b, 2000a, b, 2001). However, the Cantabrian subspecies *T. u. cantabricus* (Cantabrian Mountains, NW Spain) resides mainly in pure deciduous forests of beech *Fagus sylvatica*, birch *Betula pubescens* and sessile oak *Quercus petraea*, as well as mixed forests of beech and oaks *Quercus robur*, *Q. petraea*, and *Q. pyrenaica* (Bañuelos and Quevedo 2008). In these forests, holly *Ilex aquifolium* provides a key, evergreen winter food resource for Cantabrian Capercaillie, whereas it relies on bilberry in summer-autumn (Storch 2001; Blanco-Fontao et al. 2010). Previous studies showed, however, a negative selection to *Quercus pyrenaica* forests by Cantabrian Capercaillie at the northern slope of the Cantabrian range (Quevedo et al. 2006b).

This endemic Capercaillie subspecies is isolated and separated by more than 300km from the nearest Capercaillie population in the Pyrenees. After severe population decline in the last three decades (from 2000 to 400 adults), only 108 leks remain occupied in the northern watershed and 85 leks in the southern, corresponding to an overall occupancy rate of 32% of all known leks (Bañuelos and Quevedo 2008). Consequently, the Cantabrian Capercaillie subspecies qualifies to be listed as “Endangered” according to the IUCN criteria (Storch et al. 2006).

Capercaillie populations have so far been generally considered to be distributed in the Eurosiberian biogeographic region, outside the Mediterranean region (but see Handrinos and Akriotis 1997; Storch 2001 and “Discussion”). Unlike the Eurosiberian region, the Mediterranean region is characterised by a period of drought during the hot summer which determines the existing vegetation (e.g. Penas 1995; Blondel and Aronson 1999; Rivas-Martínez 2005). This Mediterranean environment is thought to be

unsuitable for a species primarily adapted to boreal environments. However, there are historical records suggesting Capercaillie presence during seventeenth to nineteenth centuries in Mediterranean areas in Spain (Madoz 1848; Castroviejo 1975; Martínez 1993), but the first sighting in *Q. pyrenaica* forests in this Mediterranean area was unnoticed until May 1998 (Pollo et al. 2004; No. 1 in Fig. 1).

In this study, we present information on the number of cocks and characteristics of leks located in an atypical area and habitat for the Capercaillie, i.e. Mediterranean *Q. pyrenaica* forests with virtual lack of bilberry and holly. This study is the first showing Capercaillie to be widely present in this forest type, suggesting a wider ecological plasticity of this (sub)species than previously thought. We also discuss implications that this new Capercaillie site may have in the conservation of the Cantabrian Capercaillie.

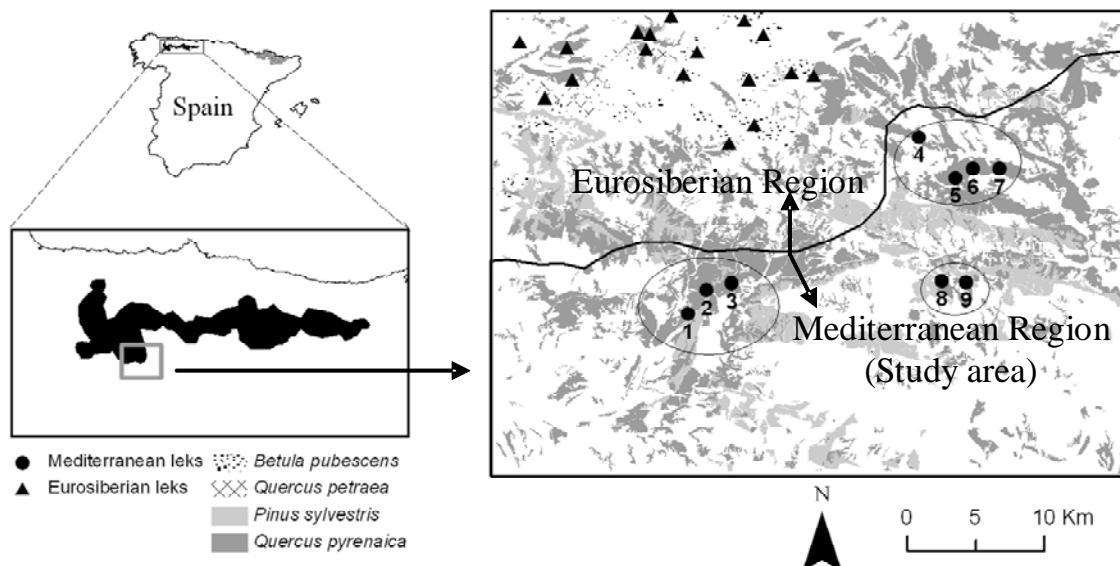
## Methods

### *Study area*

The study area is located on the southern slope of the Cantabrian Mountains in León province (NW Spain). It is centred at 42°39'N and located in the Mediterranean biogeographical region bordering the Eurosiberian region (Atlantic; Rivas-Martínez et al. 2004; EEA 2008; Fig. 1). The study area covers approximately 1500 km<sup>2</sup> below the putative line separating the two biogeographical regions in a landscape slightly mountainous (elevation ranges from 800 to 1700m a.s.l.). It belongs to the biogeographical unit Carpetan-Leonese Subprovince from the Mediterranean region with supraMediterranean bioclimate (Penas 1995; Rivas-Martínez 2005; del Rio et al. 2007). A meteorological station from our study area (Villameca) clearly shows two dry months ( $P < 2T$ ; Blondel and Aronson 1999) in summer: July ( $P = 26$ ;  $T = 19.9$ ) and August ( $P = 19$ ;  $T = 19.1$ ; data based on 37 years data).

Dominant forests are supra-Mediterranean natural (more than 50 years old), and post-fire *Q. pyrenaica* forests frequently occurring interspersed with Scots pine *Pinus*

*sylvestris* plantations (less than 50 years old). Both forest types are largely monospecific in the study area. *Q. pyrenaica* forests cover 27000ha (19% of the study area). Scots pine plantations occupy 11000ha (8%).



**Figure 1.** Area of occupancy of Cantabrian Capercaillie *Tetrao urogallus cantabricus* in 1980 (Obeso and Bañuelos 2003; black left) and study area (right). Numbers correspond to the leks according to the discovery date. Lek 1 was the first Capercaillie breeding record in *Q. pyrenaica* forest in 1998. Solid line represents the border between the Eurosiberian and the Mediterranean biogeographical regions after European Environment Agency (EEA) (2008) and Rivas-Martínez et al. (2004). Filled circles represent the recently discovered Mediterranean leks while filled triangles represent the traditional Eurosiberian leks. Light and dark grey areas represent *Pinus sylvestris* and *Q. pyrenaica* forests, respectively. According to government restrictions, lek locations are slightly moved for security.

*Q. pyrenaica* is a marcescent oak tree distributed widely in Spain as well as the western part of France and the northwest of Morocco. This tree develops under siliceous soils in the Eurosiberian region as well as in the Mediterranean region with an

extensive representation in this biogeographic region. In Spain, *Q. pyrenaica* represents the dominant species of different vegetation series (del Rio et al. 2007).

Forest fragments of the study area are embedded in a matrix mainly composed of heather *Erica australis* 1560ha (1%), brooms *Genista florida* and *Cytisus scoparius* 3640ha (3%), meadows 3460ha (3%) and riparian lowland forest of *Populus nigra*, *Fraxinus excelsior* and *Alnus glutinosa* 5340ha (4%). Understory cover is mainly dominated by heath *Erica arborea* and broom *C. scoparius*, while bilberry and holly is completely absent or very scarce (<0.5% of the forest ground cover) in the study area. The remaining 62% surface corresponds with anthropogenic landscapes such as villages, roads, opencast mines, valley bottoms, which are not suitable for Capercaillie habitat. Human population is approximately 1000 people (0.6 people/km<sup>2</sup>); it has declined by 85% since the 1950s. Livestock rearing is the main economic activity in the study area, followed by coal mining industry, agriculture, forestry and hunting.

#### *Survey methods*

No systematic sampling of the species was performed for the whole study area. We gathered information on Capercaillie presence from 2002 to 2009 from two sources: (1) questionnaires and reports sent by forest wardens, hunters and local people to the León environmental agency from the regional government (Consejería de Medio Ambiente of the Junta de Castilla y León) and (2) field surveys. Samples were recorded over the whole year. Data from the first source were validated within 2 weeks after receipt of the sample through field surveys carried out by an experienced observer (L. Robles). Field surveys consisted of a 3 to 4h systematic zig-zag walk looking for presence signs of Capercaillie (e.g. direct sightings, footprints, droppings or feathers), especially focusing on sites known to be highly used by the species (e.g. forest paths, dead trunks, big stones, oldest forest sites, etc.).

In forest patches bigger than 1km<sup>2</sup> (i.e. more than 3–4 h of sampling required), we conducted surveys over consecutive days until covering the whole forest patch (i.e. a

continuous forest isolated by a non-forest matrix). Direct sightings, footprints, droppings or feathers recorded in a site were considered as signs of Capercaillie presence. Each forest patch was completely surveyed 6–10 times throughout 1 year, with 1–2 months between each. If no sign of Capercaillie presence was found, the forest patch was labelled unoccupied and no further surveys were conducted in that specific patch.

Additionally, we surveyed the occupied patches in order to find leks. Selected sites were locations where survey after survey we found Capercaillie signs. The visits were performed throughout April and May (i.e. the display season) after 12:00h to avoid disturbing birds. A lek is defined as a site where one or more cocks consistently display for hens, plus the adjacent surrounding forest habitat. It has traditionally been used as a Capercaillie occurrence measure in the Cantabrian range (see Obeso and Bañuelos 2003).

During April–May, where fresh Capercaillie signs were found, 2–3 observers (forest wardens and L. Robles) visited the site at night as many as four times until the display finished, or until well past dawn. A site was considered as an occupied lek when at least one cock was heard calling or seen displaying.

Every detected lek was surveyed each year to label it as occupied or unoccupied just looking for presence signs after 12:00h (see above). In April–May 2009, every occupied lek was surveyed at night to get the number of displaying cocks.

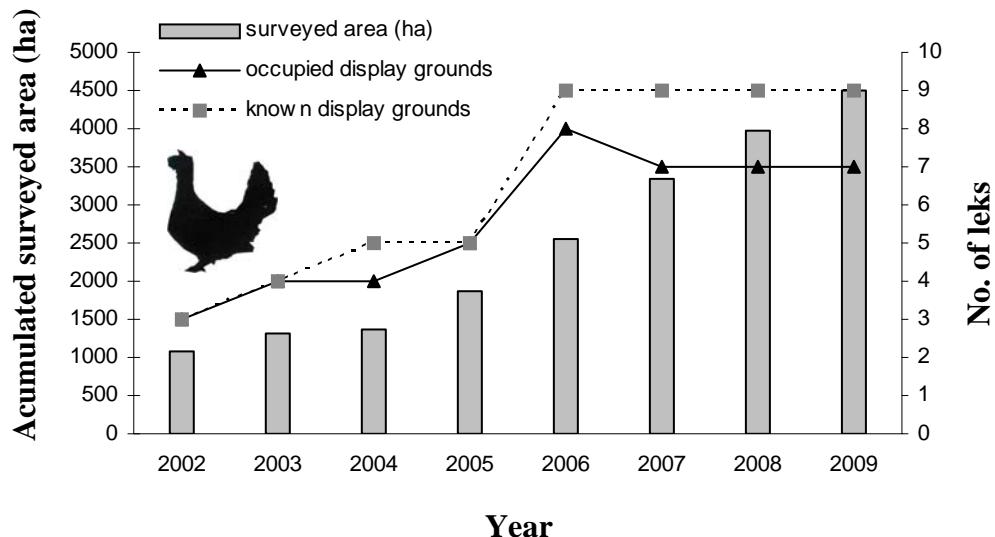
Nine forest structure variables (Appendix, Table 1) were measured in each lek consisting of 12 circular plots with 5m radius. Three plots separated by 10m were arranged in each cardinal direction from the lek centroid (i.e. the point where previously a cock was recorded displaying).

## Results

A total of nine leks, including that discovered in 1998 (Pollo et al. 2004), were registered in the study area, seven of them remained occupied in 2009 (Fig. 2). The highest occupancy was in 2006 with eight occupied leks (Fig. 2). Since 2006, no new lek was found, despite an increase of around 2000 additional hectares surveyed (60% of the total surveyed surface; Fig. 2). Leks were grouped into three sub-areas according to the watersheds: one sub-area had three leks, another had four and the last sub-area had two (Fig. 1). Mean nearest neighbour distance between leks was  $2.07 \pm 0.74\text{km}$  (*mean*  $\pm$  SE).

Leks were in *Q. pyrenaica* forests ranging from 1132 to 1398m a.s.l. (*mean*  $\pm$  SE: 1275  $\pm$  100.93, n = 9) and mainly faced in a northerly direction with two exceptions facing south (Appendix, Table 1). They showed heterogeneity in the forest structure, ranging from sites with young trees (perimeter  $0.19 \pm 0.005\text{m}$ ) with high canopy cover ( $0.81 \pm 0.06\%$ ) to mature trees (perimeter  $0.90 \pm 0.62\text{m}$ ) with low canopy cover ( $0.28 \pm 0.07\%$ ). The maximum tree height in leks varied from  $7.75 \pm 0.86\text{m}$  to  $16.50 \pm 3.20\text{m}$  (Appendix, Table 1).

Understory cover ranged from low ( $0.004 \pm 0.86\%$ ) to high ( $0.62 \pm 0.27\%$ ). In six of the nine leks, the dominant understory species was *E. arborea* while *C. scoparius* dominated the remaining one (Appendix, Table 1). In 2009, 12 cocks were recorded at the seven occupied leks. Moreover, 2 additional cocks not referred to any lek were detected during the spring 2009 fieldwork. Two nests with five and seven eggs each (both in *Q. pyrenaica* forest) were found in early June 2009 (Fig. 1, numbers 5 and 8).



**Figure 2.** Occurrence of the Mediterranean leks since 2002. *Bars* show the total accumulated forest surface surveyed (ha) through the study years. *Solid line* represents the occupied leks and *broken line* the known leks

## Discussion

So far, the Capercaillie always occurred in the Eurosiberian biogeographical region with the exceptions of the probably introduced birds of Mount Athos (Greece; Handrinos and Akriotis 1997), currently extinct (*S. Xirouchakis pers. comm.*), and two other unclear records in the Mount Grammos and Lailias Forest Reserve in Greece (Storch 2001). Therefore, the Capercaillie population we described here represents both the southern-most distribution for Capercaillie and the only one inhabiting Mediterranean *Q. pyrenaica* forests. These forests are different from the nearest ones occupied by Capercaillie leks located north of the putative line separating Eurosiberian and Mediterranean regions (Fig. 1; Appendix). These northern leks are mainly located in birch and sessile oak forests with understory dominated by bilberry (Appendix, Table 2) in a Eurosiberian bioclimatic environment (superior montane thermotype and inferior humid ombrotype). Nonetheless, lek 4, although in *Q. pyrenaica* forest, has a

Eurosiberian bioclimatic environment (Penas 1995), probably because of its most northerly relative position.

Despite an increase in the surveyed area, no new leks were found after 2006. However, the fact that we only surveyed 12% of the forest surface within our study area (Fig. 2) suggests new leks may be found in the future. Although the number of Capercaillie in the study area is small, it represents approximately 7% of the global Cantabrian population, highlighting the conservation value of this site.

All the nine leks were located in *Q. pyrenaica* forests. Conversely, no lek was located in pure Scots pine plantations, although these were available in the study area. In addition, two of four radio-tracked (one hen and one cock) Capercaillies used *Q. pyrenaica* forests of the studied area all year round (authors, unpublished data) and two Capercaillie nests were discovered in these forests. All this suggests that *Q. pyrenaica* forests are suitable year-round habitat for the Cantabrian Capercaillie. This is particularly important because the potential habitat for this endangered subspecies could thus be greatly increased, as *Q. pyrenaica* forests are highly represented with >100000ha at the southern slope of the Cantabrian Mountains (Gil and Antón 2007). Additionally, despite the idea that *Q. pyrenaica* forests are not considered as suitable habitat (Quevedo et al. 2006b), and neither are included in the recovery plans for the Cantabrian Capercaillie, our study highlights the need to take into account these forests for the conservation of this subspecies. Nonetheless, the role of the pine plantations for Capercaillie in the study area should be further assessed.

Finally, this study supports what is suggested by Quevedo et al. (2006a, b) and Blanco-Fontao et al. (2010), that many general considerations for the species overall are not fully useful for the Cantabrian Capercaillie, and suggests a wider adaptation and plasticity of this species than previously thought. For example, the near absence of bilberry and holly in the studied area suggests that Capercaillie can maintain viable populations without this important summer and winter food resource for the Cantabrian population and elsewhere (Storch 2001; Blanco-Fontao et al. 2010). Future research

could address a detailed comparison of suitable Capercaillie habitat between the two different biogeographical regions. Studying the ecology and genetic variability of this local population living in this atypical habitat would be of a great value to further understand and conserve this subspecies in particular and *Tetrao urogallus* in general.

## Acknowledgments

The forest wardens, Fernando Gonzalo, Álvaro Ortiz and Ramón Balaguer, showed us many little known aspects of the *Q. pyrenaica* forests. We wish to thank to María Angeles Osorio and César Pollo from the Consejería de Medio Ambiente de León of the Junta de Castilla y León. Particular thanks are due to Beatriz Blanco- Fontao, Patricia Mateo, Andy Dean and two anonymous reviewers whose revisions largely improved the manuscript. Manuel A. González is supported by a PhD scholarship of the Universidad de León.

## Appendix

**Table 1.** Description of the leks ( $n = 9$ ) in the study area; see (filled circle) in the map of the study area (see Figure 1). *Lek* lek number by discovery date; *Year* year when the lek was first-time recorded (April-May); *Cocks* number of Capercaillie males recorded in each lek in 2009; *m a.s.l.* elevation (meters above the sea level); *Exp.* exposure in the slope; *Tree Perimeter* mean trees perimeter measured in DBH (diameter at breast height). *Tree Height* mean trees height; *Cover* mean canopy cover (%); *Species* tree dominant species; *Height* mean understory height (meters); *Cover* mean understory cover (%); *Species* understory dominant specie. Mean  $\pm$  SE are shown for forest structure variables of the leks

Lek.	Year	Cocks	m a. s. l.	Exp.	Trees				Understory		
					Perimeter (m)	Height (m)	Cover (%)	Species	Height(m)	Cover (%)	Species
1	1998	2	1215	NW	0.45 $\pm$ 0.17	9.42 $\pm$ 1.38	0.57 $\pm$ 0.21	<i>Q. pyrenaica</i>	1.12 $\pm$ 0.38	0.39 $\pm$ 0.25	<i>C. scoparius</i>
2	2002	1	1131	NW	0.90 $\pm$ 0.62	16.50 $\pm$ 3.20	0.58 $\pm$ 0.15	<i>Q. pyrenaica</i>	0.85 $\pm$ 0.07	0.25 $\pm$ 0.06	<i>C. scoparius</i>
3	2002	0	1154	NW	0.32 $\pm$ 0.15	9.17 $\pm$ 1.75	0.54 $\pm$ 0.26	<i>Q. pyrenaica</i>	0.75 $\pm$ 0.50	0.16 $\pm$ 0.17	<i>E. arborea</i>
4	2003	2	1230	NE	0.70 $\pm$ 0.13	7.75 $\pm$ 0.86	0.28 $\pm$ 0.07	<i>Q. pyrenaica</i>	1.33 $\pm$ 0.24	0.45 $\pm$ 0.25	<i>E. arborea</i>
5	2004	3	1387	N	0.70 $\pm$ 0.15	14.08 $\pm$ 2.81	0.64 $\pm$ 0.22	<i>Q. pyrenaica</i>	0.03 $\pm$ 0.08	0.004 $\pm$ 0.01	<i>C. scoparius</i>
6	2006	1	1253	N	0.20 $\pm$ 0.05	9.50 $\pm$ 0.42	0.60 $\pm$ 0.25	<i>Q. pyrenaica</i>	0.50 $\pm$ 0.42	0.51 $\pm$ 1.41	<i>E. arborea</i>
7	2006	0	1356	N	0.23 $\pm$ 0.06	11.17 $\pm$ 0.38	0.47 $\pm$ 0.24	<i>Q. pyrenaica</i>	0.79 $\pm$ 0.25	0.39 $\pm$ 0.57	<i>E. arborea</i>
8	2006	2	1351	SE	0.43 $\pm$ 0.10	10.33 $\pm$ 1.37	0.58 $\pm$ 0.15	<i>Q. pyrenaica</i>	1.37 $\pm$ 0.31	0.40 $\pm$ 0.17	<i>E. arborea</i>
9	2006	1	1398	SW	0.19 $\pm$ 0.05	10.16 $\pm$ 0.57	0.81 $\pm$ 0.06	<i>Q. pyrenaica</i>	1.42 $\pm$ 0.45	0.62 $\pm$ 0.27	<i>E. arborea</i>

**Table 2.** Description of the Eurosiberian leks (n=17) north of the study area (see Fig 1). Mixed No tree was dominant, with the following occurring: *Betula pubescens*, *Q. petraea*, *Q. pyrenaica* and *Sorbus aucuparia*

Lek	m a.s.l.	Exposure	Tree species	Understory species
1	1440	N-W	<i>Q. petraea</i>	<i>Vaccinium myrtillus</i>
2	1520	N-W	Mixed	<i>Vaccinium myrtillus</i>
3	1450	N-W	Mixed	<i>Vaccinium myrtillus</i>
4	1550	N-E	Mixed	<i>Vaccinium myrtillus</i>
5	1490	N	<i>Q. petraea</i>	<i>Vaccinium myrtillus</i>
6	1620	N	<i>Betula pubescens</i>	<i>Erica arborea</i>
7	1650	N	<i>Betula pubescens</i>	<i>Erica arborea</i>
8	1550	N	<i>Betula pubescens</i>	<i>Erica arborea</i>
9	1680	N	<i>Betula pubescens</i>	<i>Erica arborea</i>
10	1590	N-E	<i>Betula pubescens</i>	<i>Vaccinium myrtillus</i>
11	1680	N	<i>Betula pubescens</i>	<i>Vaccinium myrtillus</i>
12	1620	N-W	Mixed	<i>Vaccinium myrtillus</i>
13	1540	N-W	Mixed	<i>Vaccinium myrtillus</i>
14	1510	N-W	<i>Betula pubescens</i>	<i>Erica arborea</i>
15	1590	N	<i>Betula pubescens</i>	<i>Erica arborea</i>
16	1620	N-E	<i>Betula pubescens</i>	<i>Vaccinium myrtillus</i>
17	1590	N-W	Mixed	<i>Vaccinium myrtillus</i>



## Chapter II / Capítulo II



Cantabrian cock displaying in an open Pyrenean Oak forest stand of the study area

*Urogallo exhibiéndose en un melojar abierto del área de estudio*



Foto: Miguel Sánchez

## Habitat selection and diet of Capercaillie *Tetrao urogallus* at its southern range edge

*Selección de hábitat y dieta del Urogallo Tetrao urogallus en el límite sur de su distribución*

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*Ibis accepted / aceptado*

Las características y requerimientos ecológicos de las poblaciones que viven en los límites latitudinales o en la \*retaguardia de la distribución de una especie a menudo difieren de las demás poblaciones. Por ello, para aplicar medidas de conservación eficaces es necesario identificar estas diferencias, especialmente cuando se trata de poblaciones periféricas en latitudes bajas en el contexto actual de cambio climático. Estudiamos la selección de hábitat y dieta de una población recientemente descrita en el límite más meridional de la distribución del amenazado Urogallo Cantábrico *Tetrao urogallus cantabricus*. Esta población de Urogallo es la única que ocupa la región biogeográfica Mediterránea. Mediante muestreos no sistemáticos basados en cuestionarios, entrevistas y trabajo de campo, y datos de radio-tracking, se analizó la selección de hábitat. Estudiamos la dieta mediante técnicas microhistológicas a partir de excrementos de la población recientemente descrita (en melojares *Quercus pyrenaica* mediterráneos y plantaciones de pinos *Pinus sylvestris*) y por otro lado excrementos de dos poblaciones de Urogallo Cantábrico que ocupan bosques eurosiberianos. Los fragmentos más seleccionados por los Urogallos fueron los melojares de mediano (100-500ha) y gran tamaño (>500ha), así como las plantaciones de mayor tamaño. Los fragmentos pequeños (<100ha) y los hábitats no forestales siempre fueron evitados. La dieta varió entre los bosques mediterráneos y eurosiberianos. El arándano *Vaccinium myrtillus*, a pesar de ser un alimento importante para la mayoría de las poblaciones de Urogallo, resulta muy escaso en nuestra área de estudio y apareció en muy bajo porcentaje en los excrementos de la nueva población. La pardalina *Halimium lasianthum*, descrita aquí como alimento para el Urogallo, fue consumida en otoño e invierno. El consumo de acículas de pino observado en invierno, podría reducir la pérdida de energía y la predación, facilitando así la supervivencia de los Urogallos en esta época crítica al emplear menos tiempo alimentándose en el sotobosque que en el resto de bosques caducifolios. Por primera vez se documenta la fuerte preferencia del Urogallo por los melojares y el consumo moderadamente elevado de las hojas, yemas y bellotas de este árbol a lo largo de todo el año. La selección de hábitat y dieta de esta población mediterránea de Urogallos difieren del resto de la población cantábrica y del resto de poblaciones de la especie. Estos resultados muestran la gran plasticidad fenotípica del Urogallo. Se recomienda la protección de esta población meridional de Urogallo y de los melojares que ocupa.

