universidad de león

Departamento de Biodiversidad
y Gestión Ambiental

PATRONES ESPACIO-TEMPORALES DE LA MIGRACIÓN DE AVES PLANEADORAS EN EL ESTRECHO DE GIBRALTAR

SPATIAL AND TEMPORAL PATTERNS OF SOARING BIRDS MIGRATION THROUGH THE STRAITS OF GIBRALTAR

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Tesis Doctoral

León, 2015

UNIVERSIDAD DE LEÓN
FACULTAD DE CIENCIAS BIOLÓGICAS Y AMBIENTALES
DEPARTAMENTO DE BIODIVERSIDAD Y GESTIÓN AMBIENTAL

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Memoria presentada por el licenciado **Alejandro Onrubia Baticón** para optar al grado de Doctor en Biología por la Universidad de León, dirigida por el Doctor Jose Luís Tellería Jorge, de la Universidad Complutense de Madrid, y por el Doctor Francisco José Purroy Iraizoz, de la Universidad de León.

2015

El doctorando
Alejandro Onrubia Baticón

Vº Bº del director	*Vº Bº del director*
Jose Luis Tellería Jorge	Francisco José Purroy Iraizoz

A mi familia

“Dicen que para su evasión aprovechó una bandada de aves silvestres..."

El Principito

Antoine de Saint-Exupéry

Agradecimientos

Como me dicen mis colegas: “25 años para hacer una tesis, bufff, ya te vale”. Tienen razón, pero es que no siempre consigues hacer lo que quieres, sino lo que la vida te deja. Pero… nunca es tarde si la dicha es buena. Probablemente en 25 años he tenido tiempo de hacer varias tesis y ésta podía haber tenido diversas posibilidades: osos en la Cordillera Cantábrica, tendidos eléctricos en la Moraña abulense, lobos en los montes vascos, avutardas en las estepas del Ebro, comunidades de fauna del recoleto Valderejo o en los bosques de Izki, perdices pardillas en las montañas del sistema Ibérico… pero al final ha versado sobre aves migratorias y me alegro de que sea así. Y ha sido en el estrecho de Gibraltar y me alegro aún más.

El hecho de que haya terminado haciendo una tesis sobre migración de aves planeadoras en el Estrecho es absolutamente circunstancial y obedece a la confluencia de diversas personas a las que creo justo agradecer su labor.

En primer lugar me gustaría expresar mi más sincero agradecimiento y admiración a mis directores de tesis: a Pancho Purroy, uno de mis padres ornitológicos, y en especialmente a Jose Luis Tellería, que me animó y apoyó en todo momento y gracias a él esta tesis ve la luz.

En segundo lugar quiero agradecer a la Fundación Migres la oportunidad de haber podido trabajar con migración en un lugar privilegiado y en especial a su presidente, Miguel Ferrer, y a su directora, Eva Casado, por haber confiado en mí y haberme dado esta oportunidad. Millones de gracias!

Del elenco de personas con las que he compartido tareas en la fundación, quiero agradecer de todo corazón a su coordinadora científica, Beatriz Martín, por toda la ayuda que me ha prestado en este proceso y por las fructíferas discusiones sobre migración que han podido cristalizar en algunas de las publicaciones que nutren esta tesis (por cierto ya te paso estos días un script de R para agradecimientos en tesis). Igualmente, es de justicia reconocer que esta tesis no hubiera sido posible sin la labor de un fantástico equipo de personas competentes e ilusionadas, con las que he compartido cientos de jornadas de campo escudriñando el cielo y muchos días mágicos. Gracias a los “incombustibles” Andrés de la Cruz, Carlos Torralvo, Blanca Pérez y Miguel Gonzalez, con los que espero seguir compartiendo muchas otras levanteras en el futuro.

Asimismo quiero mostrar mi profundo agradecimiento a otros compañeros de fatigas, que incluyen algunos de los mejores ornitólogos que he conocido: Juan Ramírez, Javi Elorriaga, David Cuenca, Rafael Benjumea, Miguel Carrero, Francisco Zufiaur, así como a otros colegas de la fundación como Carmen Ruiz, Barbara Jimenez, Andrés Sánchez, Vanesa García, Ana Cruz, Soledad Hidalgo, Juan Manuel Salazar, Beatriz Yañez, Javier Fernández, Hector Perez, Sergio Tirado, Antonio Román Muñoz, Gonzalo Muñoz Arroyo, Luis Barrios, y unos cuantos becarios, colaboradores y ayudantes, excelentes compañeros todos ellos: Aleixandre Justo, Alberto Pacheco, María León, Verónica Cortés, Darío Delgado, Carmen Azahara, Julio Roldán, Julio Utrera, Juan Avila, Antonio Rodriguez, Marta Peris, Lucía Romera, Annika Aurbach, Karen Prisby, Alex Colorado. Este agradecimiento va también al otro lado del Atlántico, a los compañeros del Intermountain Bird Observatory de Idaho (USA), buenos aliados en momentos difíciles: Rob Miller y Karyn de Kramer, Micah Scholer, Martina Zuccini, Emmy Tyrrell, Jay Carlisle, Greg Kaltenecker, Marc Bechard. Y no puedo dejar pasar todo lo mucho que he aprendido de los expertos del comité científico de la fundación: Bruno Bruderer, Keith Bildstein, Ian Newton o Martin Wikelski.

Sin duda, todo esto tampoco habría sido posible sin el trabajo silencioso y abnegado de miles de voluntarios que han participado en los conteos y que merecen una mención especial. Es imposible incluir aquí a todos ellos, así que solo me queda que enviaros un bando de un millón de gracias para que lo conteis!!!

De igual modo, han sido muchos los colegas y amigos con los que he compartido observatorio, muchos de los cuales han echado un cable en los momentos en que hacía falta: muchas gracias a todos!. Entre ellos me gustaría destacar por el apoyo prestado al equipo vasco integrado por Pablo Gonzalez, Koldo Zaballa y María Martín, Marina Guerrero (ozu!), Jordi Gomez, Azaitz Unanue, Arantza Puente, Cristina Arcocha, Joseba del Villar o Iñaki Martínez; al otro sector norteño con Jose Luis y Gloria Robles, Máximo Sánchez-Cobo, Carlines Gutierrez Exposito, Javitxu Calzada, Alberto Fernández, Fernando Jubete, Jacinto Román o Eloy Revilla; al equipo de la Complu de Madrid, con Ivan de la Hera, Guillermo Fandos, Luis Santiago Cano, Javier Fernández, Elena Tena, Antón Rodríguez, Javier Perez-Tris, Carolina Remacha, German Garrote, Oscar Gordo y Rubén Moreno-Opo; a los colegas del Peñón, con Ernest Garcia, Mario Mosquera, Keith Bensusan, Clive Finlayson y John Cortes; o al grupo "mixto" que nutre la miscelánea de los observatorios, sin los cuales los conteos no hubieran sido lo mismo: Jose Luis Garzón, Edward Eyles, Yeray Seminario, Francis Martínez, Monica Florido, Diego Herrera, Stephen Daly, Carlos Noivo, Iratxe Gonzalez, Ines Montufo, Sonsoles Benito, Dirk Vanhoecke, Jean Jacques Guitard, Dick Forsman, Michele Panuccio, Ugo Mellone, Chris Mills, Fernando Goytre, Sita Hernández, Estefania Aleu, Judit Mateos, Daniel Robledo, Fran Espinosa, Andreas Meissner, Oscar Llamas, Ana de Osma, Alfredo Martínez, Itziar Lopez, Vicky Mogrovejo, Yolanda Corrales, Nieves Ruiz, Ruben Rodríguez, Jose Manuel Mendez, Rosa Rodríguez, Juan Vargas, Carlos David Santos, Julio Blas… y muchísimos otros. Muchas gracias a Chus Fernandez y Andy Patterson por su ayuda con las traducciones al inglés.

Gracias también a la Junta de Andalucía que promovió y financió el programa Migres y los campos de voluntariado correspondientes. La mayoría de datos de esta tesis están obtenidos en el programa Migres desarrollado por la Fundación Migres. Durante el periodo de desarrollo de esta tesis, el autor ha estado trabajando como técnico de la Fundación Migres.

Y qué decir del Estrecho… Aunque había visitado el estrecho por primera vez en 1992, hice mi primera visita para ver migración en 1996, con mis colegas Mikel Elosegi, Pako Zufiaur y Teresa Andrés, y bajo la batuta de Cristina Parkes y Cesar Sansegundo contamos las cigüeñas negras que allí pasaban por unos precarios observatorios de Algarrobo y Cazalla, con apenas dos bancos y un sombrajo pero acompañados de gente con mucha ilusión. Creo que fue un flechazo porque desde entonces no he faltado ningún año: participé en los campos de voluntariado del programa Migres organizados por la Sociedad Española de Ornitología entre 1997 y 2006 y dirigidos por Guillermo

Doval y Luis Barrios. Más tarde me incorporé como técnico a la Fundación Migres donde he estado trabajando con el seguimiento de la migración desde finales de 2006 hasta la actualidad. En todo este tiempo no he parado de disfrutar de un lugar privilegiado y de un fenómeno biológico espectacular y no he parado ni un momento de aprender. Y aquí he conocido a la particular “familia del Estrecho”: Manuel Fernández-Cruz y Paz, Mike y Celia, Cristina Parkes, Fernando Barrios, David Barros, David Rios, Pablo Ortega, Salvador Solis, Joaquín Mazón, Rachid El Kamlichi, la gente de GOES y Tumbabuey, del COCN o los bulliciosos de SEO-Málaga, y tantos otros.

Pero este apartado de agradecimiento no estaría completo sin una mención particular a las aves y en especial a las aves viajeras, a las que he dedicado décadas de estudio y admiración. Es sorprendente lo que se puede aprender de la vida y de uno mismo cuando se mira a través del espejo de sus plumas.

De ellas he aprendido la importancia de la fortuna, de estar en el momento justo en el momento preciso y que un buen programa genético puede facilitarte el camino pero que el aprendizaje y la experiencia lo hacen más fácil y llevadero. He aprendido que en ocasiones hay que dejarse llevar por el instinto y confiar en la suerte, ya que por mucho que uno se empeñe no va a controlar todas las circunstancias del camino. He aprendido que para hacer el viaje, uno puede dejarse arrastrar por la corriente o puede hacerlo por sus propios medios: eres entonces más independiente pero también es más costoso. He aprendido lo importante que es tener buenos guías a los que seguir o de los que aprender. He aprendido de la importancia de una buena preparación, de alimentarse bien y de descansar cuando toca, que la grasa no siempre es mala y que no hay que perder el tiempo donde no hay nada que rascar. He aprendido también que el primero que llega escoge el mejor sitio, pero que si esperas puede que te llegue tu turno. He aprendido que cuando las cosas se ponen feas tienes que buscar a los tuyos. He aprendido que no hay que dejar escapar el momento idóneo y los buenos vientos para partir pero que hay que saber escoger el momento adecuado cuando parar. He aprendido que hay que tener buenos compañeros de viaje… y que las apariencias engañan, que alguien extravagante puede ser un aliado y que detrás de una buena apariencia puede estar un predador o alguien que te robe la merienda. He aprendido que está bien la compañía pero que tu camino lo recorres solo tú. He aprendido que no hay que dejar de mirar al sol, la luna y las estrellas para no perder el rumbo. He aprendido que no hay que asustarse de montañas, mares y desiertos porque se pueden cruzar y habitualmente más allá está el paraíso. He aprendido que tan importante como la ida es el regreso, y que no hay dos caminos iguales ni siempre se recorre la misma ruta. He aprendido que el sentido de la vida es la propia vida, y esta es un eterno viaje. Y que todos, absolutamente todos, somos viajeros. Buen viaje!

INDICE

INTRODUCCIÓN GENERAL

Introducción

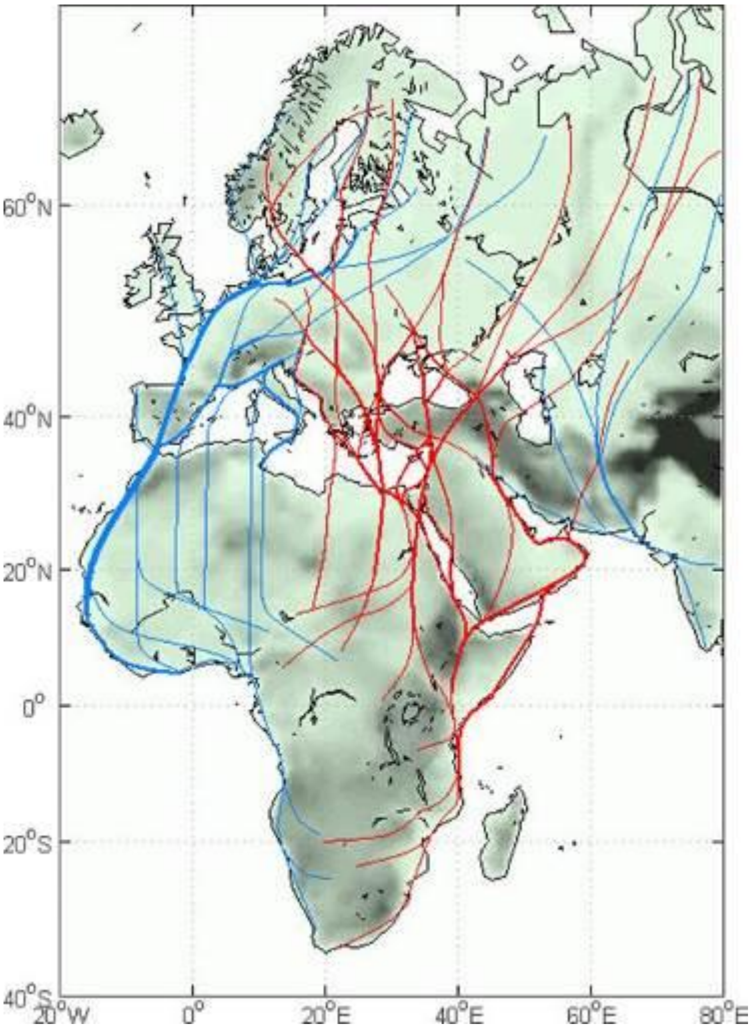
La migración como estrategia de supervivencia.