\* Traducción de rear-edge population (sensu Hampe and Petit 2005).

### Abstract

Ecological features and conservation requirements of populations at the latitudinal limits of a species' geographic range frequently differ from those in other parts of the range. Identifying these differences among populations is a key issue for implementation of effective conservation strategies for threatened range-edge populations, especially at the lower-latitude range edge in the current context of rapid global warming. We studied habitat selection and diet of the endangered Cantabrian Capercaillie *Tetrao urogallus cantabricus* in a recently discovered population at the southernmost edge of the sub-species' range. This population is the only Capercaillie population inhabiting the Mediterranean biogeographic region. We combined non-systematic surveys based on questionnaires, reports and field sampling with data from radio-tracking to study habitat selection. Diet was surveyed by micro-histological methods from dropping samples collected in both the novel population (inhabiting Pyrenean Oak *Quercus pyrenaica* forests and Scots Pine *Pinus sylvestris* plantations) and in two Cantabrian populations inhabiting Eurosiberian forests. Capercaillie preferred large (>500ha) and medium-sized (100-500ha) Pyrenean Oak forest fragments and large Scots Pine plantations. Forest fragments smaller than 100ha and non-forested habitats were always avoided. Diet markedly differed between Mediterranean and Eurosiberian areas. The Bilberry *Vaccinium myrtillus* is common in the diet of most Capercaillie populations but it was sparse in the study area and therefore scarcely occurred in the diet of the novel population. Rockrose *Halimium lasianthum* was consumed in autumn and winter and it is here described for the first time as a Capercaillie food resource. Pine needles were heavily consumed in winter which could facilitate survival by reducing energy expense and predation risk by shorter foraging time on the ground compared to deciduous forest habitats. We documented for the first time the strong preference of Capercaillie for Pyrenean Oak forests and a moderately high consumption of leaves, buds or acorns of this tree species throughout the year. Ecological features (i.e. habitat selection and diet) of the studied Mediterranean Capercaillie population differ from those of both the core Cantabrian and the global Capercaillie ranges. Our results expand the known environmental tolerance (phenotypic plasticity) for the species. We advocate specific protection for this unique range-edge Capercaillie population and its habitat of Pyrenean Oak forest.

## Introduction

Populations at the periphery of species' distribution ranges generally experience less favourable environmental conditions than in the core of the range and display lower and more variable densities (Brown 1984; Lawton 1993; Channel & Lomolino 2000). Peripheral populations hence tend to be more fragmented, more isolated and smaller in size than populations in other parts of the geographic range, making them more prone to extinction (Lesica & Allendorf 1995; Furlow & Armijo-Prewitt 1995, but see Channel & Lomolino 2000). Many populations at the edge of the species' ranges occur in marginal and unusual habitats (Brown 1984; Lesica & Allendorf 1995) thereby promoting genetic differentiation (Lesica & Allendorf 1995). There is therefore particular interest in conservation of peripheral populations on both genetic and ecological grounds (e.g. Lesica & Allendorf 1995; Furlow & Armijo-Prewitt 1995; Hampe & Petit 2005). In addition, the edges of the species' ranges are where the last populations of many species often persist, so that edge populations may be of overriding conservation value as refuges for species of high conservation concern (Furlow & Armijo-Prewitt 1995; Brook et al. 2000; Channel & Lomolino 2000).

In the face of the expected future climate change, populations that inhabit the latitudinal boundaries of the distribution range have become the focus of attention as they are expected to be the most sensitive to climate change and are the populations through which effects of climate change are manifested as range shifts (Thomas et al. 2001; Hampe & Petit 2005). In this context, populations residing in the low-latitude margins of species' distribution ranges (hereafter rear-edge populations) have been highlighted by their relevant role not only as centres of speciation and long-term reserves of genetic diversity but also to better understand the response of species to climate change (Hampe & Petit 2005). Climate change may wipe out rear-edge populations, resulting in species' range contraction (Davis & Shaw 2001; Hampe & Petit 2005; Huntley et al. 2006). Alternatively, evidence from past persistence of species through periods of

climate change suggests that rear-edge populations might endure regional-scale climate changes by matching suitable conditions through small altitudinal shifts in areas with heterogeneous topography (Hampe & Petit 2005). Today, such responses may be impeded by anthropogenic landscape and habitat alterations that reduce the suitable habitat and exacerbate potential impacts of climate change (David & Shaw 2001). Where ecological requirements of rear-edge populations differ from those at the core of the range, necessary conservation measures may also differ (Lesica & Allendorf 1995; Hampe & Petit 2005), so that knowledge of population-specific requirements (Whittigham et al. 2007) is necessary to underpin effective strategies for the management and conservation of range-edge populations.

The Capercaillie *Tetrao urogallus* is a large forest grouse widely distributed in the Palaearctic (Fig. 1a) with its core range in mature and continuous taiga forests (Storch 1993, 2001; Suter et al. 2002). In central and southern Europe populations are fragmented and largely restricted to mountain coniferous forests (Storch 2007). The only Capercaillie population living in purely deciduous forest is the Cantabrian Capercaillie subspecies *T. urogallus cantabricus* (Castroviejo 1975) which resides in the Cantabrian Mountains of north-west Spain (Fig. 1b). It is an isolated rear-edge population at the south-western margin of the species' range. This peripheral population displays distinctive phenotypic (Castroviejo 1975) and genetic characteristics, being considered as an Evolutionary Significant Unit (ESU, Rodriguez-Muñoz et al. 2007). After a 60% population decline in the last three decades (Bañuelos & Quevedo 2008), the Cantabrian Capercaillie is classified as endangered according to the IUCN criteria (Storch et al. 2006). Historically, it has been considered to be closely associated with bilberry *Vaccinium myrtillus* as a food source, and is (Castroviejo 1975; Blanco-Fontao et al. 2010) found in beech *Fagus sylvatica*, birch *Betula pubescens* and sessile oak *Quercus petraea* montane forests in the Eurosiberian biogeographic region (Quevedo et al. 2006a, b).

Until now, all Capercaillie populations have been thought to lie within the Eurosiberian biogeographic region, yet a remnant population of the Cantabrian Capercaillie has been recently found within the Mediterranean biogeographic region with a supra-Mediterranean bioclimate (González et al. 2010), further south than the previously known range. This region experiences summer drought and bilberry is very scarce (González et al. 2010). The remnant nucleus has an estimated population of at least 17 cocks (at least 7% of all Cantabrian cocks) distributed in at least nine leks and occurs in Pyrenean oak *Quercus pyrenaica* forests intermingled with Scots pine *Pinus sylvestris* plantations (Quevedo et al. 2006a; González et al. 2010).

We studied habitat selection and diet of this recently discovered rear-edge Capercaillie population. We combined non-systematic surveys based on questionnaires, reports and field sampling with data from radio-tracking to study habitat selection. We also studied the diet of Capercaillie in this supra-Mediterranean bioclimate and compared it with two Eurosiberian areas (mainly comprised of beech and birch forests) within the range of Cantabrian Capercaillie (Fig. 1).

## Methods

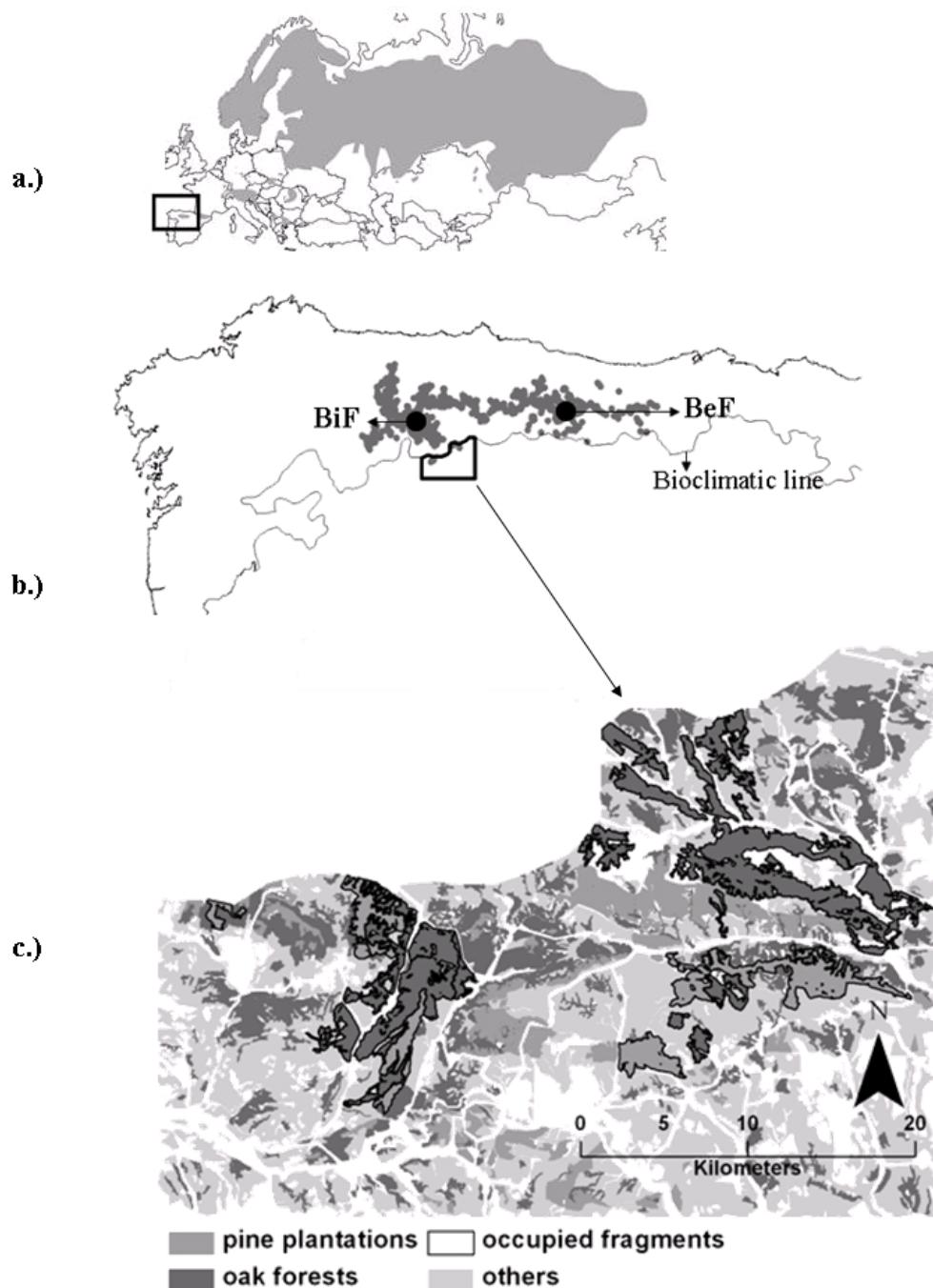
### *Study area*

The study was carried out over approximately 1500 km<sup>2</sup> on the southern slopes of the Cantabrian Mountains (Fig. 1) centred at 42° 39'N. The area is located in the Mediterranean region close to the boundary with the Eurosiberian region (González et al. 2010). Average annual temperature ranges between 4 and 9°C and the annual precipitation ranges from 866 to 1100mm. Precipitation is unevenly distributed throughout the year, with sporadic snowfalls in winter, rain mainly in spring and autumn and a severe drought for two months during summer. The landscape is mountainous (elevation ranges from 800 to 1700m a.s.l.). Dominant forests are supra-Mediterranean unburned (more than 50 years old) and post-fire Pyrenean oak forests and

monospecific Scots pine plantations younger than 50 years old (Costa-Tenorio et al. 2005). Bilberry is completely absent or very scarce (<0.5% of the forest ground cover; González et al. 2010). The remaining of the area is covered by semi-natural habitats mainly composed of *Populus nigra*, *Fraxinus excelsior* and *Alnus glutinosa* riparian lowland forests, meadows, heaths *Erica australis*, brooms *Genista* sp. and man-made infrastructures such as crops, open mines, roads and villages. Human density is very low (0.6 people/km<sup>2</sup>) and population has declined by 85% since the 1950's (INE 2008). This decline has lead to the abandonment of pastures with the consequent increase of the forested landscape (Morán-Ordoñez et al. 2011). The main economic activity is livestock rearing, followed by coal mining, agriculture, forestry and hunting (Penas 1995).

#### *Forest map*

A digital map of available habitat was created from the most recent national forest inventory (MARM 2009) using ARCGIS 9.3 (ESRI 2010). We validated this information with the most recent geo-referenced aerial photographs 0.25-m pixel resolution (PNOA 2008) and with field observations at the time of the study. We considered three types of habitat classified according to the dominant species, namely oak forest, pine plantation and non-forested habitat (consisting of heaths and/or brooms and/or meadows). Accordingly, we defined a habitat fragment as a patch of the same habitat surrounded by other habitat type (García et al. 2005). The non-forested habitat category was included because previous studies showed them to be used by Cantabrian Capercaillie elsewhere (Quevedo et al. 2006b, Bañuelos et al. 2008). On the basis of the type and size of the fragment we considered seven habitat categories: small (<100ha) (SO), medium (100-500ha) (MO), and large (>500ha) Pyrenean oak fragments (LO), small (<100ha) (SP), medium (100-500ha) (MP) and large (>500ha) pine plantations (LP), resulting in six forested fragment types, plus non-forested habitats (NF).



**Figure 1.** a) Global capercaillie distribution (adapted from Storch 2001). b) Location of the study area (black contour) and of the beech (BeF) and birch (BiF) forests sampled within the

Cantabrian capercaillie distribution (grey area). c) Detail of the study area, below the Eurosiberian-Mediterranean bioclimatic line, showing occurrence of forest fragments.

#### *Species data from observations*

We gathered information on Capercaillie presence in the study area between 2002 and 2009 from questionnaires and reports sent by forest wardens, hunters and local people to the regional environmental agency (Consejería de Medio Ambiente of the Junta de Castilla y León). Then, an experienced observer validated these data through field surveys which consisted of a 3-4 hours systematic zig-zag walk in the fragment looking for presence signs of Capercaillie (i.e. direct sightings, display grounds, footprints, droppings or feathers), every 1-2 months up to six times throughout the year, or until Capercaillie signs were found. Some biases may exist in this non-systematic sampling, mainly due to different accessibility of observers to forest fragments and differences between habitats in detectability of Capercaillie. To minimise the bias in Capercaillie distribution drawn from this non-systematic sampling, we pooled the data on presence signs of Capercaillie over all the study years (i.e. 2002-2009). We considered a fragment as occupied by Capercaillie when at least one presence sign was registered during 2002-2009 and unoccupied when no sign was observed in that period.

#### *Species data from radiotracking*

In addition, we trapped four Cantabrian Capercaillie (two females and two males) by using funnel trap boxes in the study area in May 2000, November 2006 and November 2007 (Robles 2007). Trapped Capercaillie were one adult (>2 years old) male, one subadult (<2 years old) male and two subadult females. All birds were radio-collared with adjustable necklace transmitters (Biotrack-TW 3, 21gr weight with mortality sensor). The total weight of transmitter plus harness did not exceed the recommended limit of 3-5% of body weight (Kenward 2001). Tracking equipment comprised an Icom ICR-20 receiver, a directional three-element Yagi antenna (150–152 MHz, Biotrack

Ltd., Wareham, Dorset, UK) and a hand-held GPS (Garmin e-Legend HCx). We determined the location of the radio-tagged Capercaillie using the standard triangulation technique (Millspaugh & Marzluff 2001). We tracked each bird over more than 18 months (*range*: 72–96 weeks) and at least twice a week two days apart in order to reduce autocorrelation (Harris et al. 1990). For each triangulation point we recorded x and y coordinates, habitat type (i.e. Pyrenean oak, Scots pine or non-forested) and date. Following Kenward (2001) we estimated through an experimental trial, our inherent error in determining the real position by triangulation of the transmitter which resulted in  $35.56m \pm 3.75$  (*mean*  $\pm$  SE). Hence, we buffered each location with a 35m radius point. A habitat patch (fragment) with at least one radio-location of tagged Capercaillie was considered as occupied.

### *Habitat selection analysis*

We measured Capercaillie habitat selection both at population and individual level using data from observations (presence signs) and radio-locations respectively.

At the population level, we estimated available habitat for Capercaillie as the proportion of each of the seven habitat types within a 5km radius buffer of the most outlying occupied fragment. This radius was chosen to encompass mean dispersal distances of adult Capercaillie in fragmented landscapes (Storch 1995a; García et al. 2005; Bollmann et al. 2010). Habitat used by Capercaillie was estimated as the proportion of each habitat type registered as occupied (see above). We analysed only a year-round measure of habitat selection because presence signs were impossible to assign to a precise date, thus preventing a seasonal analysis. Data were analyzed with Manly's selectivity index using *design I*, appropriate to data sets where individual animals are not distinguished, and implemented using the adehabitat package in R software (Manly et al. 2002; Calenge 2006; R Development Core Team 2008). The Manly index ranges from infinity (all observations within the habitat type) to 0 (no observations within the habitat type; 1 = use according to availability) for each habitat and tests the

selection/avoidance under the null hypothesis that animals use the habitat in proportion to availability, computing a Pearson's chi-square test for each habitat pair (Manly et al. 2002). Because there are 7 habitat types,  $P$  values were compared with Bonferroni level of  $0.05/7 = 0.007$ .

At the individual level, using data from the four radio-tagged birds, we first estimated the utilization distribution (UD), a probability density function that quantifies the animal's relative use of space (Silverman 1986; Millspaugh et al. 2006). UD is commonly estimated using the kernel technique (Worton 1989; Marzluff et al. 2004). For this, we performed computations using the B-Range software (Katajisto & Moilanen 2006) which yields a digital UD layer. Based on this layer, we calculated the smallest area associated with a 90% and 50% probability of use (HR90 and HR50, respectively) using ARCGIS 9.3 (ESRI 2010). HR90 and HR50 are generally considered robust estimators of the home range of animals and the area of frequent use (i.e. core area) respectively (Samuel et al. 1985; Börger et al. 2006).

We measured the available habitat in each of the seven categories for each tagged bird as the area delimited by a 5km radius surrounding each HR90. Used habitat was estimated as the proportion of the UD value in each habitat considered. Space use at individual level was then analyzed using the Jacobs' preference index (Jacobs 1974) which estimates an absolute selection value for each habitat considered as  $J = (r - p) / [(r + p) - 2rp]$ , where  $r$  is the used proportion and  $p$  the available proportion of habitat fragments.  $J$  ranges between +1 for exclusive selection of a habitat type and -1 for complete avoidance. We analyzed both annual and seasonal (spring: April-June, summer: July-September, autumn: October-December and winter: January- March) habitat selection. Because our sample size was only four tagged individuals, we did not undertake any formal statistical testing of these  $J$  values.

### *Sampling and analysis of diet*

To describe the diet of Cantabrian Capercaillie in Mediterranean forests, experienced observers searched for Capercaillie droppings bimonthly from December 2005 to December 2007. Observers used pre-established tracks in fragments where Capercaillie presence was previously verified. We considered any dropping within a 50m radius around the first one found as one same dropping sample and referred to that season. Droppings were collected or destroyed to prevent finding them in the next field survey. We collected and analyzed 76 dropping samples from all the forest fragments known to be occupied by Capercaillie in the study area. The total collection of dropping samples was roughly proportional to the distribution of occupied forest fragments by Capercaillie (see Results); ten came from Scots pine plantations and 66 from Pyrenean oak fragments used by the species.

To identify plant remains in the Capercaillie droppings we used microhistological methods. The technique relies on the resistance of plant epidermis to herbivore digestion leaving plant fragments undigested and identifiable (Holechek 1982; Alipayo et al. 1992). We follow protocol suggested by Blanco-Fontao et al. (2010). Briefly, each dropping sample was dried at 60°C for 48h, ground with a Retsch MM200 ball mill to grind and homogenize, and rinsed with NaOCl to improve clarity. To eliminate the supernatant fluid samples were centrifuged and then rinsed with distilled water and centrifuged twice. We sieved the resulting material through 1 and 0.2mm pore-size filters and the intermediate fraction was stored for analysis. A sub-sample of 30mg approx. of the sieved material was taken and laid on a slide with hydrophilic mounting medium (Jung tissue freezing medium) under a 100x microscope. Plant fragments (i.e. plant remains) were searched along two transects of the slide. We compared plant fragments in the droppings with reference material in a library (Holechek 1982). The asymptote of the relationship between the plant fragments counted and diversity of plant remains was reached from 50 fragments. Therefore we sampled 50 plant fragments in each dropping and expressed the frequency for each plant species as a

percentage. Samples were classified by season into spring (April-June), summer (July-September), autumn (October-December) and winter (January-March) based on Capercaillie life cycle and plant phenology in the study area.

We considered 16 potential food sources based on previous studies in the Cantabrian Mountains (Castroviejo 1975; Martínez 1993; Rodríguez & Obeso 2000) and plant availability in the study area. These were Pyrenean oak, Scots pine, hazel *Corylus avellana*, birch, holly *Ilex aquifolium*, rowan *Sorbus aucuparia*, brooms (*Cytisus* and *Genista* spp.), bilberry, heath *Erica australis* subsp. *aragonensis*, blackberry *Rubus* sp., rockrose *Halimium lasianthum* subsp. *alyssoides*, ferns, grasses, mosses and lichens. We included arthropods as an animal category and a last category grouped unidentified remains

Preliminary analyses revealed no differences in Capercaillie diet between 2006 and 2007 in the study area, so we pooled data across years in order to test seasonal variation in diet composition across the five main species found in droppings in the Eurosiberian area (Rodríguez & Obeso 2000; Blanco-Fontao et al. 2010) and in this study; namely, holly, bilberry, Pyrenean oak, Scots pine, and rockrose, by means of one-way ANOVA of arcsine transformed percentages and posthoc Tukey tests (SPSS Statistics 17.0). We also calculated the annual percentage of plant resources obtained from canopy and understory species.