Se conoce como migración el desplazamiento periódico y estacional que realizan muchas especies y que lleva consigo un cambio de su residencia habitual (Bernis 1966, Alerstam 1990, Dingle 2014). Estos viajes son en realidad una estrategia que han desarrollado numerosos seres vivos para sobrevivir a la estacionalidad del clima y de los recursos que se produce en la Tierra (Alerstam 1990). Los individuos migradores aprovechan los pulsos de alimento y buenas condiciones que se producen alternativamente en distintos lugares de la Tierra, desplazándose de unos a otros. De esta manera, mejoran su supervivencia y su productividad, escapan de las limitaciones de las épocas desfavorables (invierno o estación seca según zonas) lo que les permite mantener unos niveles poblacionales superiores a los de sus equivalentes sedentarias (Lack 1968, Bildstein 2006, Newton, 2008).

La migración es un comportamiento ampliamente extendido entre las aves gracias a la extraordinaria capacidad de desplazamiento y eficiencia que supone el vuelo como forma de locomoción (Newton 2008, Dingle 2014). De hecho aproximadamente la mitad de las especies de aves del mundo realizan migraciones anuales (Newton 2008, Cox 2010) y el componente migrador puede constituir del 50 al 100% de la avifauna regional en latitudes medias y polares de la Tierra (Somveille *et al*. 2013). Así, anualmente millones de aves se desplazan entre las zonas de cría y las de “invernada” o “no-reproducción” en uno de los movimientos de seres vivos más masivo y espectacular que se produce en la Tierra. De hecho son algunos miembros de este grupo zoológico los que ostentan los más espectaculares récords de desplazamiento a escala mundial (Newton, 2008). La mayoría de estos desplazamientos migratorios siguen un eje norte-sur, porque éste es el gradiente de las temperaturas y la producción primaria en la Tierra (Alerstam 1990, Newton 2008).

Entre 2.100 y 5.000 millones de aves de 215 especies migran anualmente entre Europa y Africa en el denominado Sistema Migratorio Paleártico-Africano (Moreau 1972, Newton, 2008, Hahn *et al*. 2009) (Figura 1). Este sistema se encuentra condicionado por la confluencia de importantes barreras geográficas como la cordillera de los Alpes, el mar Mediterráneo o el desierto del Sahara, que suponen un fuerte impedimento para su cruce, con más de 2.000 km sin posibilidades de parada o repostaje. Esta circunstancia ha conformado dos grandes corredores que canalizan la migración rodeando estas barreras por el este ("ruta oriental") a través de Oriente Medio, y por el oeste ("ruta occidental") a través de la península Ibérica (Moreau 1972, Mead 1983, Berthold 2001, Elphick 2007, Newton, 2008). La "ruta oriental" recoge una porción migratoria mayor que la occidental tanto en número de especies como de individuos, si bien es frecuente que especies ampliamente distribuidas por Europa presenten poblaciones divididas que siguen una u otra ruta en función de su posición longitudinal (Mead 1983, Berthold 2001, Elphick 2007).

Figura 1.- *Mapa y principales rutas migratorias del Sistema Paleártico-Africano.*



Las aves migran hacia el norte en primavera y aprovechan las buenas condiciones de la época estival que se producen en Europa (elevada producción primaria, mayor número de horas de luz…) para la reproducción. Después de la cría las aves migran hacia el sur al final del verano y el otoño con destino a las zonas de invierno situadas en el entorno del Mediterráneo (migrantes presaharianos) o en el sur del Sahara (migrantes transaharianos), en función de que puedan cruzar o no la barrera del Sahara (Bernis 1966, Tellería 2004, Newton 2008).

En el entorno del Mediterráneo, las lluvias de otoño-invierno unidas a unas temperaturas relativamente suaves permiten disponer de unas condiciones ambientales favorables que combinan cierta actividad de muchos invertebrados con un pico de productividad vegetal con el reverdecimiento de los pastos y la importante producción de frutos de árboles y arbustos del monte mediterráneo, circunstancias que son aprovechadas por millones de aves durante el invierno (Tellería 1988 y 2004). Por su parte, las condiciones reinantes en la franja del Sahel, principal área de invernada al sur del Sahara, son también idóneas: la llegada de los migrantes coincide con el final de la época de lluvias encontrando así los paisajes de sabana verdes, inundados y repletos de comida. Aprovechan entonces las extraordinarias explosiones poblacionales que se dan en algunos grupos de invertebrados como langostas o termitas, hasta que el avance de la estación seca va agostando los campos y las condiciones se deterioran, momento en el que los migrantes retornan hacia el norte (Moreau 1972, Salewski & Jones 2006, Zwarts *et al* 2009). En términos generales los migradores transaharianos son los últimos en llegar a las zonas de cría del norte y los primeros en marcharse de éstas, mientras los presaharianos tienden a llegar antes y marcharse más tarde, si bien cada especie suele mostrar un calendario específico de migración que viene determinado por un complejo ajustes entre diversos condicionantes (Newton 2008, Newton *et al*. 2010, Pearce-Higgins & Green 2014).

Para el desarrollo del viaje el ave debe disponer de una notable capacidad física y unas elevadas dotes para la navegación. A lo largo de miles de años se han ido seleccionando adaptaciones de distinta índole, principalmente morfométricas, fisiológicas y comportamentales, para un adecuado ajuste del organismo a estos grandes desplazamientos. Así se han seleccionado estructuras alares y corporales ligeras pero resistentes, un sistema fisiológico sumamente eficiente y unas extraordinarias dotes para orientarse utilizando el campo magnético, el sol, las estrellas o la orografía (Alerstam 1990, Berthold 2001, Newton 2008, Wiltschko & Wiltschko 2009). Además, el comportamiento migrador tiene un fuerte control endógeno, genético, calibrado con el fotoperiodo, el cual determina el momento del viaje, su duración y dirección, entre otras cuestiones, y supone fuertes cambios fisiológicos en el individuo (Gwinner 1990, Berthold 1996, Pulido 2007, Newton 2008). No obstante, este comportamiento puede presentar cierta flexibilidad en su expresión en algunos grupos de migrantes de corto recorrido (migrantes facultativos) o beneficiarse de procesos de aprendizaje o culturales en las especies más longevas (Newton 2008).

A grandes rasgos las aves tienen dos modos principales de desplazarse por el aire: planeando o batiendo las alas, y a lo largo de la evolución de las diferentes especies se han ido seleccionando estructuras y sistemas corporales tendentes hacia uno u otro tipo de vuelo (Alerstam 1990, Berthold 2001, Newton 2008, Pennycuick 1975 y 2008). La aves planeadoras o “veleras”, como cigüeñas, rapaces o pelícanos, suelen disponer de extensas superficies alares y dependen de las corrientes de aire ascendentes que se forman sobre tierra para desplazarse sin apenas gasto energético. Estas corrientes se forman cuando el viento asciende obligado por el relieve del terreno (vientos de ladera) o cuando el aire próximo al suelo se calienta al mediodía por la acción del sol y asciende a gran altura (corrientes térmicas). Muchas aves de gran tamaño aprovechan estas corrientes ascendentes para elevarse a gran velocidad (normalmente 1-5 metros por segundo) en característicos vuelos circulares de remonte, hasta alcanzar cotas elevadas sobre el suelo, habitualmente entre 800 y 1.500 metros de altura (Kerlinger 1989, Newton 2008). Desde ahí, inician un suave deslizamiento o planeo que les permitirá desplazarse grandes distancias sin apenas mover un músculo. Este modo de desplazamiento es muy rentable desde el punto de vista energético (gastan hasta 10 veces menos energía que un ave que se desplace en vuelo batido) pero tiene algunas limitaciones: las aves dependen de la existencia de esas corrientes ascendentes y estas sólo se forman sobre tierra y además con condiciones meteorológicas concretas. Esto obliga a estas aves a volar solo con determinadas condiciones ambientales y siempre sobre tierra, evitando grandes desplazamientos sobre el agua, normalmente inferiores a los 20 kilómetros de distancia (Kerlinger 1989, Bildstein 2006, Newton 2008). Esta circunstancia es tan determinante que ha llegado a condicionar completamente las rutas migratorias de estas aves, obligándolas a rodear el mar Mediterráneo y concentrarse en corredores terrestres o pequeños estrechos marinos como el Bósforo (Turquía), Messina (Italia) o Gibraltar (España-Marruecos) (Zalles & Bildstein 2000, Bildstein 2006, Newton 2008). Asimismo, ha condicionado sus patrones horarios y así las aves planeadoras concentran su migración durante las horas centrales del día cuando hay corrientes térmicas disponibles, desplazándose entonces a velocidades de 30 a 60 km/h y recorriendo distancias de 200 a 400 km al día (Bildstein 2006, Newton 2008). De esta manera, emplean de 3 a 5 días en atravesar la península Ibérica y de 7 a 10 días en atravesar el desierto del Sahara. Dado que emplean un tipo de vuelo muy eficiente, no precisan acumular grandes cantidades de grasa, a diferencia de las especies de vuelo batido (Alerstam 1990, Bildstein 2006, Newton 2008).

Las aves de presa como bioindicadores en un escenario de cambio global.

La actividad humana está ejerciendo un fuerte impacto sobre la Tierra y sus repercusiones globales distan mucho de estar bien conocidas y evaluadas. La actual crisis ambiental ha motivado la puesta en marcha de iniciativas de ámbito internacional tendentes a frenar la creciente pérdida de biodiversidad (Myers *et al*. 2000). Sin embargo estamos lejos de conocer el impacto que la acción humana ejerce sobre cada una de los millones de especies que habitan la Tierra. Esto ha obligado a centrar los esfuerzos sobre grupos de organismos con un marcado carácter bioindicador, cuya respuesta refleje los efectos sobre los ecosistemas (Andelman & Fagan 2000, Hilty & Merenlender 2000, Rodrigues & Brooks 2007). A este respecto, las aves juegan un papel importante como centinelas ambientales: se trata de organismos bien conocidos y relativamente fáciles de estudiar, se encuentran distribuidos por prácticamente todos los ambientes de la Tierra, ocupan los niveles superiores de las pirámides tróficas, y sus poblaciones responden cumplidamente a los cambios en los ecosistemas (Koskimies 1989, Furness & Greenwood 1993).

Entre los distintos grupos de aves habitualmente empleados como indicadores ambientales destacan las aves de presa, por sus elevadas exigencias ecológicas y por su papel en procesos de bioacumulación de diferentes contaminantes, y las aves migratorias, que precisan de un buen estado de conservación de los múltiples hábitat que utilizan durante sus periplos migratorios (Bildstein 2001, Gregory *et al*. 2005, Sergio *et al*. 2005 y 2006). Estos grupos ejemplifican además los principales problemas de conservación a los que se enfrentan las aves y que incluyen la persecución directa (caza, veneno…), el impacto de infraestructuras viarias o de producción o distribución de energía, o las alteraciones en los hábitats de los que dependen por contaminación, cambio de usos del suelo, cambio climático, entre otros (Bildstein *et al*. 2000, Zalles & Bildstein 2000, Sergio *et al*. 2005, Bildstein 2006). Estos grupos incluyen además muchas especies de gran tamaño, socialmente muy populares y con un marcado carácter emblemático que han protagonizado multitud de campañas de sensibilización y numerosos programas de conservación desarrollados en las últimas décadas (Simberloff 1998, Bildstein 2006). Por estas razones son también objeto de diferentes programas de seguimiento de sus poblaciones bien mediante censos periódicos realizados durante la época de cría o en cuellos de botella durante sus migraciones (McCarty & Bildstein 2005, Hardy *et al*. 2006, Bird & Bildstein 2007, Vrezec *et al*. 2012). El estrecho de Gibraltar es uno de los lugares de concentración de aves migratorias más importantes del mundo, especialmente para aves planeadoras. El seguimiento a largo plazo de la migración en el estrecho a través de programas estandarizados, está aportando una valiosa información sobre estos centinelas alados, útil para evaluar el efecto real de la actividad humana en los ecosistemas.

Area de estudio- El estrecho de Gibraltar y las aves migratorias.

El estrecho de Gibraltar es un enclave singular donde se produce la única conexión entre el mar Mediterráneo y el océano Atlántico y donde además convergen los continentes de Europa y África. Geológicamente, el estrecho representa la fisura de las dos placas tectónicas Euroasiática y Africana, y geográficamente se encuentra entre el mar de Alborán y el golfo de Cádiz. Aquí las líneas de costa ibérica y africana convergen en forma de embudo hasta el frente del estrecho que abarca unos 60 km desde la línea Punta Europa (Gibraltar)-Desnarigado (Ceuta) hasta la línea cabo Espartel (Marruecos)-cabo Trafalgar (España). Su longitud es de 14,4 km en su parte más angosta entre punta de Oliveros (España) y punta Cires (Marruecos), y su profundidad varía entre unos 280 m en el Umbral de Camarinal hasta algo menos de 1.000 m a la altura de la bahía de Algeciras. Tanto la costa ibérica como la africana se encuentran festoneadas de amplias sierras con montañas que alcanzan hasta 800 metros (Tajo de las Escobas –España-, Jbel Musa –Marruecos-), que alternan con extensos valles en su sector occidental, como Santuario y Janda o la llanura de Tanger (Figura 2).