Finally, to compare diet of Cantabrian Capercaillie in the Mediterranean and Eurosiberian biogeographic regions, we collected dropping samples from three birch forests ( $n = 24$ ) and from three beech forests ( $n = 24$ ) (BiF and BeF respectively, Fig. 1b) within the Eurosiberian region in 2007. Sampling and analyses of droppings followed the same methods described above. We tested for differences in diet by season between our Mediterranean study area and Eurosiberian birch and beech forests with non-metric multidimensional scaling (NMDS). Dissimilarities among sites were calculated on the raw frequencies of the 16 categories of feeding remains found

in the birds' faeces (see above) using Bray-Curtis distances. Results were obtained for two dimensions. These analyses were performed with library vegan (Oksanen et al. 2010) in R statistical package (R Development Core Team 2008).

## Results

Available habitat for Capercaillie consisted of 1088 fragments (*mean surface*  $\pm$  SD: 83  $\pm$  200ha; *range*: 10-3274ha) of which 325 were forested (n = 256 oak fragments and n = 69 pine plantations) and 763 non-forested.

Forested fragments encompassed 46% (41682ha; 32% oak forests and 14% pine plantations) of the total available habitat and the remaining 54% was non-forested habitat. 77% of the 325 forested fragments were smaller than 100ha.

Between 2002 and 2009, 52 questionnaires/reports were received and we observed 211 Capercaillie signs (dropping samples: n = 123; footprints: n = 13; feathers: n = 51; and direct sightings: n = 24), validating Capercaillie presence in 29 forested fragments: 6 Scots pine (26% of the occupied surface) and 23 Pyrenean oak fragments (74%). Forested fragments occupied by Capercaillie (*mean surface*  $\pm$  SD: 706  $\pm$  977ha; *range*: 17-3274ha) covered 13919ha of which 72% (9956ha) were Pyrenean oak forests and 28% (3963ha) were Scots pine plantations.

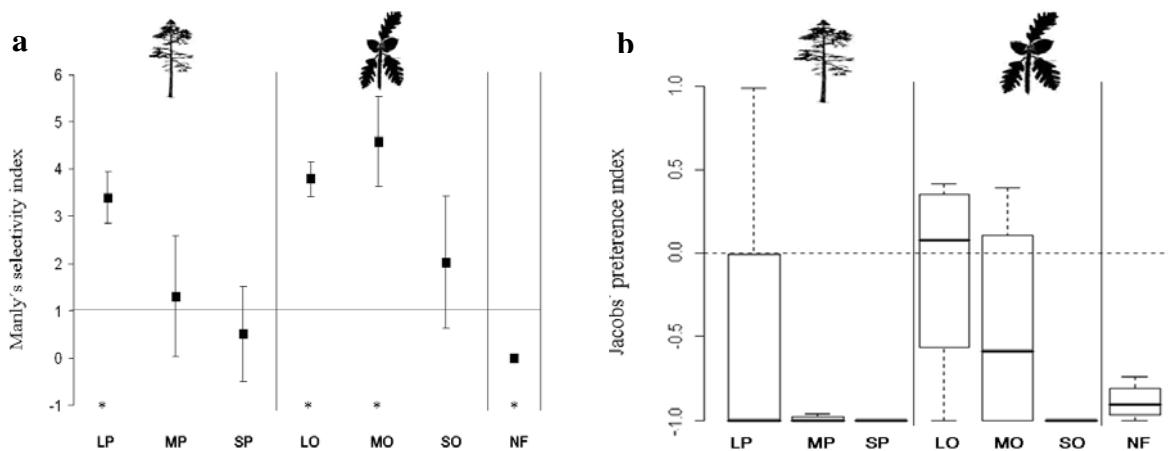
The four radio-tagged Capercaillie provided 1138 locations, across ten occupied fragments of which two were Scots pine plantations and eight were Pyrenean oak fragments, all of them within the set of 29 fragments known to be occupied via non-systematic sampling.

### *Habitat selection*

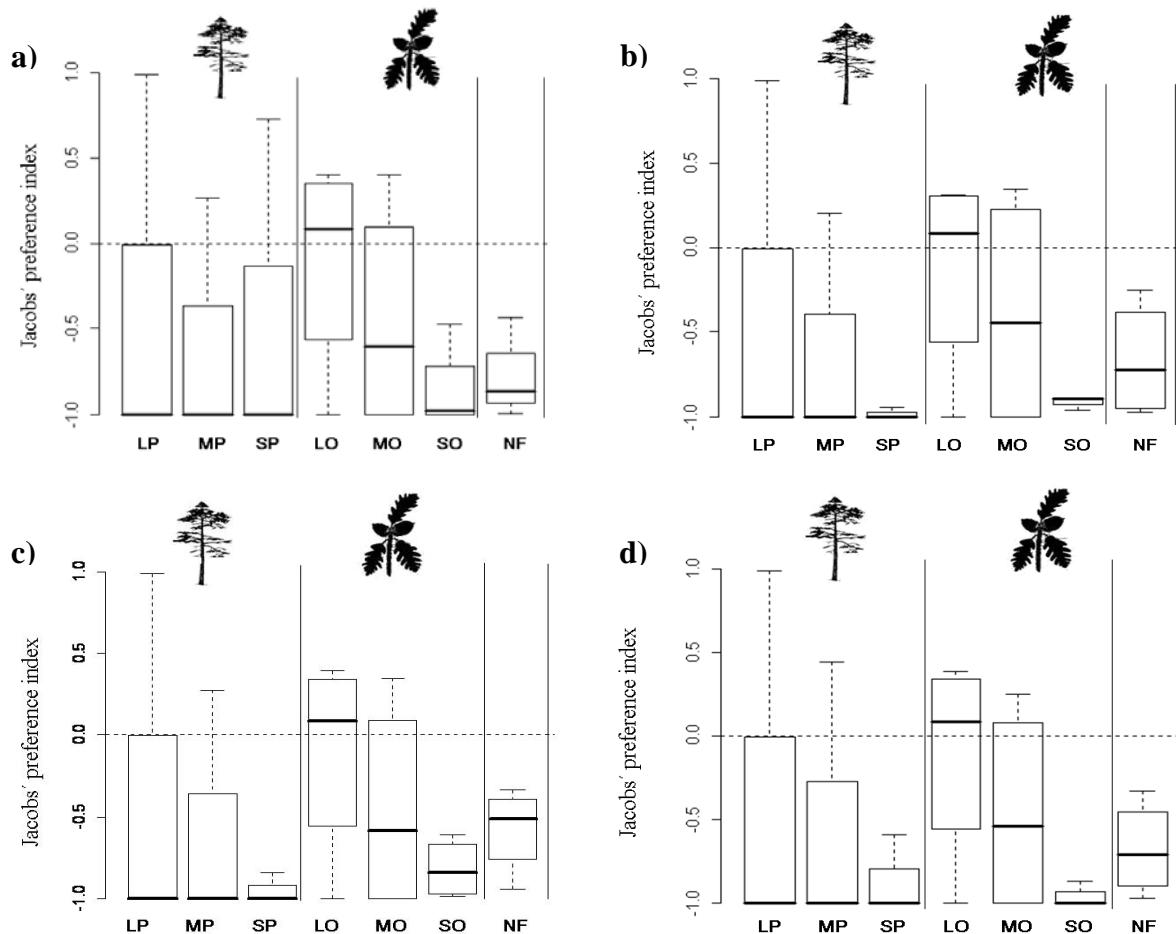
Capercaillie did not use habitat in proportion to availability ( $\chi^2=261.9$ , df = 6,  $P < 0.001$ ). Manly's selectivity index at population level showed that large Scots pine

fragments were positively selected ( $w_i = 3.40$ ;  $P < 0.001$ ), while use of medium Scots pine fragments was not significantly different from their availability ( $w_i = 1.31$ ;  $P = 0.80$ ). Large and medium oak fragments were positively selected ( $w_i = 3.80$ ;  $P < 0.001$  and  $w_i = 4.59$ ;  $P < 0.001$ ). Use of both small oak ( $w_i = 2.04$ ;  $P = 0.46$ ) and small pine fragments ( $w_i = 0.51$ ;  $P = 0.63$ ) was not significantly different from availability while non-forested habitats were never used ( $w_i = 0.00$ ;  $P < 0.001$ , Fig. 2a).

Results from Jacobs' preference indices for tagged Capercaillie were very similar for HR50 and HR90, so we only show the results for HR90 (Fig. 2b; results of HR50 are shown in Fig. S1 in Appendix). Both seasonal and annual patterns of habitat selection were very similar (see Fig. 2b and 3). There was strong variation among individuals in both the annual and seasonal use of large pine and large and medium oak fragments as shown by the wide error bars of these habitat types (Fig. 2b and 3). Capercaillie selected large oak fragments both annually and seasonally, as suggested by a median value above availability (Fig. 2b and 3). The remaining habitat types were used by Capercaillie less than expectation based on availability would suggest, except large pine plantations which were used according to availability (Fig 2b and 3). Two of the four radio-tracked capercaillie never used Scots pine plantations although these were available to them.



**Figure 2.** **a)** Manly's selectivity index (mean  $\pm$  1SE) calculated with the presence data. Values range from 0 (maximum avoidance) to infinite (maximum preference) where 1 indicates that the habitat is used according to availability. \*Significant  $P$ -value ( $P \leq 0.05$ ). **b)** Annual Jacobs' preference index for each fragment type and size used by Cantabrian capercaillie within the 90% fixed Kernel isoline. Values range from -1 (maximum avoidance) to 1 (maximum preference). Boxes indicate the 25-75<sup>th</sup> percentile range and contain the median line. Bars represent the 10<sup>th</sup> and 90<sup>th</sup> percentile values. **LP** (large Scots pine plantation fragment: >500ha), **MP** (medium Scots pine plantation fragment: >100-500ha), **SP** (small Scots pine plantation fragment: 0-100ha), **LO** (large Pyrenean Oak fragments: >500ha) **MO** (medium Pyrenean Oak fragments: >100-500ha), **SO** (small Pyrenean Oak fragments: 0-100ha) and **NF** (non forested habitats: heathlands, brooms and meadows).



**Figure 3.** Jacobs' preference index by seasons (a) Spring; b) Summer; c) Autumn; d) Winter) for each fragment type and size used by Cantabrian capercaillie within the 90% fixed Kernel isoline. Values range from -1 (maximum avoidance) to 1 (maximum preference). Boxes indicate the 25-75<sup>th</sup> percentile range and contain the median line. Bars represent the 10<sup>th</sup> and 90<sup>th</sup> percentile values. LP (large Scots pine plantation fragment: >500ha), MP (medium Scots pine plantation fragment: >100-500ha), SP (small Scots pine plantation fragment: 0-100ha), LO (large Pyrenean Oak fragments: >500ha) MO (medium Pyrenean Oak fragments: >100-500ha), SO (small Pyrenean Oak fragments: 0-100ha) and NF (non forested habitats: heathlands, brooms and meadows).

*Diet*

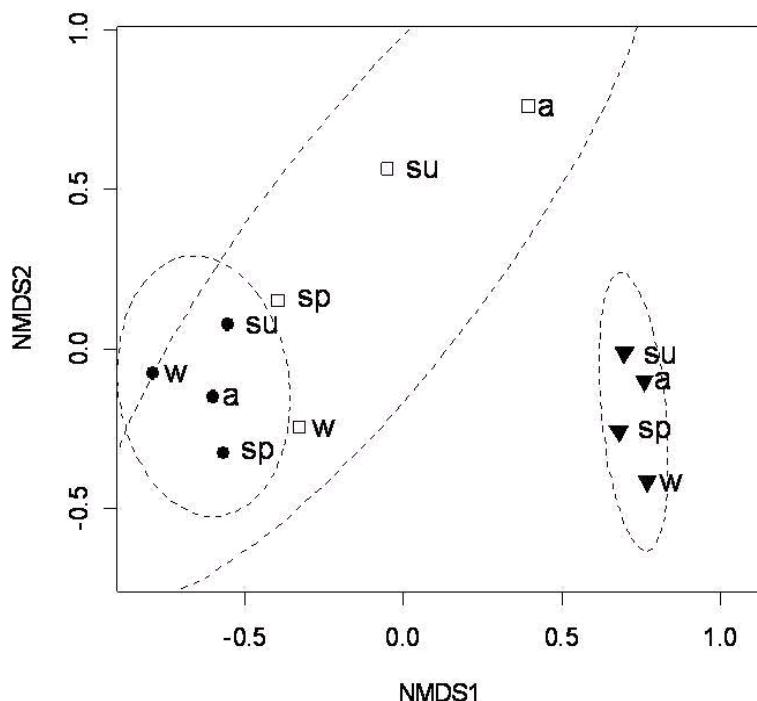
Mean annual consumption in the study area was similar for both canopy (48%) and understory resources (46%). In winter, Capercaillie droppings were mainly composed of Scots pine needles (40%), Pyrenean oak (16%), grasses (15%) and rockrose (12%; Table 1), and in five of the 17 dropping samples, the diet was wholly Scots pine needles. Spring diet was dominated by pine needles, grasses and Pyrenean oak leaves, with 29%, 22% and 20% occurrence of remains in droppings respectively. In summer the major occurrences in droppings were fern fronds (30%), Pyrenean oak leaves (19%) and grasses (17%). In autumn, Pyrenean oak (25%), fern fronds (17%), grasses (16%), Scots pine needles (9%) and rockrose (8%) were dominant in the Capercaillie droppings. In the dropping samples of the Eurosiberian area, two species occurred that were absent in the Mediterranean samples: beech and heather *Calluna vulgaris* (see Tables S1 and S2 in Appendix).

Considering seasonal variation of the five main food species separately (i.e. holly, bilberry, Pyrenean oak, Scots pine and rockrose) results from ANOVA revealed significant differences only in Scots pine occurrence ( $F_{3, 23} = 7.60, P = 0.001$ ) between winter and summer ( $P = 0.003$ ) and nearly significant between winter and autumn ( $P = 0.07$ ), with the highest pine consumption in winter. For the other species, we found no significant seasonal variation: holly ( $F_{3, 23} = 0.373, P = 0.774$ ), bilberry ( $F_{3, 23} = 0.153, P = 0.927$ ), Pyrenean oak ( $F_{3, 23} = 0.553, P = 0.652$ ) and rockrose ( $F_{3, 23} = 1.69, P = 0.199$ ).

	Percentage occurrence of remains in droppings (mean $\pm$ 1SD)				
	Summer	Autumn	Winter	Spring	Anual
Main species	32.7 $\pm$ 7.7	47.7 $\pm$ 9.4	74.0 $\pm$ 15.5	55.0 $\pm$ 12.8	52.3 $\pm$ 9.4
Understory resources	60.7 $\pm$ 9.7	52.3 $\pm$ 6.4	35.4 $\pm$ 5.3	34.3 $\pm$ 6.6	45.7 $\pm$ 6
Canopy resources	33.7 $\pm$ 7.7	42.7 $\pm$ 9.2	59.3 $\pm$ 15.2	59.0 $\pm$ 11.4	48.7 $\pm$ 9.9
* <i>Ilex aquifolium</i>	0	0.7 $\pm$ 1.6	0.7 $\pm$ 1.6	1.0 $\pm$ 2.4	0.6 $\pm$ 1.6
* <i>Vaccinium myrtillus</i>	7.3 $\pm$ 7.7	5.0 $\pm$ 8.5	4.7 $\pm$ 7.3	5.3 $\pm$ 6.4	5.6 $\pm$ 7.1
<i>Betula pubescens</i>	1.8 $\pm$ 2.4	0.7 $\pm$ 1	0	2.3 $\pm$ 5.7	1 $\pm$ 3.1
<i>Sorbus aucuparia</i>	7.3 $\pm$ 3.7	7.0 $\pm$ 5.3	2.0 $\pm$ 1.3	6.7 $\pm$ 5.3	5.8 $\pm$ 4.5
* <i>Quercus pyrenaica</i>	19.0 $\pm$ 8.6	25.2 $\pm$ 18.8	16.3 $\pm$ 10.2	19.7 $\pm$ 9.4	20.1 $\pm$ 12
<i>Corylus avellana</i>	0.3 $\pm$ 0.8	0	0	0.3 $\pm$ 0.8	0.2 $\pm$ 0.5
* <i>Pinus sylvestris</i>	6.0 $\pm$ 5.9	9.0 $\pm$ 11.1	40.3 $\pm$ 19.3	29.0 $\pm$ 17.9	21 $\pm$ 19.9
<i>Rubus</i> sp.	1.0 $\pm$ 2.4	4.7 $\pm$ 5.5	0	0	1.4 $\pm$ 3.4
<i>Erica</i> sp.	2.0 $\pm$ 2.2	1.7 $\pm$ 2.0	1.3 $\pm$ 1.6	1.7 $\pm$ 2.3	1.7 $\pm$ 1.9
* <i>Halimium lasianthum</i> subsp. <i>allyssoides</i>	0.3 $\pm$ 0.8	7.7 $\pm$ 9.0	12.0 $\pm$ 20.1	0	5.2 $\pm$ 11.7
<i>Cytisus / Genista</i> sp.	0.7 $\pm$ 1.6	0	0	0	0.2 $\pm$ 0.8
Ferns	30.0 $\pm$ 21.7	17.0 $\pm$ 14.3	2.7 $\pm$ 3.5	3.7 $\pm$ 5.6	13.3 $\pm$ 16.9
Mosses	1.3 $\pm$ 1.6	0.3 $\pm$ 0.8	0	1.3 $\pm$ 2.4	0.8 $\pm$ 1.5
Grasses	17.4 $\pm$ 12.4	16.0 $\pm$ 10.3	14.7 $\pm$ 12.8	22.3 $\pm$ 9.9	17.7 $\pm$ 11
Lichens	0	0	0	0	0
Arthropods	0.3 $\pm$ 0.8	0	0	0	0.1 $\pm$ 0.4
Unidentified	5.3 $\pm$ 3.5	5.0 $\pm$ 4.1	5.3 $\pm$ 3.5	6.7 $\pm$ 3.3	5.7 $\pm$ 3.3

**Table 1.** Percentage occurrence of plant remains in Capercaillie droppings in the study area (mean  $\pm$  SD) by season and globally (“Annual”). Main species (\*). Understory resources: brooms (*Cytisus / Genista* sp.), bilberry (leaves, berries and shots), heaths, blackberry, rockrose (*Halimium lasianthum*), ferns, grasses, mosses and lichens. Canopy resources: *Ilex aquifolium*, *Betula pubescens*, *Sorbus aucuparia*, *Quercus pyrenaica*, *Corylus avellana* and *Pinus sylvestris*. The 16 individual categories plus the amount of unidentified remains by season are also shown.

The NMDS analysis showed differences in the composition of the droppings collected in Mediterranean (i.e. Pyrenean oak and Scots pine) and Eurosiberian (i.e. beech and birch) forests (Fig. 4). Mediterranean habitat clustered apart from the beech and birch forest which partially overlap. Moreover, Capercaillie inhabiting birch forests apparently feed on quite diverse sources throughout the year (i.e. points lying more scattered in the plot). Those birds in beech and Mediterranean habitat seemed to have a more homogeneous diet over time.



**Figure 4.** NMDS ordination for diet samples at different collecting seasons (stress value = 4.7). Symbols represent forest types ( $\bullet$  = beech forests,  $\square$  = birch forests,  $\blacktriangledown$  = study area, i.e. Scots pine and Pyrenean Oak forests). Seasons are shown in lower case letters ( $\text{su}$  = summer,  $\text{a}$  = autumn,  $\text{w}$  = winter,  $\text{sp}$  = spring). The dotted lines correspond to the 95% confidence region of possible ordination values for each of the forest types.

## Discussion

The general pattern of habitat use by Capercaillie was similar whether data were based on signs or radio-tracking. Results from field signs showed a strong annual preference for large and medium Pyrenean oak forest fragments and large Scots pine plantations, while radio-tracking data from four individuals showed only a clear preference for large Pyrenean oak fragments. However, the occupation pattern inferred from the study of four radio-tracked Capercaillie in only part of the study area was consistent with the wider survey based on field signs (i.e. all 10 forest patches used by the radio-tagged Capercaillie were previously identified as occupied by the field survey). This is consistent with a recent comparative study showing that less precise data based on non-systematic surveys over large areas perform comparatively well and may be even preferable to systematically sampled data from a smaller area (Braunisch & Suchant 2010).

Both sampling approaches had clear limitations. Non-systematic sampling suffered from bias due to differences among habitats in both sampling effort and detectability of presence signs, while the study of radio-tagged Capercaillie had a low sample size ( $n = 4$  individuals). Nonetheless, both approaches showed that Pyrenean oak forests were in general more used than pine plantations year-round. Scots pine plantations in the study area are comprised of young growth stages (between 30 and 50 years old), which probably offered a lower habitat quality for Capercaillie than the older Pyrenean oak forests. Diet data also suggested that Capercaillies fed on leaves, buds or acorns of Pyrenean oak throughout the year (Table 1), and it is also known that Capercaillie use these forests as a breeding area, as indicated by leks and nests discovered in these forests (González et al. 2010). Our results support the idea that Pyrenean oak forests are an important habitat for Cantabrian Capercaillie (González et al. 2010), but contrast with those of Quevedo et al. (2006b) who observed that Cantabrian Capercaillies avoided Pyrenean oak forest on the northern slope of the Cantabrian

range in the Eurosiberian biogeographic region. These contrasting results could be due to the fact that Pyrenean oak fragments to the north are smaller and less frequent than those in our Mediterranean study area and/or due to other habitat alternatives in the Eurosiberian such as beech, birch or sessile oak forests (Costa-Tenorio et al. 2001; García et al. 2005; Quevedo et al. 2006a, b). Large and medium forest fragments, regardless of the forest type, were markedly more frequently used than the small ones, which agree with other studies that show fragment size as a more important factor explaining Capercaillie occurrence than species composition (Storch 1991; Quevedo et al. 2006b; Bollmann et al. 2010). Nonetheless, studies on structure and quality of forests should be addressed in this Mediterranean area in order to better understand patterns of Capercaillie occurrence.

Non-forested habitats (i.e. above the treeline) have been shown as important for rearing hens both in the Cantabrian Mountains (Bañuelos et al. 2008) and the Pyrenees (Menoni 1991), but were little used in our study. Here, the existence of a two-month period of drought during the summer (Rivas-Martínez et al. 2004) and the traditional use of fire both as a tool to control these non-forested habitats as well as to increase grassland surface (Luis-Calabuig et al. 2000) might have increased the plant density after fire in heathlands and brooms making them unavailable for Capercaillie. Nonetheless, more detailed research on habitat used by males and females in the study area would be needed to test this idea more formally.

As in previous Cantabrian studies we detected consumption of pine needles especially in winter (Rodríguez & Obeso 2000). The winter season is considered more critical for Cantabrian Capercaillie than for other subspecies due to the lower caloric content and the scattering of their food items in a deciduous forest, which may make winter survival difficult by increasing energy expenditure when the ground is snow-covered (Rodríguez & Obeso 2000; Quevedo et al. 2006b). However, in our warmer Mediterranean area, pine in winter may not be as critical as resource as in European populations where a greater snow cover is present in space and time (Gjerde & Wegge 1989; Spidso &

Korsmo 1994), and it is notable that two radio-tagged individuals in our study did not use pine plantations at all, despite their availability.