Figura 2.- *Estrecho de Gibraltar.*

En ambas orillas del estrecho se pueden reconocer tres grandes unidades naturales, según su relieve, naturaleza de sus materiales, clima, vegetación y uso del suelo. Las zonas de "litoral" y "campiña" comprenden la parte más occidental del territorio que coinciden con la comarca de la Janda (España) y el entorno de Tanger (Marruecos) y se caracterizan por relieves suaves que apenas superan los 150-250 metros de altura, con una clara influencia marítima en su clima y con una dedicación inminentemente agroganadera donde dominan los pastizales, campos de cultivo y dehesas. Por otra parte encontramos la “sierra” caracterizada por sucesivas alineaciones montañosas donde las fuertes pendientes y la naturaleza eminentemente silícea de sus suelos relegan estos terrenos al dominio forestal. En este caso, la cercanía al mar y la disposición norte-sur de sus cordilleras ofrece una primera barrera a los vientos cálidos y húmedos procedentes del Atlántico que al elevarse para salvar estas alineaciones montañosas se enfrían provocando elevados niveles pluviométricos que oscilan entre los 700 a los más de 2.000 (Finlayson 1992, Barros & Rios 2013).

En estas tres grandes unidades naturales pueden distinguirse una gran variedad de hábitats que incluyen bosques de quercíneas (alcornocales, quejigales, encinares, robledales), bosques de ribera, “canutos” y bosques de “niebla”, acebuchares, pinares, plantaciones leñosas, diversas formaciones de matorral (herrizas, lentiscares, palmitares, herguenales), pastizales, diversos cultivos herbáceos de secano o regadío, embalses, áreas de vegetación lacustre, playas, marismas, y roquedos y acantilados costeros. Más detalles sobre la geografía física y usos del suelo de la zona pueden consultarse en Bernis (1980), Tellería (1981), Finlayson (1992), Barros y Ríos (2013).

El clima en el estrecho está condicionado por la peculiar situación geográfica y su orografía. En general el clima es de tipo mediterráneo, caracterizado por veranos prolongados, secos y calurosos e inviernos suaves y húmedos, aunque muy atemperado por la proximidad del Atlántico. La zona se encuentra entre las isotermas 23-25ºC del mes de Julio y 11-12ºC del mes de Enero y las lluvias se concentran entre Octubre y Abril, con precipitaciones medias anuales entre 600 y 1.200 mm (Finlayson 1992). Pero si algo caracteriza la meteorología del estrecho es sin duda la notable frecuencia de fuertes vientos laterales de levante (este) o poniente (oeste), que soplan más del 85% de los días de verano y otoño (Bernis 1980). En Tarifa la velocidad mensual media del viento es de 22 km/h, con rachas superiores a 109 km/h registradas en todos los meses del año (Bernis 1980). En general, los vientos húmedos de levante están asociados con una extensión hacia el este del anticiclón de las Azores, dominante durante los meses de verano, mientras que entre Octubre y Abril el paso regular de las depresiones atlánticas produce predominancia de los vientos de poniente, habitualmente acompañados de las correspondientes lluvias asociadas al paso de los frentes fríos (Finlayson 1992, Palomares 2004). En general, el efecto embudo de la forma de la costa y las sierras litorales producen una aceleración local de los vientos, de manera que los de levante se aceleran significativamente hacia el oeste, y de manera análoga ocurre lo propio con los ponientes.

El Estrecho de Gibraltar está reconocido como uno de los puntos más importantes del mundo para la migración de las aves (Bernis 1980, Porter & Beaman 1985, Finlayson 1992, Zalles & Bildstein 2000) y constituye uno de los principales puntos de conexión en la vía migratoria del Paleártico Occidental entre los continentes europeo y africano. Esta situación geográfica, unida al efecto de los mencionados vientos predominantes del este (levante) y del oeste (poniente) hacen del Estrecho de Gibraltar uno de los “cuellos de botella” más importante para la migración en el Mediterráneo, siendo paso obligado para millones de aves terrestres en sus desplazamientos migratorios anuales. Particularmente relevante es la migración masiva de aves planeadoras (principalmente rapaces y cigüeñas) que evitan cruzar grandes extensiones de agua donde no se forman térmicas. Para estas aves, el estrecho de Gibraltar constituye un paso obligado y un punto de concentración anual (Bernis 1980, Zalles & Bildstein 2000, Newton 2008).

En el caso de los pequeños migrantes (Paseriformes y grupos afines), la migración entre Europa y África ocurre en un frente amplio, y consecuentemente no depende de aquellas áreas terrestres más cercanas entre los continentes para el cruce, como ocurre con las aves planeadoras. No obstante, existen notables evidencias de que el estrecho de Gibraltar recibe importantes concentraciones de pequeños migrantes durante ambos pasos, especialmente de migración diurna (fringílidos, abejarucos, hirundínidos, etc.) pero también nocturna (Tellería 1981, Hilgerloh 1989 y 1991, Onrubia *et al*. 2009).

Por otra parte, el estrecho de Gibraltar constituye también una de las zonas más importantes de Europa para la migración de las aves marinas y costeras, especialmente para aquellas que crían o invernan en el Mediterráneo. Este canal de sólo 14 km es la única conexión natural entre Mar Mediterráneo y el Océano Atlántico, por lo que constituye la principal vía de migración para las especies de aves marinas que utilizan el mar Mediterráneo en alguna fase de su ciclo vital (Tellería 1981, Programa Migres 2009). Todos estos flujos de migrantes convergen en una región que, debido a la escasa anchura de la franja de agua, constituye un paso obligado para las aves marinas. Además, dado que estas especies realizan la totalidad de sus desplazamientos por el mar, los efectivos que se concentran en el Estrecho abarcan la práctica totalidad de las poblaciones migratorias entre el Atlántico y el Mediterráneo (Tellería 1981).

Esta relevancia del estrecho de Gibraltar para las migraciones de aves ha convertido a ésta en una de las zonas de la península Ibérica con mayor tradición ornitológica. Fiel reflejo de ello es el notable bagaje de información disponible en forma de libros, artículos y notas que existen publicadas en la actualidad. El primer estudio exhaustivo sobre el Estrecho se debe a H.L. Irby quien en 1875 publicó su primera edición de "*Ornithology of the Strait of Gibraltar*". Desde entonces se han sucedido notables contribuciones procedentes tanto del lado marroquí como del lado ibérico, destacando por su profundidad y rigor los trabajos pioneros sobre aves planeadoras de Bernis (1980) y sobre aves no planeadoras de Tellería (1981), continuados con otras revisiones de carácter general (caso de Cortes *et al* 1980, Finlayson & Cortes 1987, Finlayson 1992) o monográficos (caso de Fernández-Cruz 2005). Cabe señalar también los trabajos sobre la migración primaveral de aves planeadoras publicados por Evans y Lathbury (1973) o el más el reciente artículo publicado por Bensusan *et al*. (2007), en el que se recogen datos de más de treinta años de seguimiento de rapaces a través de la Bahía de Algeciras y Gibraltar. En el campo de la migración de las aves marinas, destacan los trabajos desarrollados por científicos gibraltareños (Finlayson y Cortes 1984, Finlayson 1992) y españoles (Tellería 1980), así como los estudios de Hashmi (1993, 1996 y 2000). En cuanto a la migración de paseriformes y ordenes afines, señalar los estudios mediante radar en la migración otoñal (Hilgerloh 1989) y primaveral (Hilgerloh 1991), además del trabajo de Nisbet *et al*. (1961). Otras obras de carácter más divulgativo aunque no exentas de rigor son los trabajos de Barrios y Rios (2013).

Esta profusión de trabajos ha producido un notable conocimiento sobre la migración de aves por el estrecho, especialmente en lo relativo a la composición de especies, calendarios de paso, patrones temporales y espaciales de la migración, o el comportamiento en la zona, entre otros muchos aspectos. Sin embargo, existen notables lagunas de conocimiento, en especial en relación a la migración primaveral o el paso de algunas especies (cigüeña blanca, buitre leonado), sobre la entidad del paso y lo que supone en el contexto de las poblaciones europeas, los costes del cruce y el papel de la meteorología o los cambios recientes en el paso. En este contexto se plantea este proyecto de tesis que trata de completar la información disponible sobre un enclave tan relevante para las aves migratorias, y estudiar sus patrones espacio-temporales, con especial atención a las variaciones recientes acaecidos en un contexto de cambio global.

Metodología general- el programa Migres.

El Programa Migres constituye uno de los mayores esfuerzos sostenidos de seguimiento de aves migratorias que se realiza en Europa. Desde 1997, año en el que la Consejería de Medio Ambiente de la Junta de Andalucía lanza este proyecto, el Programa Migres ha trabajado intensamente con el doble objetivo de difundir entre la sociedad la importancia y la dimensión del fenómeno de la migración de aves en el Estrecho de Gibraltar y de obtener información biológica relevante sobre dicho fenómeno (Programa Migres 2009).

Durante estos años de trabajo la Consejería de Medio Ambiente ha contado con el apoyo y colaboración científica y técnica de distintas instituciones: la Sociedad Española de Ornitología (SEO/BirdLife) diseñó entre 1997 y 1999 el programa de seguimiento otoñal de aves planeadoras (SEO 2000, Barrios y Doval 2007) y la Universidad de Cádiz hizo lo propio con el seguimiento de aves marinas durante 2002 y 2003 (Perez-Hurtado *et al*. 2004). Desde finales de 2003 la Fundación Migres coordina y ejecuta los proyectos de seguimiento de aves planeadoras y marinas, y desde junio de 2006 trabaja en la ampliación del estudio de la migración de aves planeadoras al periodo primaveral (De la Cruz *et al*. 2011), y en el diseño del programa de seguimiento de la migración de pequeñas aves (paseriformes y afines) (Onrubia *et al*. 2008 y 2009). Entre 2007 y 2012, el programa Migres cuenta con programas de seguimiento de la migración prenupcial y postnupcial de aves planeadoras, marinas y paseriformes y grupos afines. Desde 1999 hasta 2015 se dispone de datos estandarizados de la migración postnupcial de aves planeadoras.

Desde un principio la intención del programa Migres fue desarrollar un proyecto de seguimiento a largo plazo de la migración en el estrecho de Gibraltar y para ello se priorizó que los diseños contemplaran protocolos metodológicos que aseguraran la consistencia de los datos durante series largas de años. Así, el seguimiento de cada grupo de aves dispone de un protocolo metodológico que optimiza los esfuerzos atendiendo a las características físicas y de comportamiento de las especies. Estos protocolos producen datos que debidamente analizados permiten obtener índices que nos informan sobre aspectos tales como la evolución de las poblaciones, cambios en los patrones migratorios o la influencia del calentamiento global en el comportamiento migratorio de las especies estudiadas (Dunn & Hussell 1995, Bildstein 2001, Bird & Bildstein 2007, Knudsen *et al* 2007, Rainio 2008, Moller *et al*. 2010, Pearce-Higgins & Green 2014). Por otra parte y con el objetivo de hacer que el Programa Migres fuera lo más participativo posible, se decidió dar pie a la colaboración activa de la sociedad a través de la participación de voluntariado, y actualmente constituye uno de los proyectos de participación ciudadana relacionados con avifauna más consolidados del territorio español.

En este contexto, el objetivo general del Programa Migres es el seguimiento a largo plazo de la migración de aves por el Estrecho de Gibraltar. Este seguimiento está encaminado a detectar: 1) Cambios en las poblaciones migratorias que puedan ser relacionados con las tendencias de estas especies a nivel global, como indicadores de su estado de conservación; 2) Cambios en los comportamientos migratorios de las especies; y 3) Desvelar el significado biológico de dichos cambios en relación con el escenario actual de cambio global.

Fundamentos metodológicos generales.

El seguimiento de la migración de aves en el estrecho de Gibraltar se basa en conteos sistemáticos en los que se utilizan protocolos estandarizados de esfuerzo constante. Los resultados obtenidos son por lo tanto comparables año tras año, gracias al control del esfuerzo de conteo y a la toma de datos objetivos, lo que permite obtener indicadores de la evolución de las poblaciones migratorias en el estrecho y detectar tendencias en los patrones de migración (Dunn & Hussell 1995, Bird & Bildstein 2007, Moller *et al*. 2010, Pearce-Higgins & Green 2014).

El diseño de los conteos está orientado a la obtención de índices anuales de abundancia para cada especie. Estos índices se construyen sobre la base de una muestra del total de aves que cruzan el estrecho de Gibraltar durante las migraciones. De manera general, los conteos no están diseñados para obtener cifras totales de individuos que cruzan el estrecho, objetivo inviable desde el punto de vista metodológico, aunque el tratamiento posterior de los datos podría permitir obtener estimaciones aproximativas para algunas especies.

El protocolo de “seguimiento de esfuerzo constante” tiene como finalidad ajustar el esfuerzo en cuanto número de días y horario de observación, número de observadores por puesto y número de puestos, así como controlar la toma de datos (Fuller & Mosher 1981y 1987, Dunn & Hussell 1995, Bird & Bildstein 2007). Así, el esfuerzo se ha planteado para que la temporada de conteo abarque el 95% del periodo de paso (“ventana temporal del 95%”), tanto del ciclo anual como del periodo diario de migración de las especies estudiadas, y que el número de observadores por puesto y el número de puestos utilizados esté regulado dentro de cada periodo migratorio y para cada grupo de especies (Barrios y Doval 2007, Programa Migres 2009). En cuanto a la toma de datos, las premisas básicas son: 1) Los observatorios son fijos dentro de cada periodo migratorio y para cada grupo de especies; 2) Cada observatorio trabaja aisladamente, obteniendo una muestra independiente del paso de aves de manera que los resultados obtenidos por cada observatorio no están influenciados por la presencia de otros; 3) La información que recogen los observadores no debe estar influida por los criterios personales de éstos. Los datos son el reflejo de un suceso claro, que no debe admitir posibles interpretaciones. De esta forma, cada observatorio obtiene una muestra independiente de datos objetivos. Con estos datos se construyen los índices de abundancia anuales. Estos índices de abundancia han de ser consistentes y estadísticamente robustos, lo que permitirá su comparación en series largas de años (Bird & Bildstein 2007).

El seguimiento de la migración de aves planeadoras

El seguimiento de la migración postnupcial de aves planeadoras en el Estrecho de Gibraltar se basa en los conteos sistemáticos de rapaces y cigüeñas en migración. El protocolo de “seguimiento de esfuerzo constante” consiste en censar diariamente durante un periodo estandarizado (25 de julio – 10 de octubre) desde dos observatorios de referencia –Cazalla y Algarrobo- todas las aves planeadoras en migración. Los conteos son llevados a cabo por grupos de dos observadores por observatorio, organizados y supervisados en todo momento por un tercer ornitólogo experto. Los tres observadores se organizan repartiendo el cielo es sectores definidos, de manera que cubran la totalidad del campo de visión. Regularmente, cada observador realiza un barrido de su sector de cielo, ayudado con los prismáticos, para detectar las aves o bandos visibles desde el observatorio. Una vez detectados los bandos o aves individuales, se procede a su conteo e identificación, contando siempre individuo a individuo, o en caso de bandos muy numerosos (ap. >500 aves), en grupos de 5 ó 10 individuos, evitando siempre realizar estimaciones menos exactas del tamaño de los bandos. El telescopio sólo se emplea para la identificación de especies dudosas. El coordinador del puesto supervisa y confirma las identificaciones y los conteos de los observadores. Cada observatorio trabaja de manera individualizada, sin comunicar la presencia de aves ni de bandos a otros observatorios, por lo que en cada observatorio se obtiene una muestra independiente de la migración diaria.

La información se recoge en agendas electrónicas personales (PDA) y en las fichas preparadas con este fin, lo cual agiliza el procesado y la actualización de los resultados de los conteos diarios. Los datos fundamentales recogidos son: fecha, hora, especie, número de aves, dirección de procedencia y dirección de destino, y las condiciones meteorológicas (dirección y velocidad del viento, cobertura de nubes) y de visibilidad reinantes en el Estrecho. En el observatorio de Cazalla, localizado en el sector más costero, se indica además aquellas aves o bandos que se observan iniciando el cruce del estrecho, esto es, se pierdan de vista cruzando hacia África. Cuando es posible se identifica el sexo y la edad de los individuos.

En algunos días con condiciones particulares las circunstancias de conteo son especialmente difíciles, bien porque el aflujo de aves que se acercan a la costa para cruzar es tal que se hace muy difícil controlarlas a todas, o bien porque el comportamiento de esos días hace que muchas aves no se decidan a cruzar y realicen movimientos de circuitaje que son difíciles de controlar. En estas circunstancias los observadores se organizan de forma que se asegure al menos la recolección de aquellos datos que contengan la información fundamental, con especial atención a los aspectos prioritarios en cada puesto.

Índices utilizados

El objetivo final es obtener índices de abundancia para cada especie, independientes para cada observatorio, que nos permitan mediante la repetición de la misma metodología año tras año, conocer la evolución de las poblaciones de aves que cruzan el Estrecho en sus migraciones. Estos índices no pretenden conocer la cifra global exacta de aves de cada especie que atraviesan el Estrecho. No obstante, la obtención de índices objetivos y representativos, a partir de métodos optimizados y repetitivos a lo largo de los años, debe permitir conocer las tendencias de estas poblaciones y sus patrones migratorios. Estos índices poblacionales son indicadores de los flujos migratorios de aves planeadoras en el Estrecho y su uso minimiza los posibles sesgos introducidos por la subjetividad del observador o por la replicación de los conteos.

Los índices empleados son: 1) Número de aves volando al sur.- se considera el número de aves contabilizadas que vuelan con alguna componente sur (S, SE o SW) en cada observatorio, con un vuelo dirigido característico de un comportamiento migratorio. 2) Número de aves en cruce.- este índice refleja el número de aves que inician el cruce desde la costa española, es decir, aquellas aves que volando con componente sur y un comportamiento claramente migratorio, se lanzan a cruzar el estrecho y se siguen con el telescopio hasta perderlas de vista.

Objetivos y estructura de la tesis

El objetivo fundamental de esta tesis es actualizar la información relativa a la migración de aves planeadoras por el estrecho de Gibraltar, uno de los lugares de concentración de aves migratorias más importantes del mundo, y describir sus patrones espacio-temporales.

A través del estrecho se canaliza el paso de la mayor parte de las poblaciones migratorias de cigüeñas y rapaces planeadoras de la ruta occidental del sistema migratorio Paleártico-Africano, entre las áreas de cría de Europa occidental y las áreas de invernada situadas en el norte de Africa (migrantes presaharianos) o al sur del Sahara (migrantes transaharianos). Es además un lugar con una larga tradición ornitológica y cuenta con numerosos trabajos enfocados a conocer la entidad del fenómeno migratorio. Entre estos destacan por su nivel de detalle los censos realizados en los años setenta del siglo pasado que cristalizan en diferentes publicaciones (Bernis 1980). Además, desde 1999 la zona cuenta con un programa de seguimiento anual ("programa Migres") que opera bajo protocolos estandarizados de esfuerzo constante. Estas circunstancias constituyen una excelente oportunidad para la comparación entre ambos trabajos en un contexto general de cambio global.

Los objetivos principales de la tesis son los siguientes:

1. Completar y actualizar la información relativa a la composición específica, magnitud y patrones espacio-temporales del paso migratorio prenupcial y postnupcial de las aves planeadoras por el estrecho de Gibraltar.
2. Valorar lo que significa el paso migratorio por el estrecho de Gibraltar en cuanto a entidad y tendencias de la poblaciones migratorias de aves planeadoras europeas.
3. Describir los cambios acaecidos tanto en la composición específica como en la entidad y fenología del paso migratorio postnupcial de aves planeadoras desde los años 1970 hasta la actualidad.
4. Explorar procesos que explican los cambios detectados en el paso por el estrecho de Gibraltar.

5. Evaluar el efecto de las condiciones meteorológicas locales y regionales sobre los conteos otoñales de aves planeadoras en el estrecho de Gibraltar.

La estructura de esta tesis se compone de una parte inicial, ya desarrollada, que consta de una introducción general, área de estudio y metodología general. En la **introducción general** se abordan aspectos básicos sobre la migración de las aves en general y sobre las aves planeadoras en particular con atención especial a su papel como bioindicadores o centinelas ambientales. En el apartado de **área de estudio** se presenta de manera global las características geográficas, bioclimáticas y naturales del área del estrecho de Gibraltar, con especial referencia a su relevante papel para la migración de las aves. En el apartado de **metodología general** se describen las bases y protocolos del seguimiento de aves planeadoras por el estrecho de Gibraltar (programa Migres), si bien la metodología específica empleada en los correspondientes capítulos se exponen ampliamente en los mismos.

El núcleo central de la tesis se desarrolla en once **capítulos** que abordan los objetivos expuestos anteriormente (Tabla 1). Cada capítulo toma la forma de un artículo científico, la mayoría ya publicados o aceptados para publicación, con sus correspondientes secciones de introducción, métodos, resultados y discusión. Le sigue un **resumen**-discusión general que aborda varias de las cuestiones tratadas en cada capítulo, y las **conclusiones generales** de la tesis.

***Tabla 1**.- Relación de los capítulos que integran la tesis y los objetivos tratados en cada uno.*

Capítulos	Objetivos
Capítulo 1.- Migración de rapaces forestales por el Estrecho de Gibraltar	1 2 3
Capítulo 2.- Magnitud y fenología de la migración de aves planeadoras por el estrecho de Gibraltar en primavera y otoño	1 2
Capítulo 3.- Cambios en la magnitud y composición del paso migratorio de aves planeadoras por el estrecho de Gibraltar: una comparativa entre 1976-2010	3
Capítulo 4.- Los censos de la migración otoñal como herramienta de seguimiento de las poblaciones de aves planeadoras de Europa continental. Actualización de las estimas de las tendencias poblacionales de rapaces migradoras europeas	2 3
Capítulo 5.- Efectos del cambio climático en el comportamiento migrador del busardo ratonero	3 4
Capítulo 6.- Presencia inusual de rapaces migradoras orientales en el Estrecho de Gibraltar	3
Capítulo 7.- Migración otoñal del águila pomerana en el estrecho de Gibraltar: accidental o regular?	3 4
Capítulo 8.- Movimientos primaverales del buitre moteado Gyps rueppellii por el estrecho de Gibraltar	3
Capítulo 9.- Variabilidad de los cambios en la fenología migratoria otoñal de las aves planeadoras en el sur de España	3
Capítulo 10.- Influencia de las condiciones meteorológicas locales y regionales sobre los conteos de migración postnupcial de aves planeadoras en el estrecho de Gibraltar, España	5

Los epítomes de los capítulos son los siguientes:

- Capítulo 1.- ***Migración de rapaces forestales por el Estrecho de Gibraltar***.

  El paso de aves rapaces por el estrecho de Gibraltar está dominado por especies que se reproducen en los bosques de Europa occidental. En este artículo se describen los patrones de paso de las rapaces forestales migratorias por el estrecho de Gibraltar, en cuanto a la entidad de su paso, sus patrones temporales (fenología de paso, patrón horario), sus procedencias y destinos, así como los cambios en los números y fechas acaecidos en décadas recientes.

- Capítulo 2.- ***Magnitud y fenología de la migración de aves planeadoras por el estrecho de Gibraltar en primavera y otoño***.

  En este estudio se actualiza y completa la información sobre la magnitud y fenología del paso de aves planeadoras por el estrecho de Gibraltar. Los censos realizados entre 2009 y 2012, con las correspondientes correcciones espaciales y temporales, permiten estimar el número de individuos en paso de las diferentes especies de aves planeadoras por el Estrecho. Esta información permite calcular la proporción de las poblaciones reproductoras europeas que utilizan este enclave durante sus migraciones y valorar la importancia del estrecho en el contexto migratorio paleártico-africano. Asimismo, los censos permiten caracterizar la fenología migratoria en cuanto a fechas medias y duración tanto del paso prenupcial como del postnupcial de las aves planeadoras, lo que permite además comparaciones con otros observatorios ornitológicos.

- Capítulo 3.- ***Cambios en la magnitud y composición del paso migratorio de aves planeadoras por el estrecho de Gibraltar: una comparativa entre 1976-2010***.

  En este trabajo se comparan los resultados de los censos de aves planeadoras realizados en tres momentos (1970, 1990, 2010) que implican un periodo de 35 años y se describen y discuten los principales cambios ocurridos en ese periodo en lo referente a la composición de especies y la magnitud del paso.

- Capítulo 4.- ***Los censos de la migración otoñal como herramienta de seguimiento de las poblaciones de aves planeadoras de Europa continental. Actualización de las estimas de las tendencias poblacionales de rapaces migratorias europeas***.

  Uno de los aspectos más relevantes del estrecho de Gibraltar es que concentra el paso de la mayor parte de aves planeadoras de Europa occidental, lo cual permite hacer un seguimiento de sus tendencias poblacionales con un esfuerzo relativamente reducido. Esta información es fundamental para conocer la evolución poblacional de especies de interés bioindicador. En este trabajo se exponen los resultados de 15 años de censos otoñales de la migración en el estrecho y se comparan con las tendencias obtenidas mediante otros protocolos centrados en el censo de las poblaciones nidificantes en Europa.

- Capítulo 5.- ***Efectos del cambio climático en el comportamiento migrador del busardo ratonero***.

  Los cambios en el paso por el estrecho de Gibraltar pueden reflejar cambios poblacionales pero también variaciones en los patrones migratorios que pueden estar teniendo lugar en un escenario de cambio global. En este caso se estudia en profundidad el caso del busardo ratonero (*Buteo buteo*), una rapaz que presenta poblaciones estables o en aumento en Europa pero que sin embargo muestra una marcada disminución en el paso por el Estrecho en los últimos 40 años. Se analizan las recuperaciones de ratoneros anillados en Europa desde 1950 hasta la actualidad para investigar si los ratoneros están cambiando sus patrones migratorios, en concreto sus distancias y direcciones de migración.

- Capítulo 6.- ***Presencia inusual de rapaces migratorias orientales en el estrecho de Gibraltar***. Capítulo 7.- ***Migración otoñal del águila pomerana en el estrecho de Gibraltar: accidental o regular?*** Capítulo

8.- ***Movimientos primaverales del buitre moteado Gyps rueppellii por el estrecho de Gibraltar***.

Uno de los cambios reseñables en el paso de aves planeadoras por el estrecho de Gibraltar es la incorporación de especies de migración oriental o de filiación africana que no se detectaban en los censos realizados hace 40 años. En estos tres capítulos se describen los patrones de paso de especies consideradas rarezas en Europa pero que tienen en la actualidad pasos regulares por el estrecho y que implican cambios recientes en sus rutas migratorias o nuevos procesos de colonización.

- Capítulo 9.- ***Variabilidad de los cambios en la fenología migratoria otoñal de las aves planeadoras en el sur de España***.

  Uno de los principales efectos del cambio climático sobre la migración de las aves se relaciona con las alteraciones que provoca en sus calendarios de paso. En este estudio se explora este aspecto comparando la fenología de paso de las aves planeadoras más comunes por el estrecho en tres horizontes temporales: 1970, 1990 y 2010.

- Capítulo 10.- ***Influencia de las condiciones meteorológicas locales y regionales sobre los conteos de migración postnupcial de aves planeadoras en el estrecho de Gibraltar, España***.