Both in the main oak/pine study area and in the sampled beech forests the percentages of understory food resources (46% and 48% respectively) were slightly higher than the mean values found in other European populations (43% in France, 43% in Slovakia, 36% in Germany and 14% and 21% in Scotland, see Jacob 1988; Picozzi *et al.* 1996; Saniga 1998; Storch *et al.* 1991; Summers *et al.* 2004), but it was smaller than that recorded by Blanco-Fontao *et al.* (2010) in Eurosiberian birch and mixed forests of the Cantabrian range (65%) as well as in the birch forests studied by us (59%). These differences among areas may be related to the availability of pine, which balances the consumption of canopy-understory resources by increasing the use of canopy food resources especially during winter. However, the understory is also relatively richer in plant species and covers a greater surface in birch than in beech forests (Costa-Tenorio *et al.* 2005). This fact seems also reflected in the somewhat higher diversity of food sources on which Capercaillie fed in birch forests (Fig. 4)

Although bilberry is usually considered a key species for Capercaillie diet in the Eurosiberian region (Storch 1995b; Quevedo *et al.* 2006b; Blanco-Fontao *et al.* 2010, this study Table S1 and S2), some exceptions occur. In some areas in the southern Pyrenees, bilberry is replaced in the Capercaillie diet by bearberry *Arctostaphylos uva-ursi* due to the lack of the former in the area (Robles *et al.* 2006). In our study area, bilberry is also nearly absent (González *et al.* 2010) and hence scarce in the Capercaillie diet (Table 1); other species such as oak, ferns, and grasses seem to replace the lower consumption of bilberry. It is worth noting the consumption of Rockrose in the Mediterranean forests, a species never described before as a food resource for Capercaillie, which is consumed frequently in autumn and winter (Table 1). Our results show significant differences in the diet between Mediterranean (i.e. Pyrenean oak and Scots pine) and Eurosiberian (i.e. beech and birch) forests which were geographically close to each other (Fig. 4, Table S1 and S2), suggesting that the

same population of Capercaillie displays some trophic plasticity and potential tolerance to environmental change.

*Implications for conservation*

The severe and rapid decline of Cantabrian Capercaillie in recent decades has renewed range-wide efforts to gather information on the ecology of this subspecies for application to conservation. We have documented for the first time the strong preference for medium and large Pyrenean oak forest fragments and a moderately high consumption of Pyrenean oak leaves, buds or acorns throughout the year, highlighting the relevance of these native forests for the conservation of the species. Our data also show that Scots pine plantations, especially of large size, may provide food resources, especially in winter and early spring, when food availability is lower in Pyrenean oak forest. Conservation efforts should focus on preventing fragmentation of all natural deciduous forest where Capercaillie occur, with emphasis on the largest fragments, but recognising the potential value of smaller fragments in providing for dispersal (Bollmann et al. 2010). We also recommend maintaining and managing some pine plantations for Capercaillie by creating structural heterogeneity in imitation of the heterogeneous and mature structure of the natural pine forests (Leclercq 1987; Rolstad & Wegge 1989; Sjoberg 1996), as they might eventually become higher quality habitats for Capercaillie in this Mediterranean area.

Our study shows that Capercaillie have a considerable plasticity in diet and habitat use within a limited geographical area at the edge of the global range which may enable a greater tolerance to environmental change. Additionally, this very peripheral Capercaillie population might diverge ecologically and/or genetically from others as a result of natural selection in this Mediterranean environment, implying even higher conservation value (Lesica & Allendorf 1995; Furlow & Armijo-Prewitt 1995; Hampe & Petit 2005). This unique, small and quite isolated rear-edge population of Capercaillie merits strong protection and further research. Immediate conservation actions should

include protection of the study area including it in *Natura 2000* network and develop conservation measures of the habitat of Pyrenean oak forests.

## Acknowledgments

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## Appendix

**Tables.** Percentage of occurrence of plant remains in Capercaillie droppings (*mean*  $\pm 1\text{SD}$ ) in beech (**Table S1**) and in birch (**Table S2**) Eurosiberian forests by season and globally (“Annual”). Main species (\*). Understory resources: brooms (*Cytisus* / *Genista* spp.), bilberry (leaves, berries and shoots), heaths, blackberry, rockrose (*Halimium lasianthum*), ferns, grasses, mosses and lichens. Canopy resources: *Ilex aquifolium*, *Fagus sylvatica*, *Betula pubescens*, *Sorbus aucuparia*, *Quercus petraea*, *Corilus avellana* and *Pinus sylvestris*. Eighteen individual categories plus the amount of unidentified remains are shown.

**Table S1**

	Percentage occurrence of remains in droppings in Eurosiberian beech forest (mean ± 1SD)				
	Summer	Autumn	Winter	Spring	Anual
Understory resources	50.2 ± 5.8	52.9 ± 15.2	39.1 ± 14.5	50.2 ± 7.8	47.9 ± 8.7
Canopy resources	46.8 ± 6.9	43 ± 4.1	56.7 ± 9.2	46.8 ± 4.7	48.2 ± 3.3
* <i>Ilex aquifolium</i>	16.4 ± 5.6	14.5 ± 9.3	25.6 ± 8.4	16.4 ± 5.7	18.2 ± 7.2
* <i>Vaccinium myrtillus</i>	22.5 ± 11.3	42.9 ± 34.1	29.8 ± 27.3	22.5 ± 11.4	29.4 ± 21
<i>Fagus sylvatica</i>	28.7 ± 9.6	20.5 ± 5.6	31.1 ± 16.5	28.7 ± 9.7	27.2 ± 10.3
<i>Betula pubescens</i>	1.7 ± 1.4	5.2 ± 2.3	0	1.7 ± 1.5	2.1 ± 1.3
<i>Sorbus aucuparia</i>	0	2.8 ± 3.1	0	0	0.7 ± 0.8
* <i>Quercus petraea</i>	0	0	0	0	0
<i>Corylus avellana</i>	0	0	0	0	0
* <i>Pinus sylvestris</i>	0	0	0	0	0
<i>Calluna vulgaris</i>	2.1 ± 3.5	0	0	2.1 ± 3.6	1 ± 1.8
<i>Rubus</i> sp.	0	0	0	0	0
<i>Erica</i> sp.	1.9 ± 2.3	1.9 ± 0.6	0	1.9 ± 2.4	1.4 ± 1.3
* <i>Halimium lasianthum</i>	0	0	0	0	0
subsp. <i>allyssoides</i>	0	0	0	0	0
<i>Cytisus / Genista</i> sp.	0	0	0	0	0
Ferns	5.8 ± 3.3	0	0	5.8 ± 3.4	2.9 ± 1.7
Mosses	8.3 ± 9.5	2.4 ± 4.1	0	8.3 ± 9.6	4.7 ± 5.8
Grasses	9.6 ± 6.1	5.7 ± 6.5	9.3 ± 3.9	9.6 ± 6.2	8.5 ± 5.7
Lichens	0	0	0	0	0
Arthropods	0	0	0	0	0
Unidentified	2.0 ± 3.2	4.1 ± 1.4	4.2 ± 2.5	2.0 ± 3.3	3.1 ± 2.6

**Table S2**

	Percentage occurrence of remains in droppings in Eurosiberian birch forest (mean ± 1SD)				
	Summer	Autumn	Winter	Spring	Anual
Understory resources	50.3 ± 8.1	72 ± 9.9	78.5 ± 11.2	47.7 ± 16.8	58.9 ± 8.7
Canopy resources	44.1 ± 3.1	17.2 ± 5.6	32.3 ± 3.5	41.2 ± 8.4	33.8 ± 4.9
* <i>Ilex aquifolium</i>	6.2 ± 6.5	0	17.3 ± 3.8	8 ± 5.6	7.8 ± 3.9
* <i>Vaccinium myrtillus</i>	20.6 ± 13.9	6.3 ± 5.8	43.3 ± 28.5	29.7 ± 32.1	25 ± 20.1
<i>Fagus sylvatica</i>	0	0	6 ± 7.4	16.1 ± 12.1	5.5 ± 4.8
<i>Betula pubescens</i>	37.3 ± 7.9	15.5 ± 9.8	0.7 ± 2.3	17.2 ± 21.4	17.7 ± 10.3
<i>Sorbus aucuparia</i>	0.6 ± 1.4	1.7 ± 3.1	1.3 ± 3.2	0	0.9 ± 1.9
* <i>Quercus petraea</i>	0	0	7.3 ± 4.6	0	1.8 ± 1.1
<i>Corylus avellana</i>	0	0	0	0	0
<i>Pinus sylvestris</i>	0	0	0	0	0
<i>Calluna vulgaris</i>	0	0	0	1.7 ± 0.5	0.4 ± 0.1
<i>Rubus</i> sp.	0	0	0	1.2 ± 2.2	0.3 ± 0.5
<i>Erica</i> sp.	2.6 ± 1.1	0	2.0 ± 1.4	0	1.1 ± 0.6
* <i>Halimium lasianthum</i>					
subsp. <i>allysoides</i>	0	0	0	0	0
<i>Cytisus / Genista</i> sp.	0	0	0	0	0
Ferns	15.8 ± 9.8	16.3 ± 5.5	3.4 ± 2.1	5.1 ± 6.3	10.1 ± 5.9
Mosses	0	12.2 ± 6.6	2.7 ± 1.7	2.3 ± 3.1	4.3 ± 2.8
Grasses	11.3 ± 5.8	37.3 ± 21.7	9.3 ± 3.6	12.9 ± 9.1	17.7 ± 10
Lichens	0	0	0	0	0
Arthropods	0	0	0	0	0
Unidentified	5.3 ± 3.2	10.7 ± 4.8	6.7 ± 5.1	5.8 ± 2.1	7.1 ± 3.8

**Figures.** Annual (**S1a**) and seasonal (**S1b**: spring; **S1c**: summer; **S1d**: autumn and **S1e**: winter) Jacobs' preference index for each fragment type and size used by Cantabrian Capercaillie within the 50% fixed Kernel isoline. Values range from -1 (maximum avoidance) to 1 (maximum preference). Boxes indicate the 25-75<sup>th</sup> percentile range and contain the median line. Bars represent the 10<sup>th</sup> and 90<sup>th</sup> percentile values. **LP** (large Scots pine plantation fragment: >500ha), **MP** (medium Scots pine plantation fragment: >100-500ha), **SP** (small Scots pine plantation fragment: 0-100ha), **LO** (large Pyrenean Oak fragments: >500ha) **MO** (medium Pyrenean Oak fragments: >100-500ha), **SO** (small Pyrenean Oak fragments: 0-100ha) and **NF** (non forested habitats: heathlands, brooms and meadows).

**Figure S1a**

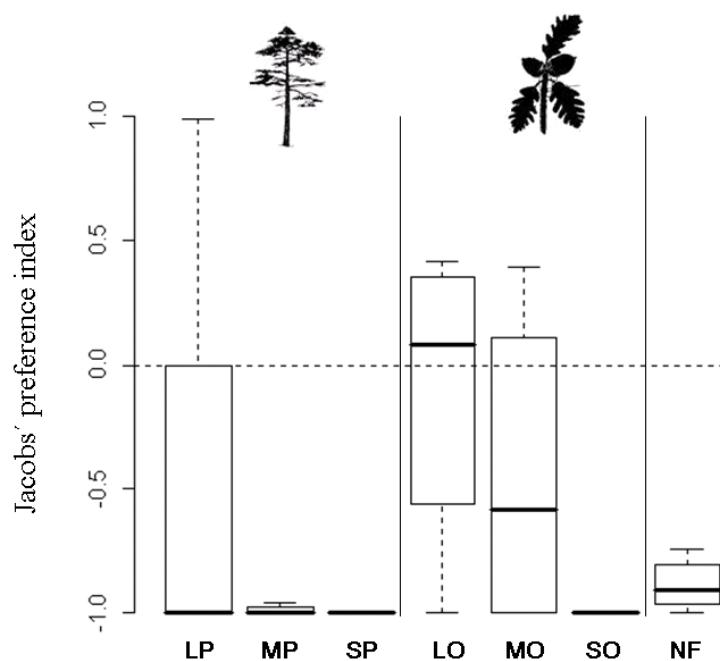


Figure S1b

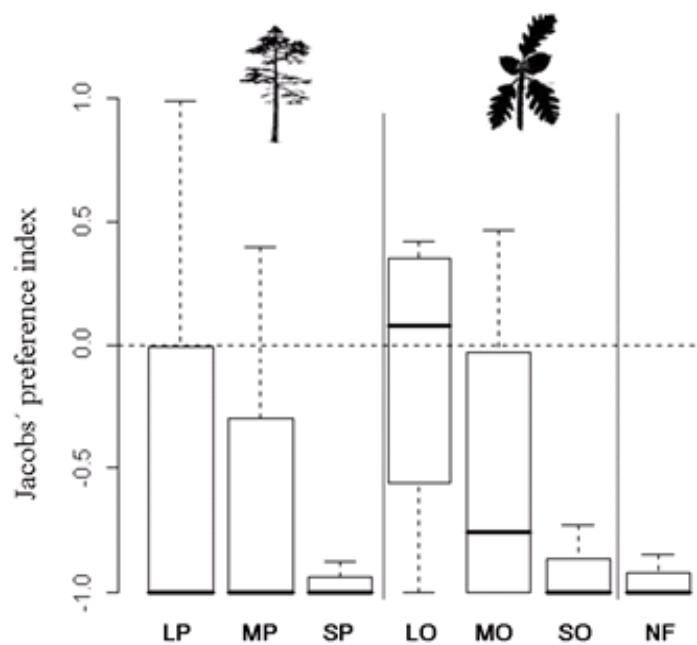


Figure S1c

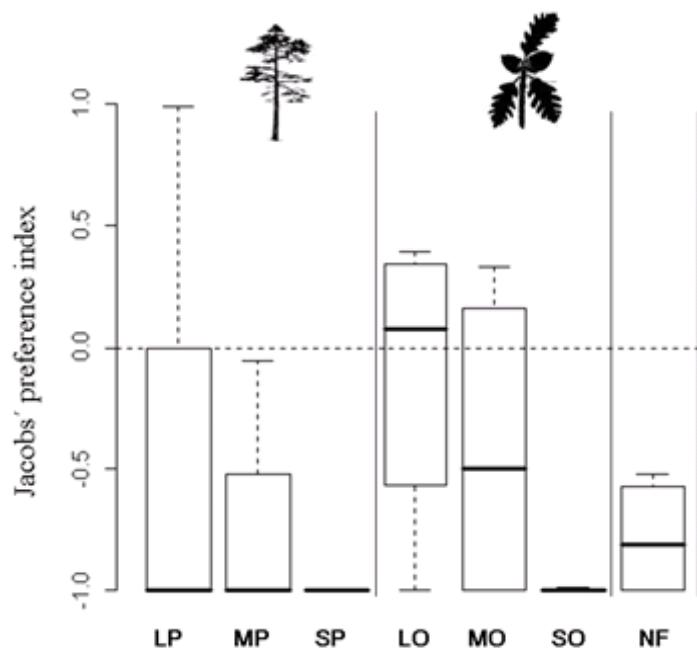


Figure S1d

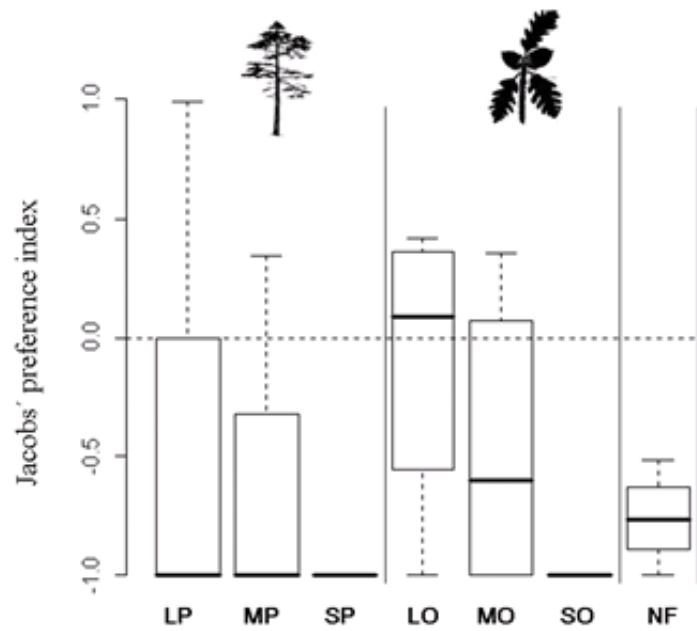
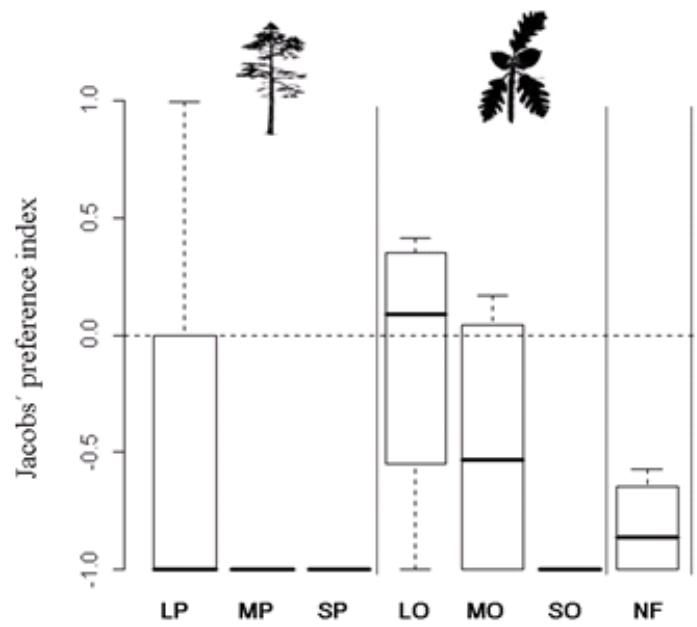


Figure S1e





## Chapter III / Capítulo III





Cantabrian hen crossing a road between Pyrenean Oak forest fragments in the study area

*Urogallina cantábrica cruzando una carretera entre fragmentos de melojar en el área de estudio*

Foto: Fernando Gonzalo

## Genetic diversity, structure and conservation of the endangered Cantabrian Capercaillie in a unique Mediterranean habitat

*Caracterización genética y conservación del amenazado Urogallo Cantábrico en un  
hábitat mediterráneo único*

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Las poblaciones animales periféricas se encuentran a menudo en riesgo de extinción debido a su aislamiento, fragmentación del hábitat, pequeños tamaños poblacionales y ambientes subóptimos. Pero estas poblaciones son sin embargo importantes para la conservación de la biodiversidad ya que pueden aportar variabilidad genética y/o tolerar el actual cambio global mejor que las poblaciones centrales. El amenazado Urogallo Cantábrico (*Tetrao urogallus cantabricus*) ocupa bosques caducífolios de la cordillera Cantábrica en el límite suroccidental del rango de la especie. Recientemente se han descrito nueve cantaderos desconocidos de Urogallo Cantábrico en bosques mediterráneos de la vertiente sur de la cordillera, dentro de la distribución histórica de la subespecie. Se desconoce el origen de estas aves, su estatus genético y si están o no en contacto con los Urogallos de la población principal de los bosques eurosiberianos más norteños. Mediante microsatélites caracterizamos genéticamente la población de Urogallos a lo largo de su distribución mediterránea y eurosiberiana. No se detectó diferenciación genética significativa entre los Urogallos de los bosques mediterráneos y eurosiberianos, y contrariamente a lo esperado el flujo genético se produjo principalmente de sur (bosques mediterráneos) a norte (bosques eurosiberianos). Los Urogallos de los bosques mediterráneos están en riesgo de extinción tanto por su localización periférica extrema como por su pequeño tamaño poblacional, baja diversidad genética y reducido flujo genético.

### **Abstract**

Populations residing at the rear-edge of the species' range are often at a high risk of extinction, due to their isolation, fragmentation, small population sizes and thriving under suboptimal habitat conditions. However, these populations also play a relevant role in the conservation of biodiversity since they may represent a valuable genetic resource and cope differently with the future global warming than core populations. The endangered Cantabrian Capercaillie (*Tetrao urogallus cantabricus*) inhabits deciduous forests of the Cantabrian Mountains of Spain, at the southwest limit of the species' range. Recently, nine unknown Cantabrian Capercaillie leks were described in Mediterranean forests of the southern slope of the Cantabrian range, where the subspecies historically occurred. The origin of these birds, their genetic status and relationship with the core population inhabiting northern Eurosiberian forests remain unknown. In order to genetically characterize the population genetic diversity and structure of the endangered Cantabrian Capercaillie across its whole diversity of habitats, we performed genetic analyses using microsatellites of all known leks in the newly described marginal Mediterranean forests

and the adjacent Eurosiberian core range. No significant genetic differentiation between Eurosiberian and Mediterranean forests was detected and, contrary to expected, gene flow mainly occurred from southern Mediterranean to northern Eurosiberian forests. The Capercaillie Mediterranean forest population faces a high risk of extinction not only because of its peripheral location but also due to its small population size, low genetic diversity, and low incoming gene flow.

## Introduction

Peripheral populations at the southern edge of the species' range can be genetically differentiated due to isolation, low gene flow and small population sizes, thus they are frequently in greater risk of extinction than populations in the centre of the species' range (Brown 1984; Lawton 1993; Lesica and Allendorf 1995; Hampe and Petit 2005). These low-latitude populations are major contributors to evolutionary change and important for species' long-term survival and evolution (Lesica and Allendorf 1995; Channell and Lomolino 2000a, b; Hampe and Petit 2005). In grouse, southern peripheral areas are the main arenas of peripatric speciation (Drovetski 2003). Furthermore, low-latitude populations live more exposed to the predicted vegetation changes associated to global warming, and thus their ranges are expected to reduce more readily. Otherwise, these populations occurring in warmer environments might also cope better with the predicted climate changes than those in the core range. Therefore, in many ways, peripheral populations are highly important for biodiversity conservation (Hampe and Petit 2005; Ohlemüller et al. 2008; Pearce-Higgins et al. 2011).

Capercaillie *Tetrao urogallus* is the largest grouse species, adapted to cold climates and considered a dweller of rich and continuous forests (Storch 2001; Suter et al. 2002). Its southernmost distribution limits correspond to the Iberian and Balkan Peninsulas, both of which acted as glacial refugia for the species and currently maintain a distinct evolutionary lineage from the northern and eastern Capercaillie populations. This southern Capercaillie lineage is considered an Evolutionary Significant Unit that should be managed locally (Duriez et al. 2007; Rodríguez-Muñoz et al. 2007; Segelbacher and Piertney 2007; Bajc et al. 2011). The Cantabrian Capercaillie *T. u. cantabricus* living in northwestern Iberian Peninsula, is the most isolated subspecies. It is located 300km to the west from the closest Capercaillie population in the Pyrenees, and it differs both ecologically and genetically from its conspecifics (Duriez et al. 2007; Rodríguez-Muñoz et al. 2007). In contrast to all the

other Capercaillie populations inhabiting coniferous forests, Cantabrian Capercaillie live and feed in deciduous forests dominated by beech *Fagus sylvatica*, birch *Betula pubescens* and oaks *Quercus* sp. (Quevedo et al. 2006b; González et al. 2010), at least since the last 4000 years (Rubiales et al. 2008). Genetically, the Cantabrian Capercaillie is the only population purely constituted by individuals from the southern evolutionary lineage and shows the lowest genetic diversity (Duriez et al. 2007, Rodríguez-Muñoz et al. 2007).

The endangered Cantabrian Capercaillie population is isolated and has declined by about 50% in the last 20-30 years due to habitat destruction and fragmentation, and human disturbances (Obeso and Bañuelos 2003; Quevedo et al. 2006a; Storch et al. 2006). Currently only 23% of the forest cover represents suitable habitat for the Capercaillie (Quevedo et al. 2006a). For example the Mediterranean forests of Pyrenean Oak *Quercus pyrenaica* (hereafter Mediterranean oak forest), which were habitat for the Cantabrian Capercaillie until the 17<sup>th</sup> century, were massively deforested in the following centuries (see Fig. 1a; Castroviejo 1975; Martínez 1993; García et al. 2005). However, this habitat is now naturally expanding southwards due to rural abandonment (Morán-Ordóñez et al. 2011) and nine unknown Cantabrian Capercaillie leks have recently been described in this habitat (González et al. 2010). So far, the origin of these birds, their genetic status and relationship with those from the northern core area remain unknown.

The marcescent Mediterranean oak forest significantly differs from the commonly considered “typical” deciduous Eurosiberian forests inhabited by Cantabrian Capercaillie as it is a much warmer habitat with two dry months in summer. According to this, at first, Mediterranean habitats would be thought to be unsuitable for a species adapted to boreal environments (González et al. 2010). Therefore, this newly described population nucleus represents an interesting case of study because: firstly, it suggests greater Capercaillie adaptability than previously thought (González et al. 2010); secondly, it is important for the conservation of the Cantabrian Capercaillie genetic and

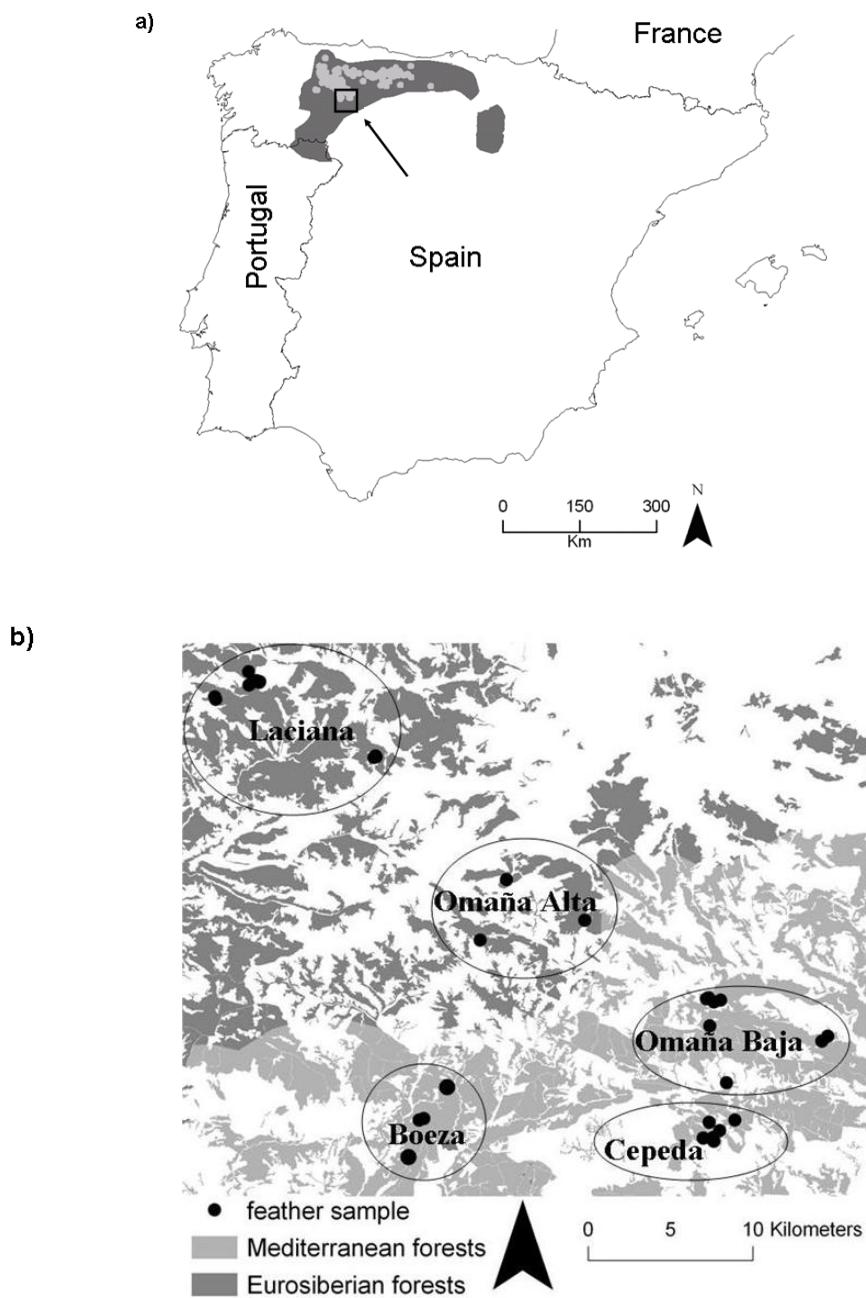
ecological diversity; and thirdly, it may raise some hope for the persistence of this endangered subspecies under potential changes of flora and fauna due to global climate change (Hampe and Petit 2005). Thus, to understand the historical distribution, decline and conservation status of the Cantabrian Capercaillie it is important to characterize the population genetic diversity and structure of Capercaillie across its entire distribution range, but so far, all genetic studies have only focused on Cantabrian Capercaillie inhabiting the well known Eurosiberian habitats (Duriez et al. 2007; Rodriguez-Muñoz et al. 2007; Alda et al. 2011).

Marginal and lower quality habitats are typically considered as sinks, whereas better quality habitats usually at the core are considered as sources (Dias 1996). Thus, we could hypothesize that Eurosiberian forests could act as source to the likely poorer Mediterranean habitat which may function as a sink habitat, not self-sustaining but persisting due to immigration (Segelbacher et al. 2003). Further, these Mediterranean forests might represent a recently established Capercaillie population nucleus that was colonized from the north, which would explain why they have remained unnoticed until recent times. Here, we performed genetic analyses using microsatellite markers in all known leks from the newly described marginal Mediterranean forest and from a wide sample of leks in the adjacent Eurosiberian main habitat to genetically characterize the diversity and structure of the endangered Cantabrian Capercaillie at its southernmost post, compare it with the nearby Eurosiberian population, and finally provide guide to inform conservation plans for this marginal Capercaillie population.

## Methods

### *Study area and non-invasive sampling*

The study area is located on the southern slope of the Cantabrian Mountains, in León province (NW Spain). It encompasses ~2500km<sup>2</sup> that span over both sides of the putative line separating Eurosiberian and Mediterranean biogeographical regions (González et al. 2010, Fig. 1b). The northern half of the area is in the Eurosiberian region within the core of the Cantabrian Capercaillie distribution. Here this subspecies inhabits birch and sessile oak forests with a humid and temperate climate situated at 1500 to 1700m a.s.l. (Obeso and Bañuelos 2003). The southern half of the area lies within the Mediterranean region with supramediterranean climate, which has two dry months in the summer. The landscape is mountainous (elevation ranges from 800 to 1700m a.s.l.) and dominated by Mediterranean oak forests intermingled with Scots pine *Pinus sylvestris* plantations. The entire and recently discovered Mediterranean Capercaillie nucleus occurs within these forests. Mediterranean and Eurosiberian leks closest to each other are found at least 10km apart and in different watersheds, therefore forests show fairly different climate and ecological characteristics (González et al. 2010).



**Figure 1. a)** Grey dark historical distribution of the Cantabrian Capercaillie in the 17<sup>th</sup> century (according to Madoz 1848; Castroviejo et al. 1974 and Martínez 1983); grey light distribution of Cantabrian Capercaillie in 2005 (according to Robles et al. 2006); arrow indicates the location of

the study area. b) Study area and sampling localities; *black dots* sites of feathers collection; *light grey shading* represents Mediterranean forests; *dark grey* - Eurosiberian forests.

To limit the disturbance to the rare Cantabrian Capercaillie, we collected 67 freshly moulted feathers in August-September 2009 from five watersheds in the Cantabrian Mountains. Three watersheds were in the Mediterranean region: Omaña Baja, Cepeda, and Boeza (i.e. the Mediterranean complete known range); and two in the Eurosiberian region: Laciana and Omaña Alta (i.e. the closest Eurosiberian leks to the Mediterranean region; Fig. 1b). In the forests of the Mediterranean region (hereafter Mediterranean forests) we sampled in all known occupied forest fragments (González et al. 2010). Feathers searches were conducted via a systematic zig-zag walk covering 1km<sup>2</sup> of forest surrounding each known lek once a month. We took geographic coordinates for each sample using Global Positioning System (GPS; Fig. 1b). We attributed feathers collected in the field to their respective sex according to the colour pattern; these feathers were then stored in paper envelopes until DNA extraction.

#### *DNA extraction and microsatellite genotyping*

We treated each feather as an individual sample for DNA extraction. Total genomic DNA was extracted from a ≈1cm segment at the base of each feather cut into small pieces using DNeasy Tissue Kit (QIAGEN, Crawley, UK) according to the manufacturer's manual with modifications for this species (Segelbacher 2002). Digestion was performed overnight in a shaking water bath at 55°C. The buffer volume was adjusted to the size of the feather tip (400-600µL for large feathers, 200µL for small feathers). DNA was eluted in 60-100µL of the buffer and stored at -20°C.

The samples were genotyped for 14 microsatellite loci: TUD1, TUD2, TUD3, TUD4, TUD5, TUD8, TUT1, TUT2, TUT3, TUT4, LLSD2, LLSD3, LLSD6 and LLSD10 (Piertney and Dallas 1997; Segelbacher et al. 2000). The microsatellites were co-amplified in five multiplex PCRs (MP1: *TUD4*, *TUT4*, *TUD5* and *TUD8*; MP2: *TUT3*, *TUT2* and *TUD3*; MP3: *TUD1* and *TUT1*; MP4: *TUD2*, *LLSD2* and *LLSD3*; MP5:

*LLSD6* and *LLSD10*). Amplifications were performed on a MJR DYAD PTC220 DNA Thermal Cycler (MJ Research, Inc., MA, USA) following QIAGEN Multiplex PCR kit protocol and using two touchdown reactions. MP1/2/3 were performed decreasing the annealing temperature by 0.5°C every second cycle for 10 cycles starting at 55°C, followed by 30 cycles at 50°C. MP4/5 were carried out decreasing the annealing temperature by 0.5°C every second cycle for eight cycles starting at 56°C, followed by 30 cycles at 52°C. The total reaction volume was 10µL, including 5µL of the QIAGEN PCR Master Mix, 1µL of primer mix, 2µL of DNA and 2µL of RNase-free H<sub>2</sub>O. Reactions were performed with three primers for each locus, following the M13-tailed primer method (Oetting et al. 1995). Fluorescently labelled PCR products were analysed on an ABI3130xl DNA analyser (Applied Biosystems, Foster City, CA, USA) and alleles were scored using GeneMapper 4.0 software (Applied Biosystems). All samples (n=67) were initially screened twice with MP1 to evaluate the quality of the nuclear DNA. Samples that showed reliable amplifications and matching genotypes (n=64) were selected to continue the genotyping process. Selected samples were independently re-genotyped 3 to 4 times to ensure reliability of the results.

For the Cantabrian Capercaillie samples the expected number of individuals with the same genotype in the population was  $6.079 \times 10^{-4}$  ( $P_I = 1.788 \times 10^{-5}$  and  $P_{Isib} = 6.496 \times 10^{-3}$ , Taberlet and Luikart 1999; Waits et al. 2001). Identical genotypes were removed from further analyses as belonging to the same individual.

#### *Data analysis*

We estimated genetic diversity parameters: number of alleles ( $N_A$ ), allelic richness ( $A_R$ ), observed and expected heterozygosity ( $H_o$  and  $H_e$ ) and inbreeding coefficient ( $F_{IS}$ ) for all Cantabrian Capercaillie samples and for the Eurosiberian and Mediterranean forests separately using FSTAT 2.9.3 (Goudet 1995). Tests for differences in the average values (over samples and loci) of genetic diversity statistics among groups of samples (Mediterranean and Eurosiberian) were also carried out in FSTAT 2.9.3.

Departures from Hardy-Weinberg equilibrium were assessed by applying exact tests in GENEPOP 3.4 (Raymond and Rousset 1995).

We employed a Bayesian clustering method to investigate the genetic structure and spatial location of genetic discontinuities. For this purpose we used STRUCTURE 2.3.3 (Pritchard et al. 2000) under the admixture model, correlated allele frequencies (Falush et al. 2003) and the LOCPRIOR option (Hubisz et al. 2009). We performed 10 independent runs for each  $K$  value from  $K=1$  to  $K=8$ . Each run had  $5 \times 10^5$  iterations with a burn-in of  $1 \times 10^5$  iterations. Mean log probabilities were used to calculate  $\Delta K$ , and find the  $K$ -value with the highest probability (Evanno et al. 2005). Once  $K$  was estimated, we ran 5 independent analyses with  $K$  fixed at the highest probability value for  $5 \times 10^6$  iterations with a burn-in of  $1 \times 10^6$  iterations value. The final  $Q$  coefficients were obtained by averaging these 5 runs using CLUMPP 1.1.2 and the ‘greedy’ algorithm and the ‘all possible input order’ options (Jakobsson and Rosenberg 2007).

To test if genetic differentiation among Cantabrian Capercaillie samples is best explained by geographical locations or forest types we performed an analysis of molecular variance (AMOVA) in GenoDive 2.0b17 (Meirmans and Van Tienderen 2004). Also, we explored the occurrence of an isolation-by-distance pattern of spatial genetic structure relationship. We calculated Euclidean distances between individuals, and tested their correlation with their genetic distance (Smouse and Peakall 1999) using Mantel tests (Mantel 1967). To find out whether patterns of population differentiation are only due to isolation by distance or also to differences between forests we performed a partial Mantel test (Smouse et al. 1986). In this test, the association between geographic and genetic distances was tested while controlling for the influence of forest type using a binary matrix to code for individuals located in the same (0), or in different forests (1). These analyses were performed in GenoDive 2.0b20 and their statistical significance was assessed by  $1 \times 10^5$  randomizations.

Recent migration among localities and between the Mediterranean and Eurosiberian forests was investigated using BAYESASS 1.3 (Wilson and Rannala 2003). To ensure

convergence of the MCMC, we performed 10 runs of  $3 \times 10^6$  iterations including a burn-in of  $1 \times 10^6$  iterations, and a sampling frequency of 2000. Delta values were tuned individually to obtain acceptance rates within 40–60% of the total.

## Results

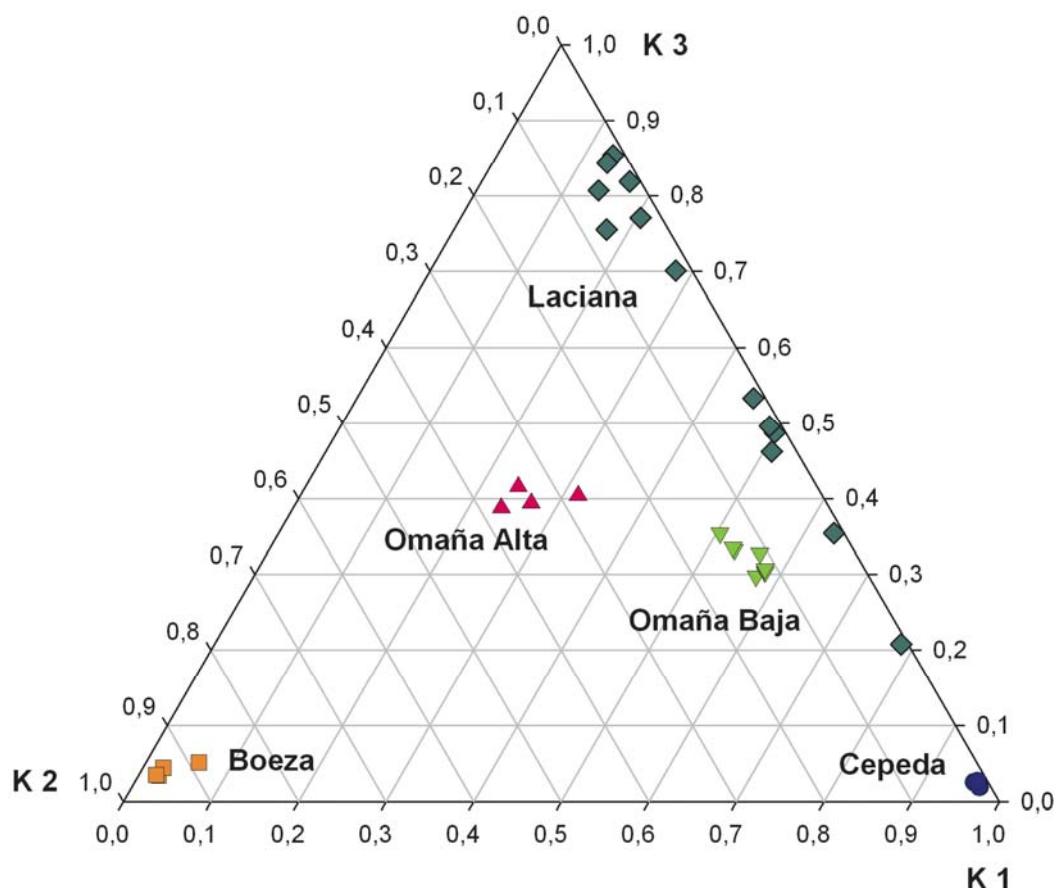
Overall, 64 Cantabrian Capercaillie feathers were genotyped for all 14 microsatellites identifying 34 unique genotypes: 17 in Mediterranean forests and 17 in Eurosiberian. These genotypes corresponded to 15 females (7 in Mediterranean and 8 in Eurosiberian) and 19 males (10 in Mediterranean and 9 in Eurosiberian). Four genotypes were found in 5 and 6 samples, and nine genotypes were found in 2 and 3 samples. All duplicates were found within the same localities and considered to represent the same individual and were omitted from the analysis (see Methods). Other genotypes were found only in a single sample.

No evidence for linkage disequilibrium between loci was found or signs of allele dropout or null alleles. Genetic diversity for the Cantabrian samples was low (Table 1). Overall, average allele number was  $N_A = 2.502$  (SD, 1.533) and observed heterozygosity  $H_o = 0.253$  (SD, 0.242). Five loci were invariant in the Cantabrian population (TUT2, TUT4, LLSD1, LLSD2 and LLSD4). Within the Cantabrian population genetic diversity was lower and inbreeding coefficient was higher, although non-significant, in the Mediterranean forests, where two additional loci (TUD4 and LLSD6) were invariant (Table 1).

Population	<i>n</i>	<i>N<sub>A</sub></i>	<i>A<sub>R</sub></i>	<i>H<sub>o</sub></i>	<i>H<sub>e</sub></i>	<i>F<sub>IS</sub></i>	Monomorphic loci
Cantabrian	34	2.667	2.272	0.253	0.303	<b>0.179</b>	TUT2, TUT4, LLSD1, LLSD2
		(1.718)	(1.287)	(0.242)	(0.271)	(0.298)	
Eurosiberian	17	2.467	2.298	0.274	0.316	<b>0.178</b>	TUT2, TUT4, LLSD1, LLSD2
		(1.685)	(1.457)	(0.268)	(0.274)	(0.378)	
Mediterranean	17	2.200	2.088	0.231	0.274	<b>0.172</b>	TUT2, TUT4, LLSD1, LLSD2, LLSD6, TUD4
		(1.320)	(1.183)	(0.243)	(0.269)	(0.267)	
Norway	10	4.933	4.762	0.492	0.555	<b>0.166</b>	
		(2.738)	(2.576)	(0.318)	(0.261)	(0.308)	

**Table 1.** Genetic diversity of capercaillie based on microsatellite loci. *n* : number of samples, *N<sub>A</sub>* : number of alleles, *A<sub>R</sub>* : allelic richness standardized to the minimum sample size, *H<sub>o</sub>* : observed heterozygosity, *H<sub>e</sub>* : expected heterozygosity, *F<sub>IS</sub>* : inbreeding index. Standard deviation is shown in parentheses. Bold values indicate significant departures from Hardy-Weinberg equilibrium (*P* < 0.05)

The STRUCTURE analysis identified the most likely genetic structure as *K*=3 (Fig. 2, Electronic Supplementary Material 1). Cepeda and Boeza were the most differentiated from other localities and were assigned with a high probability to clusters 1 and 2, respectively. Laciana had individuals with a high proportion of inferred ancestry from clusters 1 and 3, whereas Omaña Alta and Omaña Baja consisted of individuals with intermediate membership proportions of all three genetic groups (Fig. 2). When the analysis for the Cantabrian samples was performed without the LOCPRIOR option, the same clusters were recovered (*K*=3) but individuals were assigned to them with a lower probability.



**Figure 2.** Triangular plot representing individual assignment probabilities for each of the genetic groups inferred in STRUCTURE ( $K=3$ ). Each triangle vertex represents an assignment probability of 1.0 for each of the inferred genetic groups.

The AMOVA indicated a significant genetic differentiation among all Cantabrian Capercaillie localities ( $F_{ST} = 0.117$ ,  $P < 0.001$ ). However, the differentiation was not significant when the variation was partitioned by forest type, suggesting that gene flow is not interrupted between the Eurosiberian and Mediterranean forests ( $F_{CT} = -0.062$ ,  $P = 0.249$ ). Current migration rates, as inferred with BAYESASS, were non significant as all 95% confidence intervals overlapped with those simulated when there is no

information in the data (Table 2). Failure to detect recent dispersal events between populations despite high rates of gene flow may have resulted from small sample sizes (Galbusera et al. 2000). Still, some estimates were significantly different from the others and indicated a clear tendency for gene flow to primarily occur from the Mediterranean into the Eurosiberian forests ( $m = 0.295$ , 95% CI 0.244-0.332, Table 2). Also, the southern locality of Cepeda showed the highest migration rate to the northernmost locality of Laciana ( $m = 0.226$ , 95% CI 0.079-0.315, Table 2).

Comparisons of pairwise genetic (Smouse and Peakall 1999) and Euclidean geographical distances between all Cantabrian individuals revealed a significant isolation-by-distance pattern of genetic structure (Mantel's  $r = 0.111$ , one-sided  $P = 0.009$ ). When we considered not only geographic distance between individuals but also the effect of different forests, we found a higher significant correlation between genetic distance and geographic distance (Partial Mantel's  $r = 0.175$ , one-sided  $P < 0.0001$ ). Additionally, spatial genetic structure differed between forest types when these were considered separately, as a significant isolation-by-distance relationship was observed for Capercaillie individuals in Mediterranean forests (Mantel's  $r = 0.476$ , one-sided  $P < 0.0001$ ) but not for those in Eurosiberian forests (Mantel's  $r = 0.071$ , one-sided  $P = 0.273$ ; Fig. 3).