  Las condiciones meteorológicas condicionan sobremanera los movimientos migratorios de las aves pero también a sus posibilidades de detección en los observatorios de migración. La caracterización del calendario de paso de las diferentes especies suele presentar patrones en “dientes de sierra” de manera que los censos alternan jornadas de notable abundancia de aves (“picos”) con días de escasez (“valles”), y esto repercute en los parámetros que caracterizan la fenología de cada especie. En este sentido resulta fundamental comprender hasta qué punto esos “picos” y “valles” reflejan el número real de aves en tránsito o el número de aves que se pueden detectar por los observadores. En este trabajo se estudia el efecto de las condiciones meteorológicas a escala local o suprarregional sobre el número de aves que alcanzan y se mueven en el área del estrecho y sobre las posibilidades de que los observadores las detecten.

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CAPITULO 1. Migración de rapaces forestales por el Estrecho de Gibraltar.

Forest raptor migration over the Strait of Gibraltar

Este capítulo reproduce el texto del siguiente artículo:

Onrubia A., Muñoz G., Barrios L., De la Cruz A. & Muñoz A.R. 2011. Forest raptor migration over the Strait of Gibraltar. Pp: 288-297, en I.Zuberogoitia & J.E. Martínez (eds): *Ecology and Conservation of European Forest-Dwelling Raptors*. Diputación Foral de Bizkaia

Migración de rapaces forestales por el Estrecho de Gibraltar

Resumen

El estrecho de Gibraltar está considerado uno de los lugares de concentración de aves migratorias más importantes del mundo, especialmente de aves planeadoras. Este paso está dominado por especies de rapaces que se reproducen en los bosques de Europa occidental. En este artículo se analiza la migración visible de rapaces forestales a partir de los datos obtenidos en los conteos diarios realizados con protocolos de esfuerzo constante en dos observatorios principales entre 2007 y 2009 en el caso de la migración primaveral, y entre 1997 y 2009 en el caso de la migración posntupcial. Durante la migración prenupcial, los censos se realizaron entre el 1 de febrero y el 1 de junio. En el caso de la migración postnupcial, los censos se realizaron entre el 25 de julio y el 10 de octubre. En total unas 300.000 rapaces cruzan el estrecho de Gibraltar cada año, el 80% de las cuales son rapaces forestales: milanos negros, abejeros europeos, águilas calzadas y culebreras y gavilanes. El estrecho concentra el paso de la práctica totalidad de las poblaciones reproductoras de Europa occidental y los números evidencian un incremento generalizado en el paso, especialmente en la última década. La migración prenupcial se extiende desde finales de enero hasta mediados de junio, mientras la otoñal se extiende entre finales de julio y mediados de noviembre, no detectándose cambios significativos en el calendario de paso.

Abstract

The Strait of Gibraltar is considered one of the most important places of migratory birds in the world, especially for soaring birds. The crossing is dominated by raptors species that breed in the forests of Western Europe. In this article we characterize visible migration of forest raptors through standardized daily counts carried out in two observatories from 2007 to 2009 for spring migration, and between 1997 and 2009 for autumn migration. During the spring migration, censuses were conducted between February 1th and June 1th, while during autumn migration, censuses were conducted between July 25 th and October 10th. Around 300,000 birds of prey cross the Strait of Gibraltar

each year, 80% of which are forest raptors, mainly black kites, European honey buzzards, booted and short-toed eagles and sparrowhawks. The passage concentrates almost all breeding populations of Western Europe and the numbers show a general increase trend, especially during the last decade. The spring migration extends from late January to mid-June, while the autumn one extends between late July and mid-November, and no significant timing changes have been detected.

El Estrecho de Gibraltar y la migración de las aves

El Estrecho de Gibraltar es uno de los lugares más importantes de migración de aves del mundo. Su localización en un importante eje migratorio conocido como ruta occidental del sistema migratorio Paleártico-Africano y su posición geográfica entre el continente europeo y el africano, apenas separados por 14 kilómetros de mar, hacen del Estrecho de Gibraltar uno de los "cuellos de botella" más importantes para la migración de aves a través del Mediterráneo. Particularmente relevante es la migración masiva de aves planeadoras (rapaces y cigüeñas), con limitaciones para el vuelo de distancias largas sobre el mar, para las que el Estrecho constituye un paso obligado y un punto de concentración anual (Bernis 1980, Zalles & Bildstein 2000).

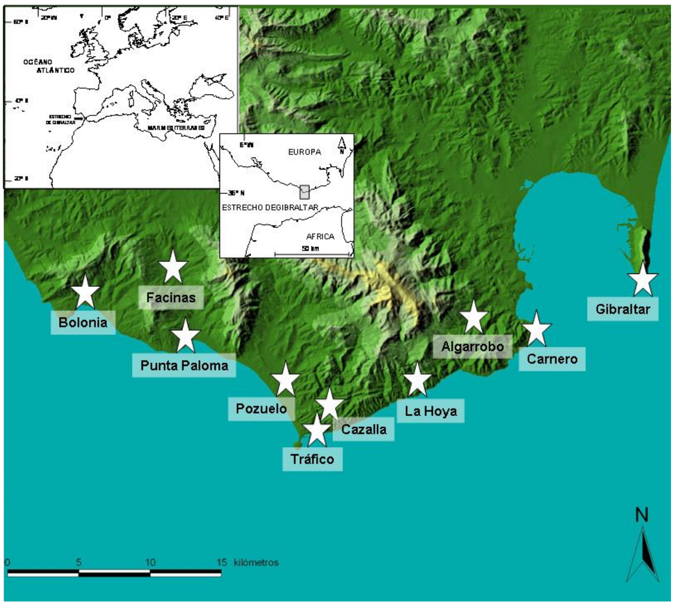
Esta relevancia del Estrecho de Gibraltar para la migración de las aves lo ha convertido en una de las zonas de la península Ibérica con mayor tradición ornitológica. Fiel reflejo de ello es el notable bagaje de información disponible en forma de libros, artículos y notas que existen publicadas en la actualidad. El primer estudio exhaustivo sobre el Estrecho se debe a H.L. Irby quien en 1895 publicó su primera edición de "*Ornithology of the Strait of Gibraltar*". Desde entonces se han sucedido notables contribuciones procedentes tanto del lado marroquí como del lado ibérico, destacando por su profundidad y rigor los trabajos pioneros sobre aves planeadoras de Evans y Lathbury (1973), Bernis (1980) y sobre aves no planeadoras de Tellería (1981), continuados con revisiones posteriores de carácter general (caso de Finlayson 1992) o más específicos (Fernández-Cruz 2005, Bensusan *et al*. 2007).

Seguimiento de la migración de aves planeadoras por el Estrecho

La migración de rapaces por el Estrecho de Gibraltar ha sido objeto de seguimiento sistemático desde finales de 1960 hasta la actualidad (Bensusan *et al*. 2007). Desde los trabajos pioneros del Grupo Español de Migración de Rapaces (Bernis 1980) se han venido desarrollando distintos programas de seguimiento por parte de la Sociedad Española de Ornitología, la *Gibraltar Ornithological & Natural History Society* y más recientemente por la Fundación Migres. El Programa Migres, auspiciado y promovido por la Consejería de Medio Ambiente de la Junta de Andalucía, coordina el seguimiento de la migración con protocolos estandarizados desde 1997 (Programa Migres 2009) e incluye el seguimiento de la migración tanto en primavera como en otoño.

El Programa Migres se basa en conteos sistemáticos en los que se utilizan protocolos de censo estandarizados. El protocolo de "seguimiento de esfuerzo constante" consiste en censar diariamente durante un periodo estandarizado, desde unos observatorios de referencia (Fig. 1), todas las aves planeadoras en migración. Los resultados obtenidos son comparables año tras año gracias al control del esfuerzo de conteo y a la toma de datos objetivos, lo que permite obtener indicadores de la evolución de las poblaciones migratorias y detectar tendencias en los patrones de migración (Bildstein & Zalles 1995).

Figura 1.- *Localización de los observatorios empleados en el censo de aves planeadoras en el Estrecho de Gibraltar por el Programa Migres y el GOHNS (Gibraltar).*



El seguimiento de la migración primaveral se inició en 2007 y, tras una fase de diseño de dos años, se fijó el periodo, lugares y horario de censo idóneos. A partir de 2009 el protocolo de seguimiento consiste en el censo diario desde dos observatorios de referencia (Cazalla y Punta Carnero) entre el 1 de febrero y el 1 de junio, con observaciones continuas entre las 10:00 y las 16:00 (hora solar). Por su parte, el seguimiento de la migración otoñal se inició en 1997 y consiste en el censo diario desde cuatro observatorios de referencia (Cazalla, Algarrobo, Tráfico y Facinas) entre el 25 de julio y el 10 de octubre, entras las 7:00 y las 16:00 (hora solar). En ambos casos la información recogida es: especie, número de aves, hora, dirección, edad y sexo, así como información de las condiciones meteorológicas reinantes (Programa Migres 2009).

La migración de las rapaces forestales por el Estrecho de Gibraltar.

¿Qué especies cruzan el Estrecho? Composición específica

En la última década se han registrado regularmente una treintena de especies de aves planeadoras por el Estrecho de Gibraltar. El listado de especies de presencia regular (observadas todos los años) incluye 30 especies de rapaces diurnas (Tabla 1) que suponen la mayor parte de especies de aves de presa presentes en el Paleártico Occidental. De estas especies, de presencia regular, la mitad (15) son rapaces ligadas a ambientes forestales. Sin embargo no todas ellas tienen la misma entidad en el paso por el Estrecho de Gibraltar. En unos casos, el cruce del Estrecho incluye unos pocos individuos durante la fase de dispersión fuera de la época de cría (*Accipiter gentilis*, *Aquila adalberti*, *Aegypius monachus*). En otros casos se trata de unas decenas de ejemplares en tránsito hacia o desde los cuarteles de invierno situados en el norte de África (migradores presaharianos), ya en el límite meridional de su distribución invernal (caso de *Milvus milvus*, *Accipiter nisus* y de *Buteo buteo Buteo*). Finalmente, por el Estrecho cruzan cientos o miles de ejemplares en ruta hacia o desde los cuarteles de invernada situados al sur del Sahara (migradores transaharianos), en la franja del Sahel (caso de *Milvus migrans*, *Pernis apivorus*, *Aquila pennata*, *Circaetus gallicus*, *Buteo buteo vulpinus*).

Tabla 1. *Listado de especies planeadoras con presencia regular en el Estrecho de Gibraltar.*

FAMILIA	Especie	Nombre común	Nombre en inglés
CICONIIDAE			
	Ciconia nigra	**cigüeña negra**	black stork
	Ciconia ciconia	**cigüeña blanca**	white stork
ACCIPITRIDAE			
	Pernis apivorus	**abejero europeo**	european honey-buzzard
	Elanus caeruleus	**elanio común**	black-shouldered kite
	Milvus migrans	**milano negro**	black kite
	Milvus milvus	**milano real**	red kite
	Neophron percnopterus	**alimoche común**	egyptian vulture
	Gyps fulvus	**buitre leonado**	griffon vulture
	Gyps ruepelii	**buitre moteado**	rüppell's vulture
	Aegypius monachus	**buitre negro**	monk vulture
	Circaetus gallicus	**culebrera europea**	short-toed eagle
	Circus aeruginosus	**aguilucho lagunero occidental**	marsh harrier
	Circus cyaneus	**aguilucho pálido**	hen harrier
	Circus pygargus	**aguilucho cenizo**	montagu's harrier
	Accipiter gentilis	**azor común**	northern goshawk
	Accipiter nisus	**gavilán común**	eurasian sparrowhawk
	Buteo buteo	**busardo ratonero**	common buzzard
	Buteo rufinus	**busardo moro**	long-legged buzzard
	Aquila pomarina	**águila pomerana**	lesser spotted eagle
	Aquila clanga	**águila moteada**	spotted eagle
	Aquila adalberti	**águila imperial ibérica**	spanish imperial eagle
	Aquila chrysaetos	**águila real**	golden eagle
	Aquila pennata	**aguililla calzada**	booted eagle
	Aquila fasciata	**águila-azor perdicera**	bonelli's eagle
PANDIONIDAE			
	Pandion haliaetus	**águila pescadora**	osprey
FALCONIDAE			
	Falco naumanni	**cernícalo primilla**	lesser kestrel
	Falco tinnunculus	**cernícalo vulgar**	common kestrel
	Falco columbarius	**esmerejón**	merlin
	Falco subbuteo	**alcotán europeo**	hobby
	Falco eleonorae	**halcón de Eleonora**	eleonora's falcon
	Falco biarmicus	**halcón borní**	lanner falcon

¿Cuántas rapaces cruzan? Estimas de paso de rapaces en el Estrecho de Gibraltar

Se estima que cada año cruzan el Estrecho unas 300.000 aves rapaces. Más del 80% del paso lo concentran cinco especies de rapaces, todas ellas forestales: milano negro (entre 100.000 y 150.000 individuos), abejero europeo (unos 50.000 individuos en primavera y entre 90.000 y 110.000 individuos en otoño), culebrera europea (entre 15.000 y 17.000 individuos), aguililla calzada (unos 14.000 individuos) y gavilán común (entre 3.000 y 4.000 individuos).

Cabe destacar que algunas de estas estimas de paso por el Estrecho de Gibraltar superan notablemente los cálculos poblacionales de parejas reproductoras en Europa occidental (BirdLife International 2004) lo cual supone que muy probablemente sus poblaciones reproductoras están subestimadas (Tabla 2).

Tabla 2. *Estimas de aves en paso en primavera (2008-2009) por el Estrecho de Gibraltar de las rapaces forestales más numerosas y su comparación con las poblaciones reproductoras (nº pp x 2) en Europa Occidental (España, Portugal, Francia, Alemania, Austria, Reino Unido, Países Bajos, Suiza) según BirdLife International (2004).*

		Europa occidental	
	Gibraltar	**Mínimo**	**Máximo**
Abejero europeo	55. 430	37.894	54. 842
Milano negro	127. 640	59. 616	87. 376
Culebrera europea	15. 100	10. 000	13. 800
Gavilán común	3. 650		
Aguililla calzada	14. 090	5. 360	11. 302

De menor entidad es el paso de otras rapaces forestales. No más de unos pocos individuos o unas decenas en el caso del busardo ratonero (*Buteo buteo*), águila pomerana (*Aquila pomarina*) o alcotán europeo (*Falco subbuteo*). El águila pomerana sigue mayoritariamente la ruta oriental (Cramp, 1980) y la vía del Estrecho es minoritaria y restringida a unos pocos individuos (Ramírez *et al*. en prensa). Por su parte el alcotán europeo cruza el mar en un frente amplio y solo una pequeña porción cruza por el área del Estrecho (Strandberg 2008). Respecto al ratonero, por el Estrecho de Gibraltar cruzan individuos de la subespecie nominal (*Buteo buteo buteo*) que invernan en el norte de África y una porción minoritaria de la subespecie *B.b. vulpinus* que invernan al sur del Sahara.

¿De dónde vienen y a dónde van? Procedencias y destinos de las rapaces en paso por el Estrecho de Gibraltar

El análisis de recuperaciones de aves anilladas y marcadas con emisores de satélite muestra que las aves que alcanzan el Estrecho de Gibraltar proceden mayoritariamente de los países nórdicos y Centroeuropa -caso del abejero europeo y del gavilán común-, o principalmente de la península Ibérica y Europa centro-occidental -caso del milano negro, culebrera europea y aguililla calzada- (Bernis 1966 y 1980, Díaz *et al*. 1996, Strandberg 2008). En todos los casos se trata de migrantes de largo recorrido (transaharianos) o que incluyen poblaciones tanto presaharianas como transaharianas (*Accipiter nisus*). Las áreas de invernada se sitúan en la franja del Sahel, principalmente en su sector más occidental –Mauritania, Senegal, Ghana, ...- (Cramp 1980).

¿Cuándo pasan? Patrones temporales de paso por el Estrecho de Gibraltar

Por el Estrecho de Gibraltar hay cruce de aves planeadoras prácticamente durante todo el año. La migración primaveral se extiende de mediados de enero hasta principios de junio (5 meses) y la migración otoñal desde mediados de julio hasta finales de noviembre (4 meses, Fig. 2). La secuencia de paso en primavera corresponde a culebrera europea (máximo a principios de marzo), milano negro, busardo ratonero, gavilán común y aguililla calzada (máximos a finales de marzo-principios de abril) y abejero europeo (máximo a principios de mayo, Tabla 3). La mayor parte de la llegada de rapaces se concentra entre el 20 de febrero y el 30 de marzo. Hay un segundo pico de entrada, a finales de abril y principios de mayo, que se corresponde con la llegada masiva y concentración de los abejeros. Entre ambos picos de migración hay un paso difuso y menos intenso de rapaces entre abril y principios de junio que se corresponde con la llegada de ejemplares inmaduros o no reproductores (Fig. 3). La duración del paso en el Estrecho en primavera oscila entre un mes y medio y dos meses según especies (Tabla 3), con la excepción del abejero europeo que presenta un paso muy concentrado en el tiempo: el 80% de los efectivos en paso –varias decenas de miles- cruzan en 9 días!

Figura 2. *Fenología de paso de aves rapaces por el Estrecho de Gibraltar (año 2008).*

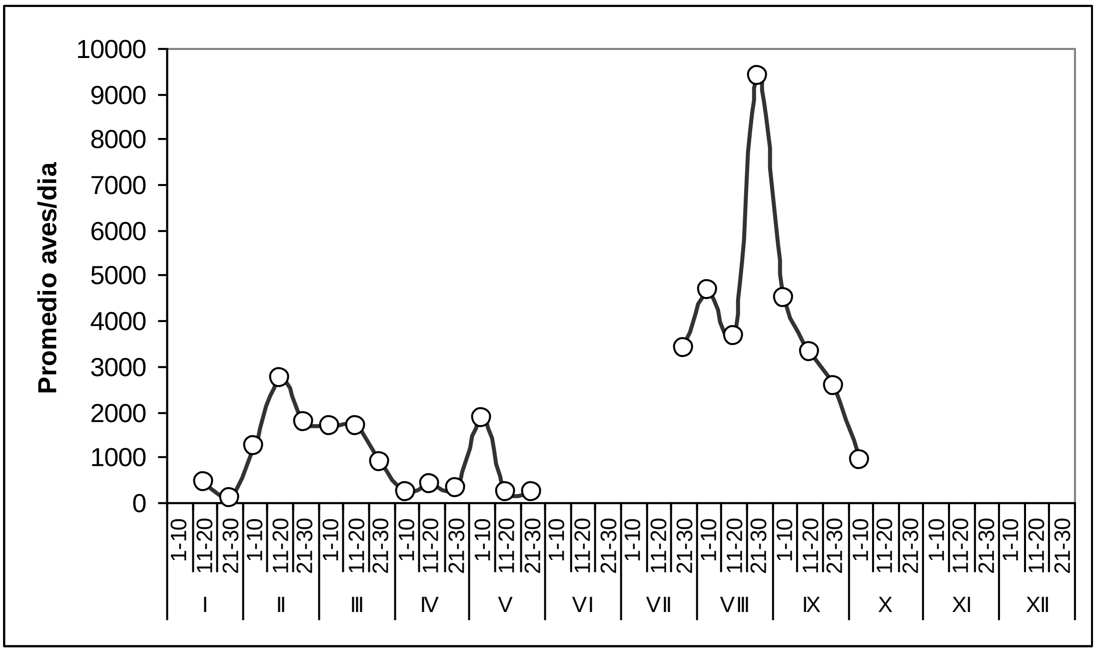
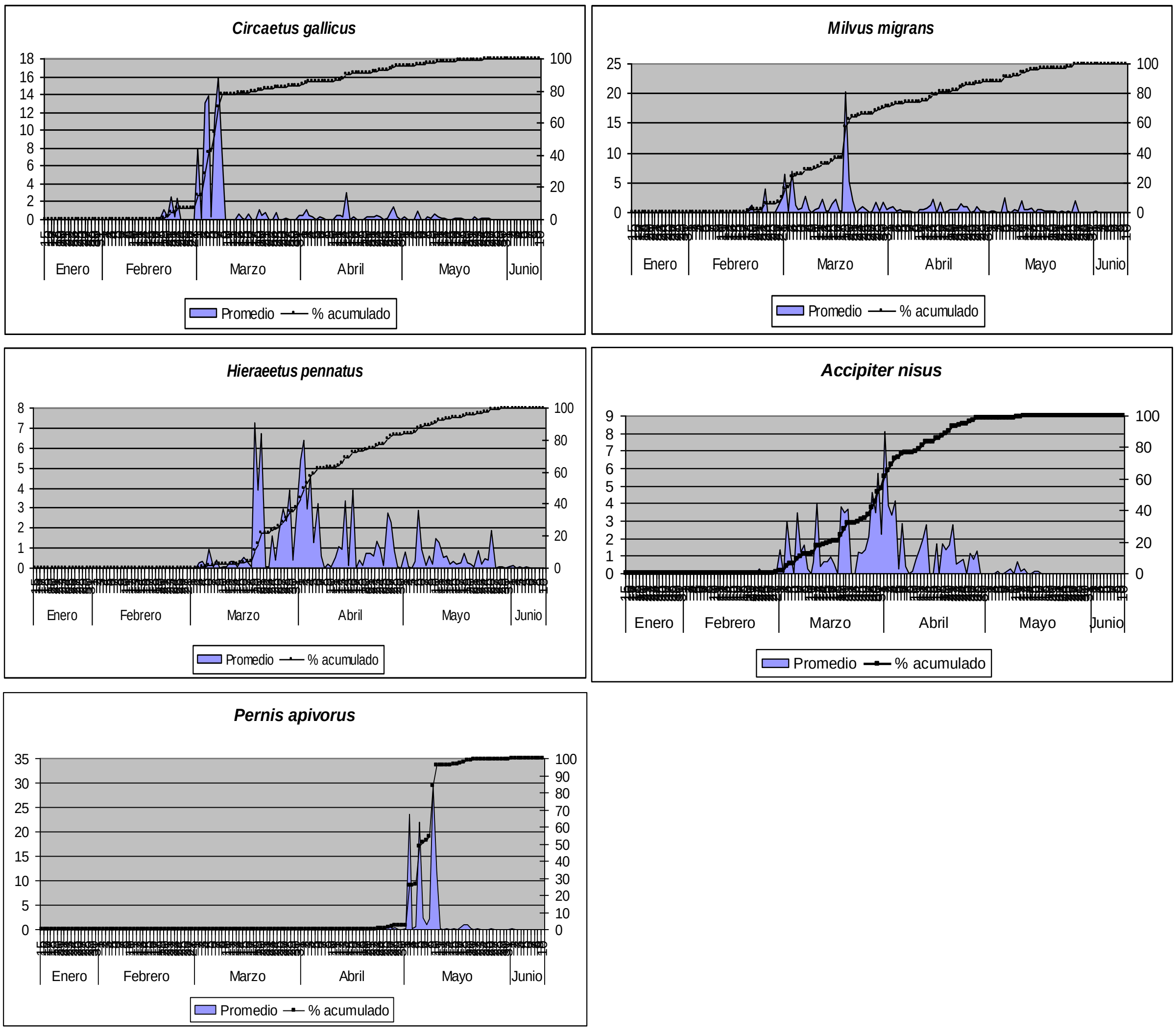


Tabla 3.- *Fecha media de paso (50% de los individuos) y duración del paso en días (80% del total de individuos) de la migración primaveral de rapaces forestales por el Estrecho de Gibraltar.*

	Fecha media paso	**Duración paso**
Abejero europeo	06-may	9
Milano negro	19-mar	66
Águila culebrera	06-mar	45
Gavilán común	30-mar	45
Busardo ratonero	21-mar	98
Aguililla calzada	03-abr	53

Figura 3. *Fenología migratoria primaveral (2008/2009) para las principales especies de rapaces forestales. Datos expresados en porcentajes (media diaria y acumulada).*



La migración otoñal de rapaces sucede con el paso de las diferentes especies de modo secuencial. Comienza con el paso de los milanos negros en julio y agosto (pico a mediados de agosto), el paso masivo en pocos días de los abejeros a finales de agosto y principios de septiembre (máximo en torno al 1 de septiembre), y el paso de gavilanes, calzadas y culebreras en septiembre y principios de octubre (máximos hacia el 20 de septiembre). Al final de la temporada, en octubre, pasan los ratoneros y los escasos migrantes presaharianos que cruzan el Estrecho (milanos reales, …; Fig. 4 y Tabla 4). La duración del paso en otoño está en torno a un mes para todas las especies con la excepción del abejero que se concentra en apenas 17 días (Tabla 4).

Figura 4. *Fenología migratoria otoñal (1999/2008) para las principales especies de rapaces forestales. Datos expresados en porcentajes (media diaria y acumulada).*