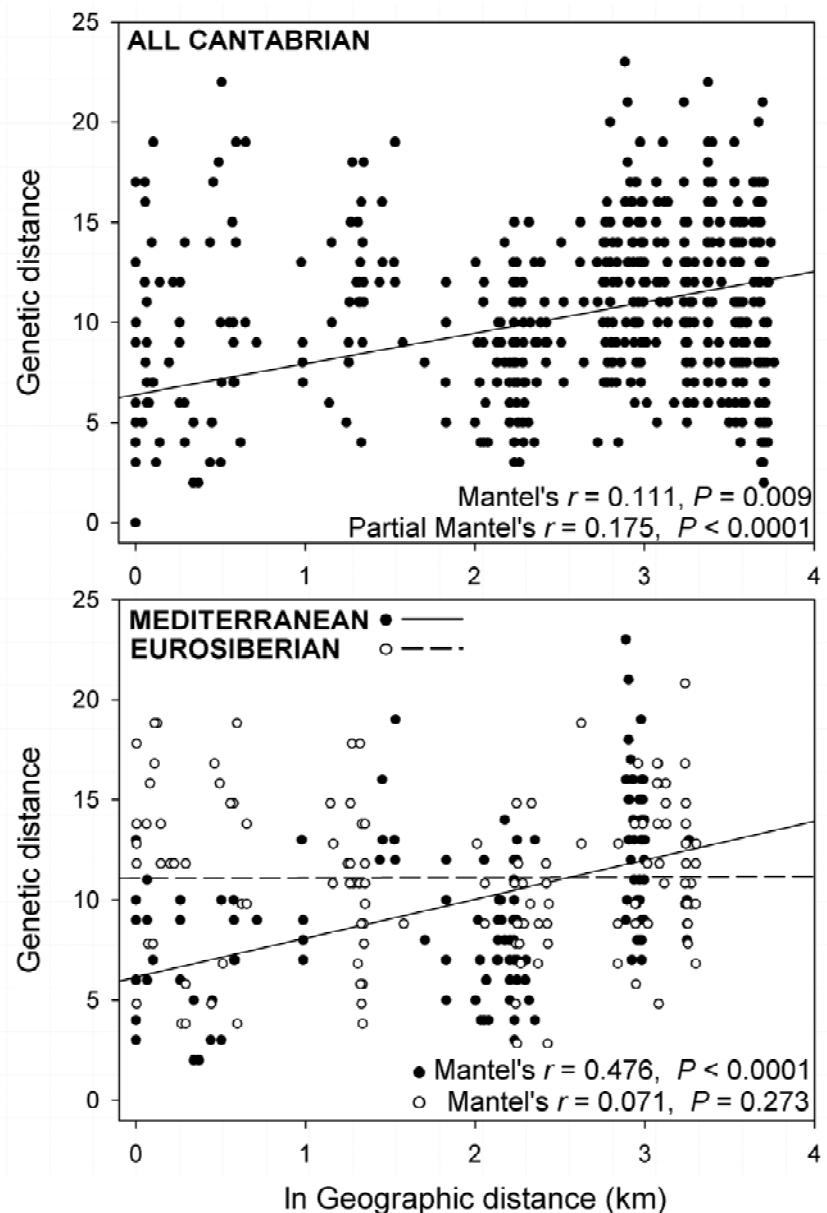
		from	
		Mediterranean	Eurosiberian
into	Mediterranean	<i>0.975</i> (0.852-0.998)	0.014 (0.001-0.147)
	Eurosiberian	0.295 (0.244-0.332)	0.699 (0.667-0.756)

Simulated 95% confidence interval when there is no information in the data: for the non-migration rates (0.675-0.992) and migration rate between two populations (0.008-0.325).

		from				
		Cepeda	Boeza	Omaña Baja	Omaña Alta	Laciana
into	Cepeda	<i>0.950</i> (0.844-0.998)	0.012 (2.757x10 <sup>-6</sup> - 0.072)	0.011 (1.897x10 <sup>-6</sup> - 0.064)	0.012 (7.423x10 <sup>-7</sup> - 0.066)	0.013 (1.308x10 <sup>-6</sup> - 0.066)
	Boeza	0.030 (2.990x10 <sup>-5</sup> - 0.140)	<i>0.734</i> (0.669-0.950)	0.118 (2.099x10 <sup>-4</sup> - 0.297)	0.087 (5.469x10 <sup>-5</sup> - 0.279)	0.029 (5.52x10 <sup>-5</sup> - 0.135)
Omaña Baja	Omaña Alta	0.202 (0.001-0.312)	0.017 (2.144x10 <sup>-5</sup> - 0.080)	<i>0.745</i> (0.668- 0.976)	0.016 (3.911x10 <sup>-5</sup> - 0.071)	0.018 (3.350x10 <sup>-5</sup> - 0.099)
	Omaña Alta	0.086 (1.7x10 <sup>-4</sup> - 0.262)	0.027 (4.746x10 <sup>-5</sup> - 0.120)	0.117 (3.986x10 <sup>-4</sup> - 0.287)	<i>0.739</i> (0.669- 0.872)	0.029 (4.245x10 <sup>-5</sup> - 0.132)
Laciana	Omaña Alta	0.226 (0.079-0.315)	0.013 (2.491x10 <sup>-5</sup> - 0.124)	0.025 (4.373x10 <sup>-5</sup> - 0.124)	0.015 (3.264x10 <sup>-5</sup> - 0.077)	<i>0.720</i> (0.668-0.861)
	Laciana					

Simulated 95% confidence interval when there is no information in the data: for the non-migration rates (0.675-0.992) and migration rate between five populations (1.79x10<sup>-5</sup>-0.185).

**Table 2.** Migration rates inferred using BAYESASS between habitats and localities of Cantabrian Capercaillie. Values in columns represent migration rates into localities indicated to the left. Values in italics in the diagonal represent the proportion of non-migrant individuals. 95% confidence intervals are shown between brackets.



**Figure 3.** Correlation plots obtained for the Mantel test between genetic (Smouse and Peakall 1999) and geographic distances for all Cantabrian individuals, and for the Mediterranean and Eurosiberian forests separately.

## Discussion

Habitat loss and fragmentation have a profound effect on the genetic isolation, structure and dispersal of Capercaillie (Segelbacher and Storch 2002; Segelbacher et al. 2003; Segelbacher et al. 2008; Alda et al. 2011). After the contraction of the Cantabrian Capercaillie distribution in the last centuries due to deforestation mainly in the southern part of the range (Madoz 1848; Castroviejo 1975; Martínez 1993; Fig. 1a), the Cantabrian Capercaillie was thought to persist only in the Eurosiberian forests at the north of its distribution. However, recently it was found that the subspecies also occurs in Mediterranean oak forests (González et al. 2010). Our results showed a lack of significant genetic differentiation between Eurosiberian and Mediterranean forests considered as a whole. Importantly, and contrary to the expectation that populations at the edge of the species' range may function as sinks (Segelbacher et al. 2003), here the northern Eurosiberian forests seem to receive immigrants rather than acting as source habitat that supplies emigrants to the Mediterranean forests (Table 2). Therefore, gene flow into the Mediterranean forests is low since the proportion of non-migrants is high (see Table 2). Furthermore, these results suggest that Mediterranean forests have not been recently colonized by Capercaillie from Eurosiberian forests, rather it is likely that these individuals have remained unnoticed until now although maintaining genetic contact with the northern Cantabrian Capercaillie.

It is obvious that if the Mediterranean forest population is not a sink, any existing gene flow must occur to the north, as no habitat is available southwards. Thus, we would expect that the south to north gene flow could take place by two pathways: i) Cepeda and Omaña Baja exchanging individuals with Laciana via Omaña Alta, and ii) Boeza exchanging individuals with Laciana via Omaña Alta. The first route was supported by the Bayesian clustering method that showed a high connectivity among the localities of Cepeda, Omaña Baja and Laciana (Fig. 2) and, the migration analysis suggested that this was primarily due to the immigration of individuals from Cepeda to the northern localities (Table 2). However, there is little gene exchange between Boeza and Omaña

Alta-Laciana (Table 2). Because we surveyed each lek and surroundings known to be currently occupied by Capercaillie in the Mediterranean region (González et al. 2010), the reduced connectivity along this route could be related to the significant degradation of habitat surrounding Boeza, presence of 2000m a.s.l. peaks to its north, and to the relatively large distance between Boeza and northern localities (Omaña Alta and Laciana) that may altogether reduce the bird chances to move between Boeza and the other locations. Omaña Alta and Omaña Baja appear to act as stepping stones connecting Eurosiberian and Mediterranean forests and thus playing a crucial role in the maintenance of the regional metapopulation (Storch 1997). Our data also suggest that Boeza faces the highest risk of losing Capercaillie because it is the most geographically and genetically isolated locality.

The presence of gene flow between different forest types and the non-significant AMOVA results suggest that the forest type in the Cantabrian Capercaillie has little effect on its genetic differentiation. On the other hand, forest quality and its spatial distribution could be responsible for the observed pattern of genetic structure among individuals within each habitat type (Alda et al. 2011). Here we found an overall positive significant correlation between genetic and geographical distances, which was even more significant when accounting for the effect of forest types. However, when looking individually at each of these forests, only the Mediterranean showed a pattern of isolation-by-distance (Fig. 3). Such patterns of isolation-by-distance have been reported for the Capercaillie at large geographical scales and are expected for species with lekking reproductive systems and low dispersal (Bouzat and Johnson 2004; Segelbacher et al. 2007), but at smaller scales this pattern is not always observed (Segelbacher and Storch 2002; Segelbacher et al. 2003; Alda et al. 2011). Although these differences might be an effect of sampling scale, as this has proven to be highly important for analyses of dispersal (Segelbacher et al. 2008; Mäki Petäys et al. 2007), in our case sampling and geographical areas (although small) were balanced between habitats. Thus, it seems that the overall observed genetic structure could be mainly due to Mediterranean individuals. This is supported by greater genetic differentiation among

Mediterranean localities than among Eurosiberians, as revealed by the Bayesian clustering method. The more fragmented and border Mediterranean forests may limit dispersal to short distances and avoid dispersal to the deforested south, and thus, resulting in the greater genetic differentiation among localities than in Eurosiberian ones. Also, fragmented or low habitat availability in Mediterranean forests may increase the probabilities that males establish on leks close to their natal sites, thus increasing kinship between individuals (Regnaut et al. 2006) and leading to within-site high genetic homogeneity (e.g. in Boeza and Cepeda) and genetic differentiation between sites. In turn, these habitat-related facts may be limiting the capacity of the Mediterranean forests to hold large bird numbers while forcing Capercaillie dispersal into the north.

Besides the general risk of extinction of the Cantabrian Capercaillie, the Mediterranean forests Capercaillie face additional threats for its conservation. Not only because populations at the periphery are more susceptible to decline and extinction than populations at the core of their range (Segelbacher and Storch 2002, Segelbacher et al. 2003), but also due to its lower genetic diversity, low number, and very importantly, low incoming gene flow from other regions which at last is a key process for population persistence (Hanski and Gilpin 1991, Segelbacher et al. 2003). On the other hand, the Mediterranean oak forest is naturally expanding to the south and expected to continue expanding in the future (Morán-Ordóñez et al. 2011). According to the historical distribution of Cantabrian Capercaillie in the 17<sup>th</sup> century, when the subspecies occupied ~200km further south (Fig. 1), we speculate that deforestation might have been an important trigger of Cantabrian Capercaillie distribution range reduction rather than global warming. Therefore, in the short term, preserving habitat availability should be of greater concern than the possible effects of global climate change.

Although at risk, the Cantabrian Capercaillie is still one functionally metapopulation (our results; Alda et al. 2011) but in the Cantabrian range the forest cover is low (23%) and only 5% of the Cantabrian landscape may be considered available for Capercaillie

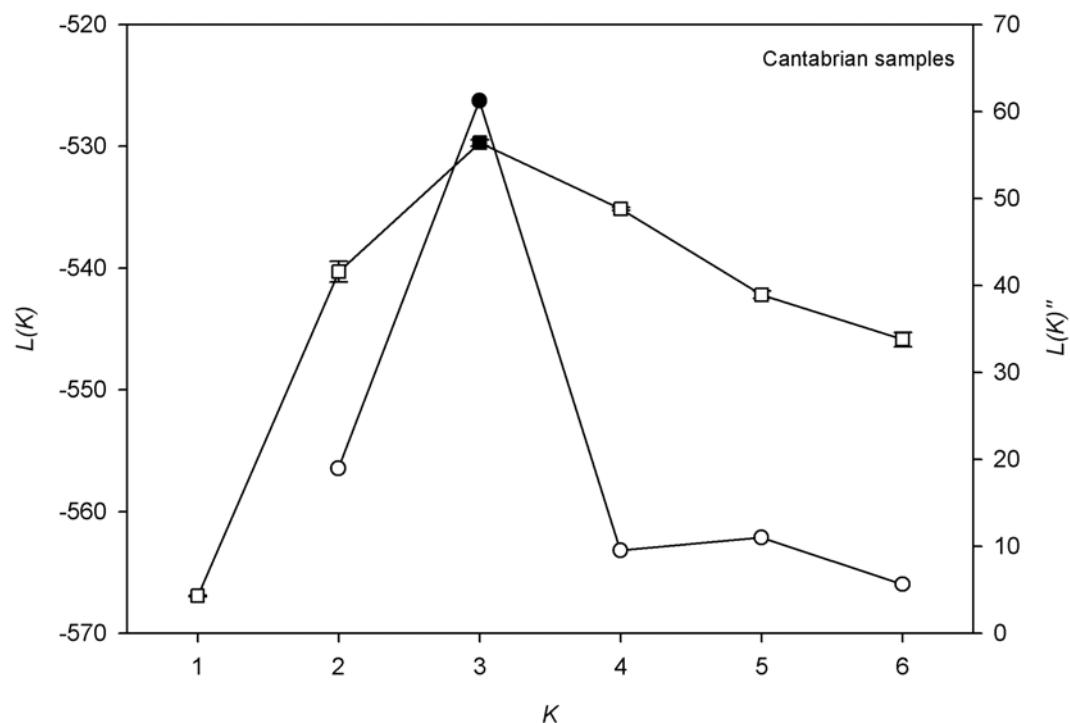
(Abajo 2007). Conservation measures should promote the preservation of any area occupied by the Capercaillie and promote connectivity both within and between Mediterranean and Eurosiberian forests in order to increase the long-term survival of the Cantabrian metapopulation. A particular effort should be made to allow the natural recovery of the Mediterranean oak forests since its predicted expansion could allow the Cantabrian Capercaillie to re-colonize part of its lost historical distribution.

## Acknowledgements

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## Appendix

**Appendix 1.** Plots representing mean log probabilities  $L(K)$  and associated standard errors (squares) and the second derivative of the mean log probability  $L(K)''$  (Evanno et al. 2005) (circles) for each of the  $K$  populations inferred in STRUCTURE for the Cantabrian capercaillie data set. Filled symbols represent chosen  $K$ -values with the highest probabilities.





## Chapter IV / Capítulo IV





**Construction of a wind farm in winter at the study area**

*Construcción de un parque eólico durante el invierno en el área del estudio.*

**Evaluating contemporary threats to the Mediterranean habitat of Capercaillie**

*Evaluación de las amenazas actuales del hábitat mediterráneo del Urogallo*

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*Manuscript in preparation / Manuscrito en preparación*

Las especies forestales con amplios requerimientos de hábitat están sufriendo declives generalizados consecuencia de las actividades humanas que fragmentan y degradan sus hábitats. El Urogallo Cantábrico es un ave tetraónida de gran tamaño que ha sufrido un declive general en las últimas décadas. En este estudio evaluamos las amenazas actuales al hábitat de la especie en su área de distribución más meridional al sur de la cordillera Cantábrica, la cual no se encuentra bajo ninguna figura de protección. La superficie forestal solo ocupó el 27.8% del área de estudio. Al igual que sucede en otras áreas cantábricas, aquí el paisaje forestal estuvo altamente fragmentado. Observamos que los fragmentos con presencia de Urogallo fueron los de mayor tamaño y menos aislados. Los incendios y especialmente los parques eólicos constituyeron las principales molestias antropogénicas en este hábitat de Urogallo. Sólo registramos tres incendios que afectaron a 387.2ha de fragmentos forestales con presencia de Urogallo. Entre 2009 y 2010 el número de aerogeneradores en el área de estudio aumentó de 0 a 65. 16 de los aerogeneradores se encuentran a menos de 4km del cantadero más cercano. Es urgente incluir esta área dentro de la *Red Natura 2000* para evitar grandes infraestructuras que fragmenten aún más el hábitat del amenazado Urogallo Cantábrico.

### **Abstract**

Forest species with large habitat requirements are suffering generalized declines due to human activities that fragment and degrade their habitats. Cantabrian Capercaillie is a big forest grouse which has suffered a strong decline in the last decades. We evaluate contemporary threats to the habitat at the southernmost Cantabrian Capercaillie range, which is not included under protection figure. Forested surface only occupied the 27.8% of the study area. Forest landscape resulted to be highly fragmented the same as in other Cantabrian areas. We observed the largest fragment sizes, smallest distances to the nearest presence fragment and lowest degrees of isolation in forest fragments with Capercaillie presence. Fires and specially wind farms constituted the main anthropogenic disturbances to Capercaillie habitat. We registered only three fires which burnt 387.2ha of forested surface with detected Capercaillie. Between 2009 and 2010 the number of constructed turbines increased from 0 to 65 in the study area. 16 wind turbines were closer than 4km to the nearest lek. It is urgent to include this area within the

*Natura 2000* network in order to avoid large infrastructures that further fragment the habitat of the endangered Cantabrian Capercaillie.

## Introduction

Capercaillie *Tetrao urogallus* is a big lekking grouse of western Palearctic coniferous forests. It is considered a bioindicator of bird forest diversity and ecosystem functioning since it is very demanding with respect to habitat quality (Pakkala et al. 2003; Thiel et al. 2008; Laiolo et al. 2011). It has extensive spatial requirements (average home range: ca. 550ha) and prefers landscapes with mosaics of dense, open old-growth coniferous forest and more open areas, both making it highly susceptible to habitat and landscape changes (Gjerde and Wegge 1989; Storch 1995a). Throughout most of the European industrialized countries, Capercaillie populations are fragmented, isolated and declining (see Fig. 1, Storch 2007). An important pulse of decline for European Capercaillie occurred following 20<sup>th</sup> century industrial development and the subsequent forest felling (Storch 2001). The species' decline at a global scale is usually attributed to habitat loss and fragmentation and climate change (Moss et al. 2001; Storch 2007). This latter, is expected to contract Capercaillie's current range northwards with the extinction of southern populations by the end of this century (Huntley et al. 2007). In the central and southern Europe alpine fragmented habitats, Capercaillie is negatively impacted by habitat deterioration and anthropogenic disturbances (Storch 1995a, 2007; Thiel et al. 2008). These populations are mostly endangered and declining; they mostly remain in the larger and less disturbed forests fragments (Rolstad 1989; Storch 2000a; Quevedo et al. 2006a; Bollmann et al. 2011).

At the south-western edge of the species range, occurs an isolated Capercaillie population: the Cantabrian Capercaillie *T. urogallus cantabricus* (Fig. 1). It mainly inhabits beech *Fagus sylvatica*, oaks *Quercus* sp. and birch *Betula pubescens* forests; being the only population of Capercaillie that entirely lives in purely deciduous forests. At least until the 17<sup>th</sup> century and prior to the massive deforestation that took place in the Iberian Peninsula in the next centuries (Castroviejo 1974; Martínez 1993; García et al. 2005), Cantabrian Capercaillie was distributed throughout most of the montane

forests of the North West quarter of the Peninsula. After centuries of anthropogenic forest exploitation (Muñoz-Sobrino et al. 1997), the Cantabrian landscape is currently highly fragmented, showing less than 22% of forested surface (García et al. 2005). In the 20<sup>th</sup> century Cantabrian Capercaillie dramatically diminished and it is currently restricted to the largest forest fragments of the eastern and western parts of the Cantabrian range (Robles et al. 2006). The estimated current population is around 500 adult birds, which has led to consider this subspecies as endangered according to the IUCN criteria (Storch et al. 2006). *T. u. cantabricus* is an ESU (Evolutionary Significant Unit), part of a Capercaillie southern lineage (Duriez et al. 2007; Rodríguez-Muñoz et al. 2007; Bajc et al. 2011). This genetic divergence is probably related to the glacial refugia character of the Cantabrian range and makes Cantabrian Capercaillie a genetically valuable population to be locally conserved (Rodríguez-Muñoz et al. 2007).

Habitat fragmentation is broadly considered as the main cause of the Cantabrian Capercaillie decline (Obeso & Bañuelos 2003; Suárez-Seoane & García-Rovés 2004). The Cantabrian landscape has been modified by humans for at least two thousand years ago (Sobrino et al. 1997; Ezquerra and Rey 2011). Human activities such as arson fires, opening tracks and open mines exploitation are some of the main causes of habitat destruction and fragmentation. For instance, the remaining occupied leks of the Cantabrian Capercaillie in a nature reserve (i.e. Integral Natural Reserve of Muniellos, Asturias, NW Spain) were those with less human disturbances, sited far from roads, paths, hunting sites, houses and burnt areas (Suárez-Seoane and García-Rovés 2003). Overall, a general consensus exists that any further habitat destruction or fragmentation of the already fragmented Cantabrian forests may be seriously detrimental for the Capercaillie (Suárez-Seoane and García-Rovés 2003; Quevedo et al. 2006a; Quevedo et al. 2006b).

The southernmost Cantabrian Capercaillie population inhabits Pyrenean Oak *Quercus pyrenaica* Mediterranean forests (hereafter Mediterranean oak forest) (Fig. 1). This Capercaillie population remained unnoticed until recently (1998), however it is not likely

to be a recent colonization (González et al. submitted). In 2009 breeding season, a minimum of 14 cocks were censused at leks in this habitat (González et al. 2010), and field surveys looking for moulted feathers gave an estimate of 40 adult birds during 2010 moulting season (own unpublished data). These Capercaillie dwell well in Mediterranean forests by strongly selecting and feeding on Pyrenean oaks and may constitute 10% of the total population of the subspecies (González et al. 2012).

In this particularly southern location, arson fires have been a management tool during centuries to convert forest into grasslands for livestock use. This management practice was favoured by the Mediterranean climate of this area, which shows a two-month period of drought during the summer (Luis-Calabuig et al. 2000; del Rio et al. 2007). These recurrent illegal fires are much more common than wild fires and seem to be the main disturbances to this Mediterranean oak forest ecosystem. This traditional use has been partially abandoned in the last few decades after the decrease in the rural population (Calvo et al. 1999; Rada et al. 2009).

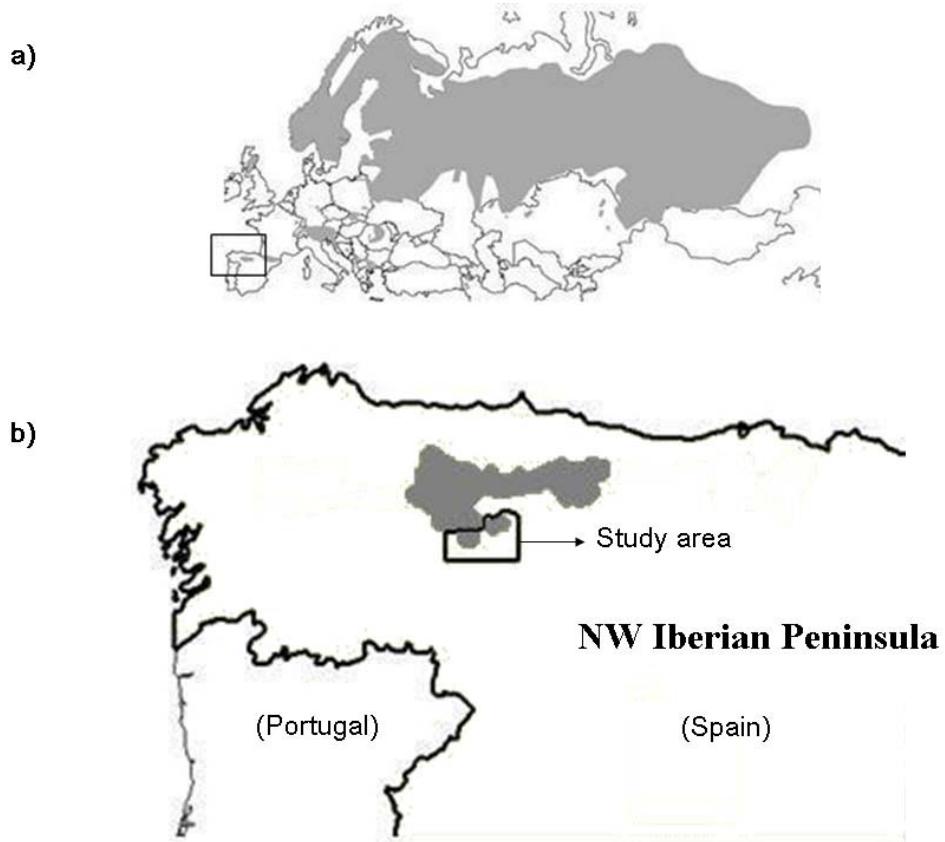
Many endangered species persist in the periphery of their historical distribution in remote areas less disturbed by humans (i.e. mountain ranges, Channel and Lomolino 2000a, b; Towns and Daugherty 1994; Naves et al. 2003). Peripheral populations in low latitude margins of the species range frequently cope naturally with distinct environmental conditions than those in the core which make them relevant to conservation (Lawton 1993; Hampe & Petit 2005). In this context, the Cantabrian Capercaillie is to be protected throughout its entire distribution range according to the subspecies regional Recovery Plan (*Plan de Recuperación del Urogallo Cantábrico en Castilla y León*, Decreto 4/2009). However, the peripheral Mediterranean Capercaillie habitat remains mostly unprotected (under no protection figure), and thus likely exposed to anthropogenic activities not allowed in protected areas.