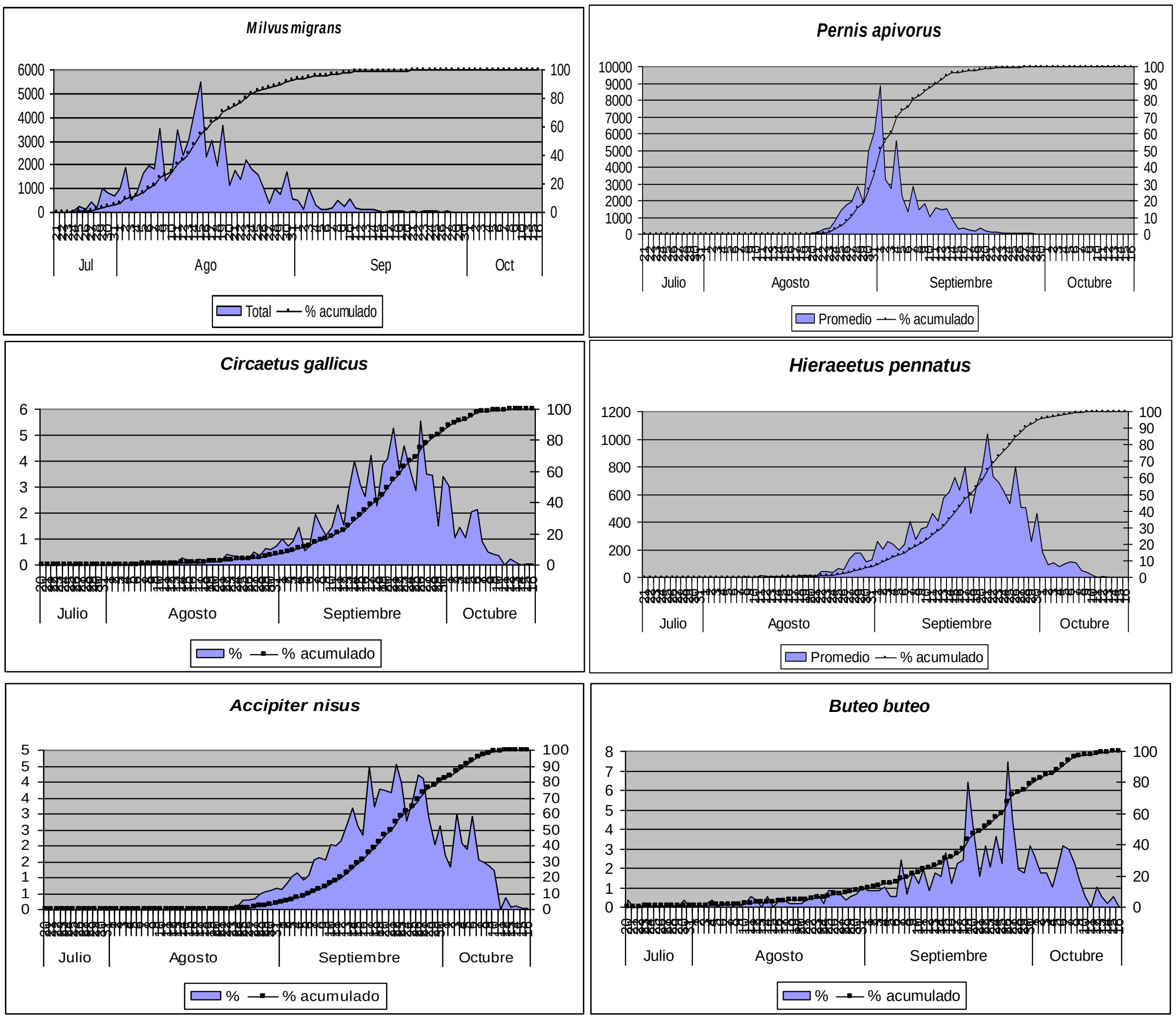


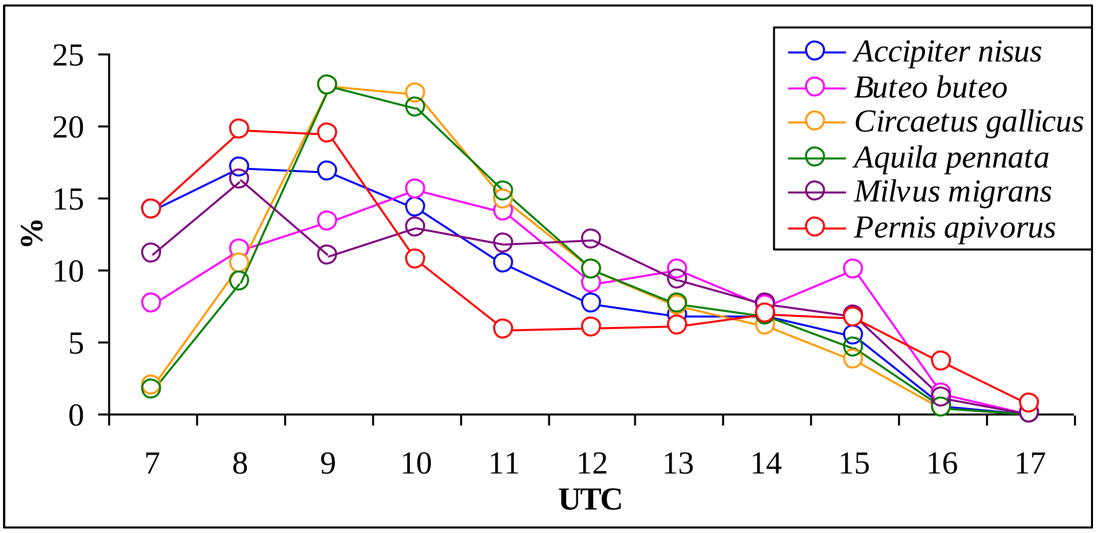
Tabla 4. *Fecha media de paso (50% de los individuos) y duración del paso en días (80% del total de individuos) de la migración otoñal de rapaces forestales por el Estrecho de Gibraltar.*

	Fecha media paso	**Duración paso**
Abejero europeo	01-sep	17
Milano negro	15-ago	28
Águila culebrera	21-sep	29
Gavilán común	22-sep	29
Busardo ratonero	22-sep	38
Aguililla calzada	18-sep	26

La secuencia de paso de las diferentes especies por el Estrecho en primavera no tiene su espejo en el otoño: el orden de paso es diferente en ambas estaciones (Tablas 3 y 4). Con la excepción del abejero, la duración del paso en todas las rapaces es mayor en primavera que en otoño (entre 15 días y más de un mes). Este hecho se ha relacionado con la entrada más tardía y difusa de ejemplares inmaduros o no reproductores (Newton 2008), aspecto que se ha refrendado en el Estrecho al menos para el caso de la culebrera europea y el milano negro.

Respecto al patrón diario de paso, en otoño la práctica totalidad tiene lugar entre las 7:00 y las 15:00 h (UTC). En este caso, las especies más ligeras y de vuelo más batido tienden a ser más madrugadoras y concentran el paso en las 4-5 primeras horas de la mañana, como es el caso del abejero y gavilán. En estas dos especies, el 50% de los efectivos han pasado ya antes de las 10 de la mañana (UTC). Las especies más pesadas y más planeadoras aprovechan las corrientes térmicas más potentes de mediodía y concentran el paso entre las 9:00 y las 13:00 (UTC), como es el caso de la culebrera y la calzada. En este caso, el 80% de los individuos pasan entre las 8:00 y las 13:00 (UTC). Finalmente, milanos negros y ratoneros tienen máximos a media mañana similares a culebreras y calzadas, pero prolongan mucho más el periodo diario de paso (Fig. 5).

Figura 5. *Patrón horario de paso (otoño) de las diferentes especies de rapaces forestales por el Estrecho de Gibraltar.*



¿Por dónde cruzan? Patrones espaciales de cruce del Estrecho de Gibraltar

La mayoría de las rapaces que cruzan el Estrecho de Gibraltar lo hacen por el sector central aprovechando la mínima distancia entre los dos continentes, apenas 14 kilómetros entre Punta Camorro (España) y Punta Cires (Marruecos). En la porción ibérica del Estrecho, la llegada y la partida se concentran entre el Peñón de Gibraltar y Zahara de los Atunes (Bernis 1980). No obstante, existen numerosos registros que indican que el cruce puede realizarse desde localidades más lejanas que suponen recorrer distancias mucho mayores sobre el mar. Este hecho se ha confirmado con estudios de radar y con seguimiento de diversas aves de presa con emisores de satélite. En este caso, se ha confirmado que un número importante de aguiluchos, águilas pescadoras, gavilanes, cernícalos primillas y alcotanes, entre otros, son capaces de sobrevolar grandes distancias sobre el mar y que el Estrecho apenas concentra una porción variable del paso de estas especies (Meyer *et al*. 2000 y 2003, Strandberg 2008).

Por lo demás, el análisis de los patrones espaciales de cruce está todavía por resolver. Se sabe que la meteorología y especialmente los fuertes vientos de poniente y levante, dominantes en la zona, condicionan notablemente la partida y llegada de las aves (Bernis 1980). Por otro lado, la procedencia de las aves puede jugar un papel importante en la llegada al Estrecho: por ejemplo, la mayoría de abejeros, pescadoras, ratoneros y gavilanes que cruzan el Estrecho proceden de Centroeuropa y acceden al Estrecho por su sector más oriental tras el tránsito por la mitad este de la península. De otro lado, calzadas y culebreras tienen un origen mayoritariamente ibérico y el acceso al Estrecho se hace desde el sector más occidental (Bernis 1980).

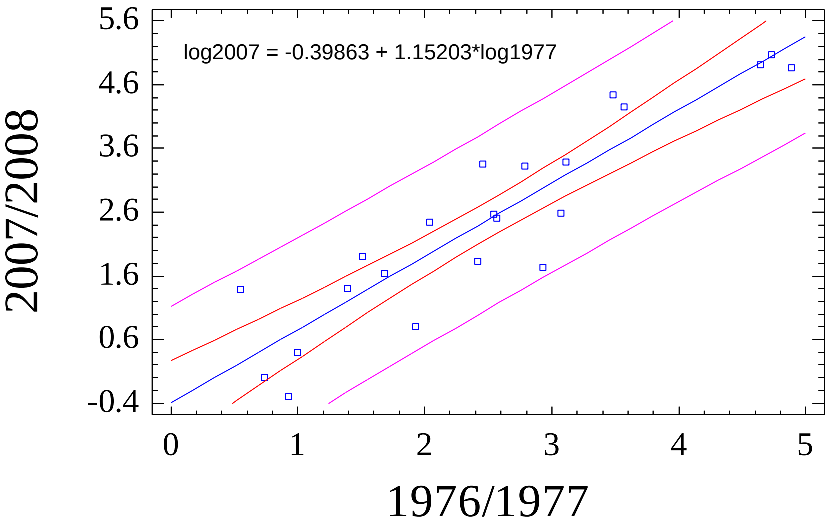
¿Solos o acompañados? Gregarismo de las rapaces en migración por el Estrecho

Un aspecto llamativo de la migración de las rapaces es el gregarismo que exhiben muchas especies durante el viaje. Especies que se caracterizan por su comportamiento agresivo, territorial y, muchas veces, exclusivo durante la cría, se vuelven gregarias y más sociables durante la migración. Este hecho se ha relacionado con la ventaja del grupo para localizar de manera eficaz las corrientes ascendentes más favorables (Kerlinger 1989, Bildstein 2006). En el Estrecho de Gibraltar, milanos negros y abejeros muestran un elevado gregarismo y el tamaño medio de grupo oscila entre 14 y 40 individuos. Por su parte, culebreras y calzadas son menos propensas a formar grupos numerosos y abundan los individuos solitarios o las agrupaciones de pequeño tamaño (tamaño medio de grupo de 4 a 5 individuos). Finalmente, gavilanes, ratoneros y alcotanes suelen aparecer solitarios en el tránsito por el Estrecho.

Tendencias en el paso

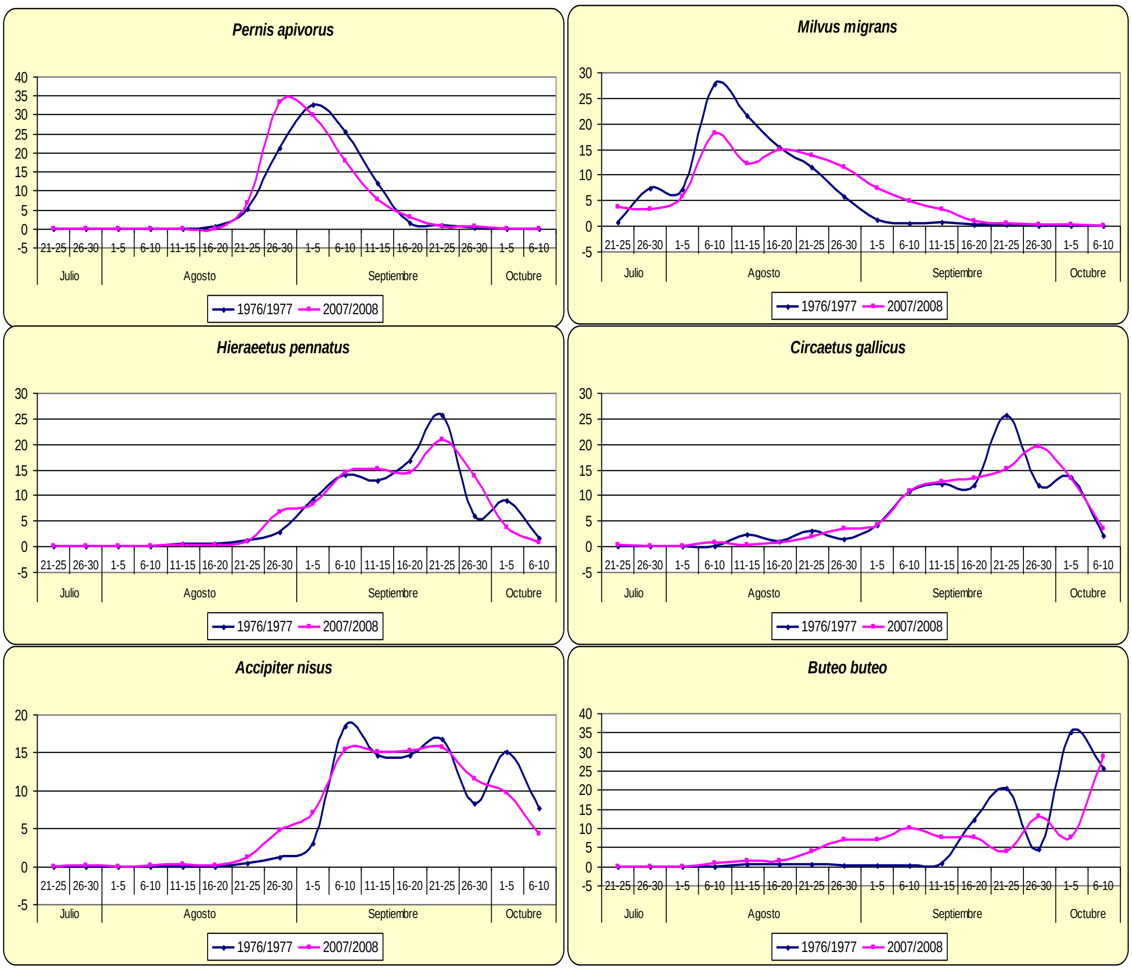
La comparativa entre los resultados de los censos realizados en 1976-1977 (Bernis 1980) y los actuales del bienio 2007-2008 indican un incremento general del paso de planeadoras por el Estrecho de Gibraltar. Únicamente especies como el busardo ratonero, el esmerejón y el cernícalo común presentan tendencias negativas (Fig. 6). De otro lado, Bensusan *et al*. (2007) señalan tendencias positivas en el paso de milanos negros, gavilanes y aguilillas calzadas, y negativas en el caso del abejero europeo y el busardo ratonero, entre 1967 y 2004. Por su parte, los datos de tendencias en el paso de rapaces forestales por el Estrecho de Gibraltar en la última década (1999-2008) indican un aumento generalizado en el número de aves y son estadísticamente significativos para milano negro, culebrera europea y aguililla calzada (Muñoz *et al*. en preparación). Respecto a la fenología de paso, pendiente de un análisis más profundo, no se detectan variaciones significativas (Fig. 7).