## Methods

### *Study area*

The study was conducted in the only Mediterranean area known to be occupied by Capercaillie (González et al 2010). The area covers approximately 1500km<sup>2</sup> and is located below the putative line separating two bio-geographical regions (Eurosiberian to the north and Mediterranean to the south). The landscape is slightly mountainous with elevations ranging from 800 to 1700m a.s.l. Climate is temperate with supramediterranean thermotype (winter mean temperature -4°C, summer mean temperature 9°C) and subhumid ombrotype (precipitation: 866-1100mm year<sup>-1</sup>). The forested landscape is divided in two main classes: native fragmented Mediterranean oak forest (~20% of the total study area) intermingled with Scots pine *Pinus sylvestris* plantations younger than 50 years old (~8% of the total study area). The remaining natural landscape is composed of heather *Erica australis* and brooms *Genista* sp., shrublands, meadows, and riparian lowland forest (*Populus* sp., *Fraxinus excelsior* and *Alnus glutinosa*). The forest understory cover is mainly dominated by heath *Erica arborea* and broom *Cytisus scoparius* while bilberry *Vaccinium myrtillus* is nearly absent (<0.5% of the forest ground cover, see González et al. 2010).

The study area mostly corresponds with public hunting lands without any protection figure (Pollo 2001; Pollo et al. 2004). Only a small surface (<10%) in the northern part is within the *Natura 2000* (i.e. Important Bird Area of Sierras de Gistreo y Coto, SEO-Birdlife 2011, Fig. 2).



**Figure 1:** a) Global Capercaillie distribution range (*in grey*, Storch 2006); b) Cantabrian Capercaillie distribution in 2005 (*in grey*, Storch et al. 2007) and location of the study area

#### *Presence/absence data*

We constructed a digital forest map with the available habitat for the Capercaillie. According to the dominant tree species, two types of habitat were considered as available habitat, namely Mediterranean oak forest and Scots pine plantation (see González et al 2012). Accordingly, we defined a forest fragment as a patch of the same forest type surrounded by other habitat or forest type (García et al. 2005). The forest map was created from the most recent national forest inventory (MARM 2009) using ARCGIS 9.3 (ESRI 2010). This information was validated with geo-referenced aerial

photographs (0.25m pixel resolution, PNOA 2008) and with field observations at the time of the study.

We divided the forest fragments in two categories: with and without detected Capercaillie presence. This was based on data collected from 2002 to 2009 using two sources: field surveys and radio-tracking. Field surveys were based on questionnaires and reports from forest wardens and hunters who said to have seen any sign of Capercaillie presence (i.e. individuals, droppings, feathers footprints). An experienced observer validated these data through field surveys consisting of a 3-4 hour systematic zig-zag walk in the fragment looking for Capercaillie presence signs. Fragments with likely Capercaillie presence (i.e. according to questionnaires and reports) were surveyed until the experienced observer found one Capercaillie sign unless. Those fragments were completely surveyed up to six times each 1-2 months without finding any presence sign.

To minimize a possible bias in the Capercaillie distribution drawn from this non-systematic sampling, data on presence signs of Capercaillie were pooled over all the study years (2002-2009). In addition, we also got data from four Cantabrian Capercaillie (two females and two males) trapped and radio-collared in the study area between 2000 and 2007 (Robles 2007). For more details, see González et al. (2012). We considered a fragment with Capercaillie presence when at least one presence sign (i.e. field surveys or radiotracking) was registered during the 2002-2009 period and without presence when no sign was observed in that period.

Finally, we linked the presence data and leks location (see González et al. 2010) to the digital forest map with the vegetation types where Capercaillie occurred: Mediterranean oak forest and Scots pine plantation, using ARCGIS 9.3 (ESRI 2010).

### *Threats*

#### 1. Fragment size and proximity

We used three variables to characterize major forest fragmentation: i) fragment size, ii) nearest neighbour distance, and iii) a proximity index. All variables were derived from ARC.GIS 9.3 (ESRI 2010) and V-LATE extension for ARC.GIS, a vectorial tool for quantitative analyses of landscape structure. The fragment size was the area (ha) of a single monospecific forest fragment. Nearest neighbour distance (NND) as the simplest connectivity measure was the minimum distance of a focal fragment to the next fragment where we detected Capercaillie presence (Moilanen and Nieminen 2002). The proximity index is a fragment-level measure of neighbourhood isolation that considers the size and proximity of all fragments whose edges are within a specified search radius of the focal fragment. This proximity index reflects the tendency of fragments to be relatively isolated from other forest fragments within a neighbourhood. In this case we specified a buffer of 5km-radius according to mean dispersal distances of Capercaillie in fragmented habitats (Bollmann et al. 2010). The index is computed as the sum, over all fragments of the corresponding fragment type whose edges are within the specified radius of the focal fragment, divided by the square of its distance from the focal fragment. The index is dimensionless (i.e., has no units) and therefore the absolute value of the index has little interpretive value; instead it is used as a comparative index. Higher values of the proximity index indicate lower fragmentation (McGarigal et al. 2002).

#### 2. Fires

In an attempt to eradicate human fires in the study area the local government (Consejería de Medio Ambiente of the Junta de Castilla y León) develops a policy (i.e. Plan 42) at the municipality level. This policy aims to increase local people

environmental education, forest management, fire prevention and extinction, and to comply with the current law (García 2002).

To analyze the risk of fires which could affect Capercaillie Mediterranean habitat, we used data on the location and frequency of forest fires between 2000 and 2009 (Consejería de Medio Ambiente of the Junta de Castilla y León, unpublished data). We built a vectorial layer of the study area for an index of fire history at municipality scale. This index accounted for fire frequency and time since fire for each municipality  $c$  with  $i = 1, \dots, n_c$  fires since January 2000. The value of the index of fire history ( $F_c$ ) is calculated as:

$$F_c = \sum_{i=1}^{n_c} \frac{1}{T_i}$$

$T_i$  is the time in years since the month of fire  $i$  until January 2009 and the sum is over all fires in municipality  $c$ . If there was no fire since January 2000, then  $F_c = 0$ . The index accounts for fire frequency and time since fire while assuming that the impact of each fire declines over time, and that the effect of successive fires is additive (Rhodes et al. 2006). According to the value of the index of fire history, we considered three local categories for relative risk of fire: low risk (1-10), medium risk (11-20), and high risk (>20). We also considered whether forest fragments were included within Plan 42 (see above) or not. Layer maps of Capercaillie presence and risk of fire were overlapped in ARC.GIS 9.3 (ESRI 2010).

### 3. Wind farms

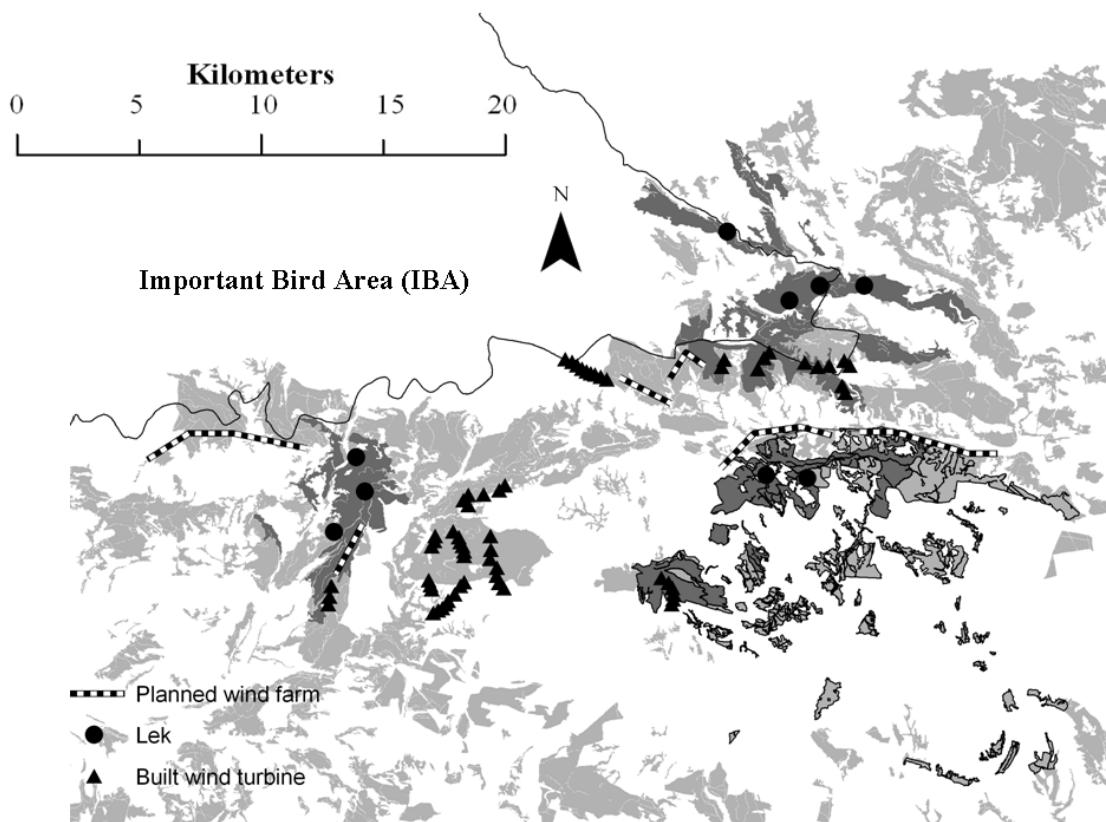
Data on the number of wind turbines and farms currently constructed in the study area, as well as those allowed to be installed in the next years, were obtained from field

surveys, from a private conservationist NGO data base Plataforma para la Defensa de la Cordillera Cantábrica (<http://www.cordilleracantabrica.org>) and from reviewing the Official Gazette of Castilla y León). Information on wind farms was geo-referenced on a digital map and overlapped with the Capercaillie presence layer. We measured the linear distances between leks and wind farms as the meters from the lek center to the nearest wind turbine (constructed or planned) using ARC.GIS 9.3 (ESRI 2010). We placed the lek centers by direct observations as the areas of highest display activity (Storch 1995a). Distances from lek to the nearest wind farm were compared for constructed and planned wind farms by means of a paired Wilcoxon test. Since conservation recommendations for Capercaillie suggest preserving habitat within 3-4km from the lek core (average Capercaillie home range in fragmented landscapes, Storch 1995a), we consider two buffer of 3 and 4Km around each lek to count the number of turbines within this distance and thus assessing the potential threaten to Capercaillie.

## Results

A total of 416km<sup>2</sup> of the study area (27.8%) were forested habitats (i.e. Mediterranean oak forests and pine plantations). Mediterranean oak forests covered 298km<sup>2</sup> (71.5% of the total forest surface) and Scots pine plantations covered the remaining 118km<sup>2</sup> (28.5%). Capercaillie presence was detected in 39% (162km<sup>2</sup>) of the forested habitat of which 23% (96km<sup>2</sup>) corresponded to Mediterranean oak forests and 16% (66km<sup>2</sup>) to pine plantations.

Only 18km<sup>2</sup> (13%) of the total forest surface was protected within an IBA (Important Bird Area; *Natura 2000* network). Three of the nine leks located in the study area are within the IBA; the remaining six leks are within public hunting lands without any specific protection (see Fig. 2).



**Figure 2:** Map of the study area. The *line* in the upper left corner corresponds to the limit of the Important Bird Area (IBA); *light grey polygons* represent forested fragments where Capercaillie signs were not detected whereas *dark grey* are forests with Capercaillie presence; *forest fragments surrounded by a black line* are those that show a high risk of fires; • correspond to leks, ▲ to wind turbines currently operating and ■■■■ to planned wind farms.

### 1. Fragments size and proximity

The mean forest fragment size was 128ha (10-3275; *median* = 33ha; SD: 325; n = 325 fragments). Capercaillie occurred in 29 forest fragments with a mean size of 468ha (18-3275; *median* = 218ha; SD ± 700; n = 30); whereas the mean size of fragments where no presence sign was found was 94ha (*range* 10-2498; *median* = 29ha; SD ± 234; n = 295; Table I). Fragments where Capercaillie presence was detected, were: i) significantly bigger, ii) closer to the nearest presence fragment and iii) showed a higher

proximity index than absence fragments (Wilcoxon tests:  $W = 1477$ ;  $P < 0.001$ ,  $W = 7724$ ;  $P < 0.001$ ,  $W = 2382$ ;  $P < 0.001$  respectively).

	Min	Max	Mean	SD	Median
<i>All fragments (n=325)</i>					
Size (ha)	10	3275	128	325	33
NND (m)	20	11822	2740	3058	1552
Proximity index	1.8	16335	633.9	1563.3	57.5
<i>Presence fragments (n=30)</i>					
Size (ha)	18	3275	468	700	218
NND (m)	20	5857	377	1120	20
Proximity index	6.6	4017.5	592.5	1.71.2	84.4
<i>No presence fragments (n=295)</i>					
Size (ha)	10	2498	94	234	29
NND (m)	20	11822	2983	3088	1873
Proximity index	1.7	7935.3	441.2	1086	54.6

**Table I.** Metrics on forest fragments with and without detected presence of Capercaillie. *Size of fragment (ha)*; *NND (m)* distance to the nearest neighbour forest fragment (m); *Proximity index* measure of neighbourhood isolation (see text for details)

## 2. Fires

Between 2000 and 2009, 183 forest fires burnt 4.9% of the forested surface (2033.6ha). Only three fires occurred in forest fragments with detected Capercaillie presence (two in Mediterranean oak fragments and one in Scots pine plantations) which burnt 387.2ha (Table II).

Municipality	Fires/year	Burnt total (ha)	Burnt (ha/year)	Medit. oak	Scots pine	Occupied	Plan 42	Fires risk
Bembibre	0.6	15.5	1.6	1	0	0	1	1.0
Castropodame	1.5	790.0	79.0	1	0	0	1	2.7
Folgoso de la Ribera	0.7	5.7	0.6	1	0	0	1	0.9
Igüeña	1.5	377.1	17.0	1	0	2	1	4.5
Noceda del Bierzo	0.7	37.3	3.7	1	0	0	1	3.8
Quintana del Castillo	3.7	77.7	7.8	1	0	0	0	25.2
Riello	3.8	418	41.8	1	0	0	1	7.8
Soto y Amio	2	119.5	12.0	1	0	0	0	9.8
Torre del Bierzo	2.8	179.03	17.9	1	0	0	1	9.8
Valdesamario	0.6	10.1	1.0	1	1	1	0	2.7
Villagatón	0.4	3.7	0.4	1	0	0	0	0.6

**Table II.** Summary of forest fires in the municipalities of the study area: *Fires/year*: average number of fires between 2002 and 2009; *Burnt total*: forest surface burnt in period 2002-2009; *Burnt (ha/year)* ha burnt each year (2002-2009); *Medit. oak / Scots pine*: 1- forest type burnt, 0-forest type not burnt; *Occupied* number of burnt fragments with Capercaillie presence; *Plan 42*: 1-municipality included in *Plan 42* policy, 0-not included; *Fire risk*: value of fire index (Rhodes et al. 2006).

7.3% of the forested surface (1.3% were oak forests and 6% pine plantations) with detected Capercaillie presence showed high risk of fire (Table III).

	TF (%)	FP (%)	FF (%)	FPF (%)
<i>Q. pyrenaica</i> oak	71.5	(32) 23	(7.2) 5.1	(1.8) 1.3
Scots pine plantation	28.5	(62.8) 18	(23) 6.5	(21) 6
Total forest	100.0	41.0	11.6	7.3

**Table III.** Forest type percentages related to fire risk and Capercaillie presence: *TF (%)* percentages of the total forest surface; *FP (%)* percentage of the forest surface with Capercaillie presence; *FF (%)* percentages of the forest surface with high risk of fires; *FPF (%)* percentage of forest surface with high risk of fires and Capercaillie presence; numbers in parentheses are those percentages of the surface of each forest type

### 3. Wind farms

Between 2009 and 2010 the number of wind farms increased from 0 to 5, and the number of constructed turbines increased from 0 to 65. Six further authorised wind farms will be constructed in the near future. Hence the number of turbines would rise to 127 in 11 wind farms (Table IV).

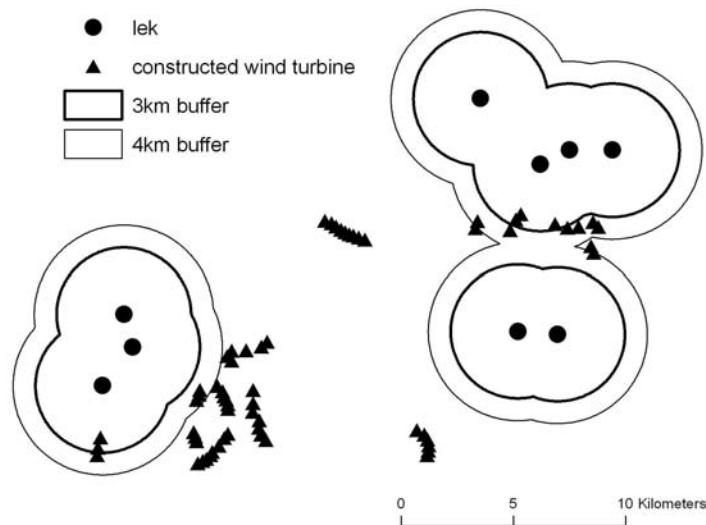
Wind farm site	State	Year of completion	Power capacity (MW)*	N of authorized turbines
<i>Valdesamario</i>	built	2010	26	13
<i>Peña del Gato</i>	built	2009	49.5	33
<i>La Espina</i>	built	2009	16.2	9
<i>Valdelacasa III</i>	built	2009	12	7
<i>Valdelín</i>	partly built	2009	24	12
<i>Anexo a Valdelín</i>	authorized	—	6	3
<i>San Feliz</i>	authorized**	—	32.4	36
<i>Quintana</i>	authorized	—	33.75	27
<i>Ampliación San Feliz</i>	solicited	—	7.2	4
<i>Ampliación Valdesamario</i>	solicited	—	5.4	3
<i>Ampliación La Espina</i>	solicited	—	23.4	13

\* (MW) megavatio

\*\* provisionally stopped by a judge *ad hoc*

**Table IV:** Summary of the wind farms in the study area

The distance between the known leks and the nearest constructed wind farm averaged  $2932\text{m} \pm 1569\text{m}$  (*mean*  $\pm$  *SD*, *range* = 350-5330). Once the planned wind farms will be constructed, this distance will be significantly reduced to  $2058\text{m} \pm 1694\text{m}$  (*mean*  $\pm$  *SD*, *range* = 250-5330; Paired Wilcoxon test,  $Z = -1.826$ ;  $P = 0.068$ ). Five wind turbines occur within 3km of a lek and 16 wind turbines occur within 4km. The remaining 49 ( $n = 65$ ) constructed wind turbines occur closer than 10km to the nearest lek (see Fig. 3).



**Figure 3:** leks and wind farms in the study area. • leks; ▲ constructed wind turbine; *narrow line*: 4km buffer around the leks; *thick line*: 3km buffer around the leks

## Discussion

In the study area only 27.8 % was covered by forest. This forest surface is similar to that found at the northern slope of the Cantabrian range (approx. 23%) that is considered as highly fragmented (García et al. 2005). We also found larger fragment sizes, smaller distances to the nearest presence fragment, and lower degree of isolation in forest fragments where Capercaillie was detected than those where do not. It suggests that Capercaillie survives in available forest fragments which are least fragmented. Any further habitat fragmentation of Capercaillie suitable habitat at the Mediterranean distribution may render detrimental for Capercaillie as seemingly occurs at the northern Cantabrian Capercaillie stronghold (Quevedo et al. 2006a).

Fire activity frequently reflects human intervention rather than underlying natural processes in anthropogenic landscapes (Rhodes et al. 2006). In the Mediterranean forests of the Cantabrian range fires are one of the main drivers of forest fragmentation (Luis-Calabuig et al. 2000). They increase forest fragmentation due to the formation of

gaps that decrease the total interior habitat and increase the boundary length (García et al. 2005). Moreover, after a fire in Pyrenean oak forest there is a significant decrease in its cover and an increase in the shrub cover (Calvo et al. 1999). The policy Plan 42 is established in 65% (n=7) of the municipalities and all of them showed low risk of fires. Between 2000 and 2009, fires burnt 8.9% of the total forested surface in the study area from which 387.2ha (2.4%) were habitat with Capercaillie presence. In general, the densities of oportunistic animal species typical of open habitats increase after fires (Rollán and Real 2010). However, fires may be detrimental to specialist forest species like Cantabrian Capercaillie as they increase forest fragmentation and shrub cover. Then, any further habitat loss or degradation in this highly fragmented landscape should be avoided. We recommend extending the Plan 42 to any municipality with high risk of fires.

Another major reason of habitat fragmentation and degradation are linear infrastructures (Braunisch and Suchant 2007). Among these, wind farms are widely associated with habitat destruction and fragmentation derived from the infrastructures, roads, and tracks as well as disturbances and deaths by collision in birds (Langston and Pullan 2003; Lucas et al. 2007; Bright et al. 2008). More specifically, wind farms and its associated infrastructures (i.e. paths, roads and electric lines) constitute barriers to movement in grouse and galliforms (Devereux et al. 2008; Pearce-Higgins et al. 2009; Pruett et al. 2009) and may lead to avoidance behaviours in Capercaillie (Summers et al. 2007; Thiel et al. 2008). For instance, we observed one tagged hen abandoning the nesting site coinciding with a bulldozer working <500m far from the nest (González and Ena 2011). In the study area wind farms are rapidly being constructed (APECYL 2010); currently 18 wind turbines are within 4km from three leks (Fig. 3). In alpine fragmented landscapes, a 4km buffer around leks is recommended to be protected from human disturbances for Capercaillie conservation (Storch 1995a). Thus, these three leks may be disturbed by the proximity of wind turbines.

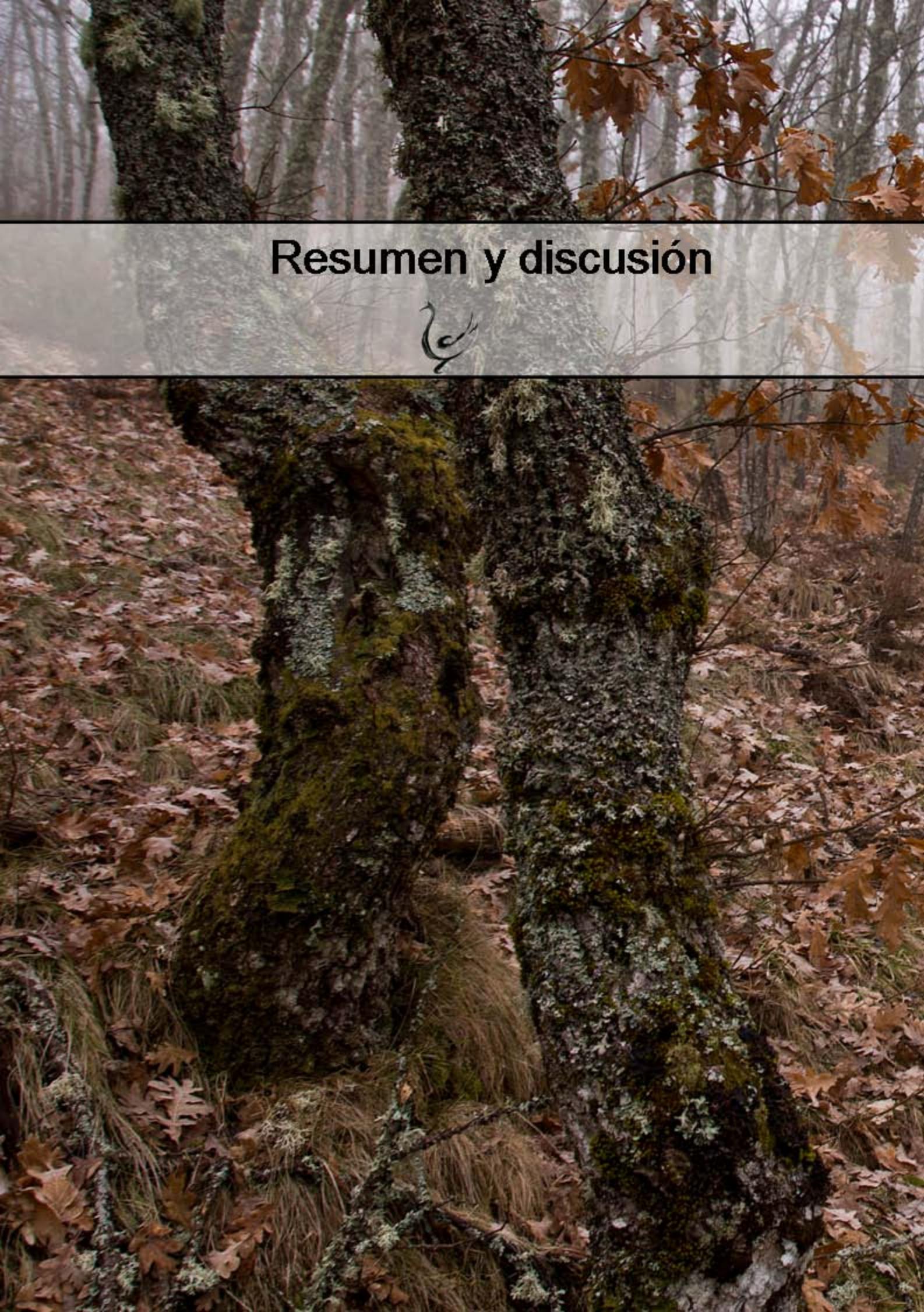
### *Design of nature reserves and the Cantabrian Capercaillie conservation*

Many populations of endangered species persisting in the periphery of their historical distribution are frequently apart from conservation measures (Channel & Lomolino 2000a, b; Hampe and Petit 2005). The establishment of protected areas involves more restrictive policies which limit large infrastructures (i.e. roads and wind farms) and reduce the incidence of some so-called “traditional” management practices, such as burning and hunting.

The current reserve network (i.e. *Natura 2000* sites) in the Cantabrian range includes the core range of the Cantabrian Capercaillie but not its Mediterranean distribution (Gil and Torre 2007; Sundseth and Creed 2008; Decreto 4/2009). Consequently, in the study area, large infrastructures (i.e. wind farms) are allowed and traditional practices (i.e. burning and hunting) are little controlled. In order to avoid more habitat fragmentation and intrusive human disturbances to this Capercaillie habitat, the first priority should be to integrate the study area within *Natura 2000* (Decreto 4/2009).

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# Resumen y discusión



### Resumen y discusión

Las últimas poblaciones de especies amenazadas se encuentran frecuentemente en hábitats periféricos, fuera del rango central de distribución, de modo que estos hábitats periféricos diferentes al central a menudo constituyen una oportunidad para la conservación de especies amenazadas (Lesica and Allendorf 1995; Furlow and Armijo-Prewitt 1995). Especialmente los lugares periféricos en latitudes bajas o en retaguardia, debido a su aislamiento, menor perturbación humana y mayor estabilidad climática, suelen albergar poblaciones con características ecológicas y genéticas diferentes a las del conjunto de la especie y son por tanto importantes para la conservación de la biodiversidad (Channell y Lomolino 2000a, b; Hampe y Petit 2005). Un ejemplo de la importancia de las poblaciones en retaguardia son los Urogallos del área de estudio de esta Tesis. A pesar de que su contribución numérica al total de la población de la especie no sea significativa, sí suponen una importante aportación al acervo ecológico de la especie.

En melojares mediterráneos del sur de la cordillera Cantábrica describimos una población de Urogallos distribuidos en nueve cantaderos. En la primavera de 2006 ocho de los nueve cantaderos estuvieron ocupados por algún Urogallo, mientras que en los años posteriores permanecieron ocupados siete de los nueve cantaderos. En la primavera de 2009 se detectó un mínimo de 14 machos. Este hábitat periférico y minoritario se encuentra actualmente en “la retaguardia” de la distribución de la especie tanto a nivel global (*T. urogallus*) como a nivel regional (*T. u. cantabricus*). Es probable que existan cantaderos aún desconocidos en el área de estudio (**Capítulo 1**).

La ecología del Urogallo en este hábitat periférico difiere en algunos aspectos a la del resto de su distribución mundial y cantábrica. Al norte de la cordillera Cantábrica los fragmentos de melojar son evitados por el Urogallo (Quevedo et al. 2006b), sin embargo, en el área de estudio los fragmentos de melojar de mayor tamaño (>500ha) son los más seleccionados por el Urogallo. Esta diferencia podría explicarse por el

mayor tamaño y abundancia de los fragmentos de melojar en el sur de la cordillera. Las abundantes plantaciones de pino también tienen importancia en la tendencia de ocupación del Urogallo Cantábrico.

La presencia del Urogallo está más relacionada con la superficie del bosque que con su composición específica (Røstad y Wegge 1987a; Suchant y Braunisch 2008; Obeso y Bañuelos 2003; Quevedo et al. 2006a, b). Esto sucede en el área de estudio ya que son los melojares más extensos los más importantes para la presencia del Urogallo. La selección de los fragmentos más grandes de melojar, la utilización de las plantaciones de pino más extensas y la evitación de los hábitats no forestales, sugieren una adaptación del Urogallo a las condiciones locales. Dos de los cuatro Urogallos radiomarcados nunca utilizaron los pinos a pesar de tenerlos disponibles.

El arándano en los bosques eurosiberianos de la cordillera Cantábrica (abedulares, hayedos y otros robledales) es una especie clave para el Urogallo, al igual que sucede en la mayoría de la distribución europea de *T. urogallus* (ver Rodríguez y Obeso 2000; Blanco-Fontao et al. 2010). También en esos bosques y exclusivamente en la cordillera Cantábrica, el acebo es parte importante de la dieta del Urogallo (Blanco-Fontao et al. 2010). Pero en los melojares mediterráneos ambas especies vegetales están casi ausentes, y el Urogallo consume aquí otros recursos disponibles, como acículas de pino especialmente en invierno, hojas, brotes y bellotas de melojo, helechos, herbáceas y pardalina en otras estaciones. La frecuencia de aparición de acículas de pino en los excrementos puede estar magnificada debido a su menor digestibilidad. La pardalina es descrita por vez primera como alimento del Urogallo. A lo largo del año el melojo constituye de manera constante un importante recurso alimenticio. La totalidad de cantaderos y nidos localizados estuvieron en melojar. Todo esto apoya la hipótesis del melojar mediterráneo como hábitat del Urogallo Cantábrico (**Capítulo 2**).

El 27.8% del área de estudio es superficie forestal. Este porcentaje es muy similar al que encontramos en el paisaje altamente fragmentado del norte de la cordillera

Cantábrica (23% en Asturias, ver García et al. 2005). Ya que la supervivencia del Urogallo Cantábrico depende principalmente de los bosques menos fragmentados, cualquier proceso que incremente el nivel de fragmentación existente puede resultar perjudicial para el Urogallo (Quevedo et al. 2006a). Para mantener la conectividad funcional y el flujo génico entre núcleos de Urogallos es vital que exista dispersión entre fragmentos forestales, de modo que las poblaciones pequeñas y aisladas tienen alto riesgo de extinción por efecto de la endogamia y deriva genética (Grimm y Storch 2000; Segelbacher et al. 2003, 2008; Graf et al. 2006). Entre los bosques mediterráneos y eurosiberianos estudiados, existe flujo génico que se produce principalmente de sur a norte. Los melojares, contrariamente a lo esperado, parecen actuar como fuente de Urogallos hacia los bosques eurosiberianos en los que se encuentra la población central de Urogallos Cantábricos, más estable y con mayor variabilidad genética. Los abedulares de Omaña Alta actúan como corredor, permitiendo este flujo. Probablemente Omaña Alta es la única zona con bosque suficiente para permitir la dispersión de los Urogallos del área de estudio, ya que al sur el paisaje se encuentra más deforestado y degradado por acción humana. La dirección de este flujo génico junto con los datos históricos, sugieren que la presencia del Urogallo Cantábrico en estos melojares mediterráneos no parece debida a una reciente recolonización. Probablemente el Urogallo ha permanecido en estos melojares mediterráneos, como remanente de una distribución más amplia, pero en tiempos recientes ha pasado desapercibido para el hombre (**Capítulo 3**).

Estos Urogallos pueden constituir el 10% de la población de la subespecie, aunque sólo el 5% del área de estudio está incluida en *Red Natura 2000*. La consecuencia más grave de esta desprotección, es la construcción de grandes infraestructuras. Ya existen cinco parques eólicos que suman 65 aerogeneradores, de los cuales 16 se ubican a menos de 4km del cantadero más cercano. Además, está previsto aumentar la cifra de parques eólicos en el área. Este desarrollo eólico, representa un riesgo de fragmentación para el hábitat del Urogallo. La elevada fragmentación de los bosques cantábricos puede ser causa indirecta del declive generalizado del Urogallo Cantábrico

(Quevedo et al. 2005), sin embargo, el área de estudio no está incluida en el Plan de Recuperación del Urogallo Cantábrico en Castilla y León. La construcción de grandes infraestructuras como los parques eólicos, no está permitida en áreas protegidas de *Red Natura 2000*. Por tanto, urge incluir esta área en *Red Natura 2000*. Esto repercutiría no sólo en la conservación del Urogallo Cantábrico, sino también en el control de actividades tradicionales como los incendios provocados, que aumentan la fragmentación y degradación de estos bosques ya altamente fragmentados. Estas medidas de protección ayudarían en el mantenimiento de la elevada biodiversidad de todos los bosques donde habita el Urogallo Cantábrico (**Capítulo 4**).



## Conclusiones

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### Conclusiones

- 1.- La población de Urogallo Cantábrico estudiada en esta Tesis ocupa melojares mediterráneos del sur de la cordillera Cantábrica y representa la distribución actual más meridional tanto de la subespecie Cantábrica, como de *Tetrao urogallus*.
- 2.- En estos melojares existen al menos nueve cantaderos. La población estimada de Urogallos es de 40 adultos y puede suponer el 10% de la metapoblación cantábrica.
- 3.- En el área de estudio el bosque de roble melojo fue el hábitat más importante para el Urogallo Cantábrico a lo largo de todo el año. El Urogallo prefiere los fragmentos de melojar de mayor tamaño ( $>500\text{ha}$ ) y evita todo tipo de fragmentos pequeños, así como los hábitats no forestales.
- 4.- De acuerdo al patrón de diferenciación ecológica entre poblaciones periféricas y centrales, existen diferencias entre la dieta de los Urogallos Cantábricos del área de estudio y de los bosques eurosiberianos. En nuestra área de estudio los recursos más consumidos a lo largo del año fueron hojas, bellotas y brotes de melojo, acículas de pino, helechos y herbáceas. El arándano, debido a su escasez en esta área, no constituye un recurso importante para el Urogallo. La pardalina *Halimium lasianthum* ssp. *alyssoides* se describe por vez primera como alimento para el Urogallo, y su consumo coincidió con épocas de escasez de recursos (otoño e invierno).
- 5.- No existe aislamiento genético entre los Urogallos Cantábricos de las zonas mediterránea y eurosiberiana. La evidencia genética sugiere que, al contrario de lo esperado, los melojares mediterráneos actúan como “fuente” y no como “sumidero” de Urogallos.
- 6.- Los bosques de Omaña Alta son clave en la conexión funcional entre los Urogallos del sur y los del norte. Boeza es la zona que corre mayor riesgo de extinción debido a su reducido flujo génico, y aislamiento genético y geográfico.

## Conclusiones

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7.- El hábitat forestal del Urogallo en el área de estudio está altamente fragmentado, ya que la superficie forestal fue sólo el 27.8% del área total. Al igual que sucede en los bosques eurosiberianos altamente fragmentados del norte de la cordillera Cantábrica, en los melojares mediterráneos la presencia del Urogallo depende de los bosques más extensos y menos fragmentados.

8.- La principal amenaza para el Urogallo en esta área es la fragmentación del hábitat y molestias producidas por la construcción y mantenimiento de parques eólicos. Los parques eólicos son producto de la desprotección generalizada del territorio.

9.- La medida más recomendable para la conservación del Urogallo en el área de estudio es la inclusión del área en *Red Natura 2000*.



Masa extensa y continua de melajar en el área de estudio

## Conclusiones

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Se proponen a la Administración algunas medidas urgentes de gestión y conservación derivadas de esta Tesis Doctoral y contempladas en el Plan de Recuperación del Urogallo en Castilla y León (Decreto 4/2009), con el fin de que sean aplicadas al área de estudio de esta Tesis:

- 1.- Proteger, mediante inclusión en *Red Natura 2000*, las masas forestales dentro de las cuales se encuentran los cantaderos conocidos y aquellas en las que se detectara cualquier otro cantadero.
- 2.- Desarrollar medidas de gestión y conservación del hábitat forestal formado por roble melojo, protegiendo de manera especial los fragmentos de melojar de más de 500ha, pero sin descuidar fragmentos más pequeños que puedan ser importantes en la dispersión de los Urogallos.
- 3.- Mantener el actual estado de conservación de los bosques de Omaña Alta de manera que siga existiendo conexión genética entre las poblaciones de Urogallo Cantábrico del sur y del norte, para que no se produzca la fragmentación por aislamiento de ambas poblaciones.
- 4.- Diseñar medidas de manejo enfocadas a la conservación de las plantaciones de pino existentes. Por ejemplo, realizar actuaciones forestales que aumenten la heterogeneidad de dichas plantaciones respetando siempre las épocas críticas para el Urogallo.
- 5.- Realizar un seguimiento del impacto de los parques eólicos instalados sobre la población de Urogallos mediante el seguimiento constante de los cantaderos.
- 6.- Continuar con el estudio de la diversidad genética del Urogallo en esta área mediante métodos no invasivos (p.ej. recogida de plumas y excrementos), con el fin de conocer el riesgo de extinción de la población por efecto de la deriva genética.

7.- Diseñar un seguimiento protocolizado y comparable en el tiempo de presencia y abundancia del Urogallo Cantábrico en toda su distribución actual, para conocer la tendencia real de la población a medio plazo. Para conseguirlo, es muy recomendable que los agentes medioambientales que trabajan dentro del área de distribución histórica de la especie colindante a la distribución actual, reciban formación básica en ecología de la especie y localización de indicios.



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Dos hembras de Urogallo Cantábrico en el borde de un melojar del área de estudio.

Autor: Fernando Gonzalo

## Agradecimientos

Podría en este apartado ser breve, objetivo, claro y conciso al estilo científico, pero llegado este punto voy a hacer un poco lo que me apetece. Podría dedicar la Tesis a todas aquellas personas que hicieron del trabajo algo tan interesante, y que saben bien quienes son. Podría dedicársela para ser muy correcto a aquel profesor del colegio que me metió la ciencia en la cabeza, y decir que todo esto es su culpa. Podría dedicársela a todos mis mentores pasados, presentes y futuros por compartir su tiempo, pasión y talento conmigo, y gritarles muy alto un enorme ¡gracias! Y así en cuatro líneas arreglar este apartado. Pero no, no lo voy a hacer de esa correcta manera, lo voy a hacer, como no podía ser menos en esta Tesis, un poco más al estilo Mediterráneo, porque yo, aunque en el límite, nací en el Mediterráneo...

Dicen las malas lenguas que dominar una ciencia es dominar su lenguaje, y hasta aquí me he limitado a eso, hablar en clave científica. Pero llegados a este punto quiero disfrutar escribiendo para que todos los que la leáis, recordéis que existe algo más allá de que *generally the Kernel method and choice of smoothing parameter method adopted in home-range data analysis will depend on the intended use of the UD density estimate*. Gracias a esa pasión que algunos sentimos por otros seres vivos, se puede conseguir acabar una Tesis de este tipo. Por eso paso a describir libremente el factor más importante de toda Tesis y que se merece algo más de cuatro líneas. El factor humano, que me ha concedido gratuitamente dones y favores sin merecerlos.

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Materialista puede parecer, pero esta Tesis habría sido imposible sin el SUZUKI JIMNY 5137FZX que mi padre me regaló al comienzo de toda esta historia, a sabiendas de que sin todo-terreno no había forma humana de hacer una Tesis que pretendiera conocer algo acerca del Urogallo Cantábrico. Reflejo real de lo que ha supuesto mi familia para llegar hasta aquí, sin su apoyo económico y emocional, ni sería ni estaría aquí. Mis padres, que tras haber recorrido sus caminos despacio me dejaron equivocarme solo e ir haciendo el mío. Esta Tesis no es más que el resultado de su saber hacer, de su saber vivir, que han hecho de mí lo que soy. Ellos hace

tiempo que se doctoraron en la vida y nunca dejarán de ser mi fuente de energía renovable. Todo es gracias a vosotros.



Pancho, Francisco J. Purroy Iraizoz, catedrático de Zoología, “el profe de los pájaros” o como sea que te conozcan, has sido para mí la más completa persona que he conocido en mi periplo doctoral. A tu lado viví el suceso más extraordinario de toda la Tesis. Nuestro secreto de aquella “magna mañana” de campo en Omaña, quedará grabado a fuego en nuestros corazones. Gracias amigo. No olvidaré los dos “Burros amenazados” que dedicaste a los Gallos de esta Tesis (*Urogallo* y *Urogallos de Omaña*) y de los que más tarde Pedro García-Trapiello se haría eco en su impecable columna “Cornada de lobo” bajo el título *Caput, Urogallo*. Este último y Julio Llamazares, pusieron gallardía en esta Tesis con los mejores prólogos literarios a los

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Y ahora, ya que en agradecimientos se nos permite liberar el alma, algo que tanto necesitamos algunos, tengo que dedicar estas líneas a las tremendas juergas vividas en Laciana (merecedora de un capítulo de esta Tesis, al igual que lo aparecido en prensa durante estos años mencionando a Urogallos y eólicos). Andrés y Óscar, los mineros (pre-jubilados) que más me enseñaron de los Gallos patsuezos, nunca podré olvidar mi primer Gallo cantando en Currietsus aquella mañana de perros de Mayo de 2004, con frío y nieve, Andrés inmóvil caído en la nieve, Vero y Bea heladas tiritando y castañeteando los dientes, Diego sin acabar de creérselo, y yo narcotizado por un espectro de Urogallo entre la niebla clavado en mis ojos y su canto haciéndose un hueco (tamaño de cráter volcánico) eterno en la memoria sonora de mi cerebro.

Tras aquella “mi primera vez” otras muchas se han sucedido desde entonces con los mejores compañeros para semejante evento, los patsuezos: Andrés, Óscar, Vero, Michel, Dani, Pedro, Susana y las Anas que me hicieron y seguirán haciéndome sentir como en casa siempre que me escape a aquellas tierras mineras, o cualquier otro lugar del mundo donde haya raíces tsacianiegas. La poderosa mente humana, que sabe bien que para enfrentarse al futuro hay que olvidar lo malo del pasado y recordar sólo lo bueno, siempre asociará mi tiempo de Tesis a las noches en El Castro y las farras en el pub de Palacios (del Sil), a una guitarra, alguna braña (cualquiera de las seis que tiene Palacios...) y un amanecer en un cantadero con místico nombre, como puede ser, por ejemplo, Trasmundo, Braña Ronda o la Chomba. En cuanto pueda me escapo a veros. Gracias a todos los del Valle. A tus padres Vero, con un afecto especial, y una mención en honor a tu abuela Maruxa por haber tenido el honor de conocerla, disfrutarla en tu mesa, que esté donde esté dejó en vosotros mucho del buen saber popular que se fue con ella.

Y que aquí quede la poesía “El Faisán” que vuestra vecina y paisana Eva Fernández González (Poesía completa 1980-1991) dedicó a la más admirada ave de vuestros bosques:

Gatsu, faisán, urogatsu,  
nos rebotsales t’alcuentras,  
mátante al amanecere,  
cuandu rondas a la fema

Sos el ave mas guapina  
que vive nas nuesas sierras,  
¡cómo cantas a la pita  
con celu na primavera!

Gallu cantor ya formosu,  
dame muita muita pena  
que quixándote d’amores  
tiros tua vida rompieran.

En trabajos como el que esta Tesis lleva implícito, los guardas (agentes medioambientales) son una pieza clave. Te van abriendo sus conocimientos de campo a medida que van confiando más en ti. Entre esa esquiva fauna se encuentran los guardas de zonas urogalleras como Ramón Balaguer, Álvaro Ordiz, Jose Manuel Castro y Fernando Gonzalo a los que tengo que agradecer el mimo con el protegen los últimos reductos del Gallo Cantábrico contra el afán constructor-destructor de empresas que se autodenominan verdes, ecológicas, y que manipulan la información para que los ciudadanos creamos que respetan el medio ambiente. Cuando en verdad estas empresas no son siquiera capaces de interpretar el significado de las palabras con las que se autodefinen. Señores guardas, aunque vuestro trabajo no siempre haya tenido los efectos deseados y muchas veces fuera ignorado por las altas cúpulas que

dirigen la Administración para la que trabajáis, vuestro trabajo es la pieza más importante en la conservación directa de nuestros montes. Por eso, enhorabuena. Os deseo continuidad en vuestra manera de trabajar. Habéis creado escuela.

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Mis amigos de toda mi vida, Luna y Andrés, Andrés y Luna, secretario y empresario, funcionario e ingeniero, torero y veterinario, constructor y doctor, compartir momentos con vosotros (aunque cada vez más esporádicamente), los buenos y los malos, me hace recordar lo que soy y de donde vengo, me dan esa tranquilidad de sentirse como en casa, como en la infancia, cuando sólo éramos felices. Nunca perderemos esos momentos, nunca dejaremos de sentirnos como en el colegio, nunca dejaremos de vernos, nunca dejaremos de prepararlas gordísimas, nunca dejaremos de ser amigos.

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Aquí empieza todo