Figura 6. *Tendencias en el paso de aves planeadoras por el estrecho de Gibraltar 1976-2008.*



Un caso especial es el busardo ratonero. Bernis (1980) estimaba el cruce de cerca de un millar de ratoneros por el Estrecho en el otoño y actualmente no superan el centenar. Los análisis de recuperaciones de aves anilladas e individuos radiomarcados apuntan la posibilidad de una reducción en las distancias de migración, situando las áreas de invernada cada vez más al norte (Strandberg 2008).

Figura 7. *Fenología comparada 1976/1977 y 2007/2008 de las principales de rapaces forestales en tránsito por el Estrecho de Gibraltar. Datos en porcentajes.*



Importancia del Estrecho de Gibraltar para la migración de las rapaces forestales

Más de 300.000 rapaces de 30 especies diferentes cruzan el Estrecho de Gibraltar cada año durante sus migraciones. Las especies más numerosas en tránsito corresponden a rapaces forestales de migración transahariana. Las dos especies más abundantes en el Estrecho, el milano negro y el abejero europeo, suman más de cien mil individuos, cada una, durante el paso otoñal. Los efectivos migradores de la culebrera europea y el aguililla calzada por el

Estrecho superan los quince mil individuos, de cada una. Además varios miles de gavilanes y decenas de alcotanes y ratoneros cruzan cada año el Estrecho. La entidad numérica y específica de rapaces en tránsito erige al Estrecho de Gibraltar como uno de los lugares más importantes del mundo para la migración de rapaces. Las cifras de paso de milano negro, aguililla calzada y águila culebrera son las más altas del mundo (Zalles & Bildstein 2000).

Esta elevada concentración de rapaces en paso ofrece la mejor posibilidad de estudiar las tendencias en sus poblaciones y patrones migratorios, teniendo en cuenta la dificultad de trabajo en las áreas de cría –densidades bajas, comportamientos discretos o elusivos…– (Bednarz *et al*. 1990, Bildstein & Zalles 1995). Además constituye un lugar idóneo para el estudio de la migración de las aves rapaces (cantidad, condicionantes de vuelo, estrategias migratorias…) que puede aportar una información complementaria a otros sistemas y métodos de estudio. Finalmente tampoco se puede olvidar la importancia del Estrecho de Gibraltar para otros intereses: lugar de formación de nuevos ornitólogos o estudiosos de las aves de presa, enclave para enmarcar programas de sensibilización o educación ambiental, zona para desarrollar proyectos de ecoturismo y de desarrollo socioeconómico con la migración como gancho, … amén de otros intereses de tipo estético, artístico o cultural.

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CAPITULO 2. Magnitud y fenología de la migración de aves planeadoras por el estrecho de Gibraltar en primavera y otoño

Magnitude and timing of soaring bird migration over the Strait of Gibraltar in spring and autumn

Este capítulo reproduce el texto del siguiente artículo en revisión:

Martín B., Onrubia A., De la Cruz A. & Ferrer M. *en revisión*. Magnitude and timing of soaring bird migration over the Strait of Gibraltar in spring and autumn: a recent update. *Ardeola*.

Magnitude and timing of soaring bird migration over the Strait of Gibraltar in spring and autumn: a recent update

Resumen

Este estudio es el primer intento de estimar la magnitud real de la migración de aves planeadoras a través del estrecho de Gibraltar, uno de los cuellos de botella más importantes a lo largo del sistema migratorio europeo-africano y el cuello de botella más importante para las aves migratorias de toda Europa occidental. Se analizó la migración visible de las aves planeadoras en el sur de España a través de registros recogidos entre los años 2009 y 2012. Las estimas del número de aves en migración se basaron en conteos diarios recogidos en dos observatorios principales cada estación, tras aplicar una corrección temporal y espacial para las aves no observadas. En total, alrededor de 135.000-150.000 cigüeñas (dos especies diferentes con presencia regular durante el periodo migratorio) y 290.000-350.000 rapaces (28 especies observadas con regularidad durante el periodo de migración) pueden observarse en migración a través del estrecho de Gibraltar. Tanto la composición de las especies como sus abundancias fueron muy similares en primavera y otoño. Sin embargo, la migración otoñal tiene lugar en un marco temporal mucho más reducido en comparación con la migración primaveral. Las estimas de aves en migración a través del Estrecho sobrepasan enormemente las estimas disponibles de población reproductora en el caso de muchas de las especies de aves planeadoras estudiadas.

Abstract

This study is the first attempt of estimating the real magnitude of soaring bird migration over the Strait of Gibraltar, one of the most important bottlenecks in the entire European–African flyway system and the most important bottleneck in Western Europe for migratory birds. The visible migration of soaring birds in southern Spain was analyzed from records collected in 2009-2012. Estimates of the total number of migrating birds were based on daily counts recorded at the two main observatories per season and after applying a spatial and temporal

correction for missing birds. Overall, about 135.000-150.000 storks (two different species with regular presence during migration) and 290.000-350.000 raptors (28 species regularly crossing during migration) can be observed migrating over the Strait of Gibraltar. Both the species and their abundance are very similar in spring and autumn. However, autumn migration occurs within a much narrower temporal frame and on a narrower front when compared with spring migration. Estimates of the number of birds migrating over the Strait for many of the studied soaring species greatly exceed the available estimates of their breeding populations in Europe.

Introduction

Soaring birds largely rely on thermal uplift for assisted flight as they tend to avoid crossing wide extensions of open water where a lack of such uplifts requires compensation by flapping (Finlayson *et al*. 1976, Kerlinger 1989). This leads to the occurrence of large concentrations of soaring birds in areas known as ‘bottlenecks’ where migration routes converge and large numbers of migrants can be observed (Zalles and Bildstein 2000).

The Strait of Gibraltar is the only area in the Western Mediterranean where a relatively narrow sea passage (only 14 km wide) connects Europe with Africa. This site is one of the most important bottlenecks in the entire European–African flyway system and it has long been recognized as the most important bottleneck for migratory soaring birds in Western Europe. The number of soaring migrant birds which cross the Strait is the largest, both in terms of numbers and species, at a single site in western Europe, (Bernis 1980a, Porter and Beaman 1985, Finlayson *et al*. 1992) and this bottleneck is used by most of West European and Iberian long-distance migrants (Bijlsma 1987).

The first coordinated and full-scale survey of soaring bird migration across the entire width of the Strait was carried out in the 1970s (Bernis 1980a). This survey provided thorough information about the phenology and the magnitude of the autumn migration of these species in the Strait of Gibraltar (Bernis 1973, 1975a, 1975b, 1980a, 1980b, Evans and Lathbury 1973, Finlayson *et al*. 1976). Over the years, changes in climate, habitat and breeding populations may lead to shifts in migratory population sizes and in migration phenology (e.g. Jenni and Kéri 2003). Since 1999 to the present date, the autumn passage of soaring birds over the Strait of Gibraltar has been surveyed systematically using a standardized monitoring protocol (Programa Migres 2009). Although migration surveys in the Strait have been mainly carried out during autumn because autumn migration occurs on a much narrower front than the spring migration (Bernis 1975a, but see Evans and Lathbury 1973, Finlayson *et al*. 1976, Cortés *et al*. 1980, Bensusan *et al*. 2007), a similar monitoring protocol was also used to survey spring migration in the Strait of Gibraltar during 2009-2012 (De la Cruz *et al*. 2011). In contrast with autumn migration, however, monitoring during the spring increases the precision of the counts by reducing the incidence of double counts since we are certain that all the birds sighted reaching European shores have truly completed the crossing over the sea.

As top predators, soaring birds, and particularly birds of prey, have characteristics that could make them good indicators of the health of the ecosystem (Sergio *et al*. 2005). Thus, the monitoring of their population trends is an important tool not only to assess the conservation status of these species but, more generally, to prioritize resources devoted to protecting natural environments and biodiversity (Yosef *et al*. 2000, Vrezec *et al*. 2012, Martin and Ferrer 2013). However, available information about their abundances on large spatial scales in Europe is still incomplete or inaccurate depending on species and breeding areas (Vrezec *et al*. 2012). More than 90% of the soaring birds in the Palearctic are migratory species, thus sampling their numbers during migration offers a cost-effective and efficient method for monitoring regional populations of these species (Bildstein *et al*. 2007) when compared with more direct methods such as nesting surveys (Lewis and Gould 2000).

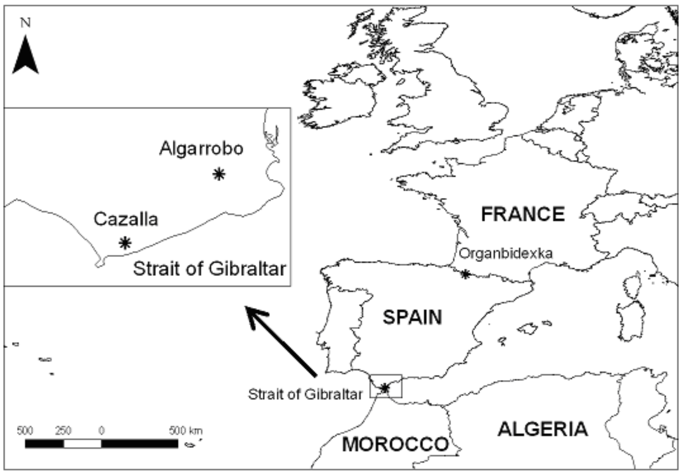
This study presents updated information on the magnitude and phenology of the soaring bird migration over the Strait of Gibraltar based on recent data collected both during spring and autumn. We summarized the numbers and periods of passage of the most common migrant species. In addition, we compared these migratory population numbers for each species with the most recent population estimates on their breeding grounds as summarized for Europe by BirdLife International (2004). Finally, we discussed the abundances and passage dates observed in the Strait of Gibraltar in relation to those published for Batumi (at the eastern Black Sea coast, Georgia; Verhelst *et al*. 2012) and Eilat (northern Israel, Leshem and Yom-Tov 1996, Shirihari *et al*. 2000). On the whole, these three sites are the most important Western Palearctic bottlenecks for monitoring soaring bird migration over the south-west (Strait of Gibraltar) and south-east (Batumi and Eilat) migratory flyways (Porter and Beaman 1985).

Methods

Study site

The movements of soaring birds crossing the Strait are strongly governed by the prevailing weather conditions. Particularly, the routes of migration are markedly dependent on wind direction and wind strength (Finlayson *et al*. 1976, Bernis 1980a). During autumn migration, westerly winds give rise to higher concentrations of birds following the Mediterranean coast, but along the Atlantic coast when winds are easterly (Bernis 1980a). Regarding spring migration, this situation is reversed, with higher concentrations of birds along the Atlantic coast when winds are easterly whereas bird concentration takes place along the Mediterranean coast with westerly winds. Furthermore, the migration routes of different birds vary making the Atlantic side optimal for viewing some species while others concentrate further east along the Mediterranean (Finlayson *et al*. 1976, Bernis 1980a). We therefore collected count data for migratory soaring birds at three different observatories positioned near the coast of the Strait of Gibraltar: Punta Carnero 36°4’34’’N, 5°25’45’’W and Algarrobo 36°5’25’’N, 5°29’02’’W which are situated along the Mediterranean and Cazalla 36°1’58’’N, 5°34’36’’W, located closer to the Atlantic coast (Figure 1). Due to the particular characteristics of migration passage in spring and autumn, Punta Carnero and Cazalla are the optimal observatories for surveying spring migration, whereas Algarrobo and Cazalla allow for the best autumn survey (Barrios and Doval 2007, Programa Migres 2009).

Figure 1. *Location of the study area.*



Count method

From 2009-2012 counts were carried out at three different observatories by a minimum of four observers with at least one of the observers at each site being a trained ornithologist (Programa Migres 2009). All observers were equipped with binoculars and telescopes. During spring migration counts were started in early February and finishing at the end of May whereas autumn migration counts were conducted between mid-July and mid-October. Monitoring schedule was 9:00 to 16:00 (UTC) for spring migration and 7:00 to 16:00 (UTC) for autumn migration. These time frames concentrate about 90% of the migration time window for most of the study species (Barrios and Doval 2007, Programa Migres 2009).

All birds detected were assigned cardinal values for their direction of origin and destination. We only considered individuals for analysis if they were assigned a southern trajectory to minimize the possibility of over-estimating the number of birds migrating. During adverse weather conditions in the Strait, such as high winds, rain, or low visibility between Europe and Africa, the crossing of soaring birds is delayed and the birds are obliged to wait until conditions improve. Therefore, counts were not conducted on days with persistent precipitation or when wind speeds exceeded force 6 on the Beaufort scale (i.e., > 10.8 m/s), when little migration across the Strait takes place.

The number of soaring birds counted in the Strait of Gibraltar differs substantially from year to year mainly because of the prevailing weather conditions for one particular year which determine where and when the bird crossing takes place birds and therefore conditioning whether the birds are sighted or not. Fluctuations in total counts among years may be reduced by averaging annual counts over a representative time period. We provide averaged spring and autumn migration counts and their coefficient of variation for the period 2009-2012 (Table 1). All analyses and comparisons were based on those averaged counts except for griffon vulture *Gyps fulvus* and white stork *Ciconia ciconia*. Autumn passage of griffon vultures and spring migration of white storks take place over a longer period of time than those for other soaring bird species (see Results) thus we needed to conduct a more extensive survey to obtain a complete record of the migration of these particular species. Autumn migration counts for griffon vulture and spring migration counts for white storks reported in the present study were based on additional surveys conducted in 2008 (between mid-July to mid-November) in the case of griffon vulture and in 2010-2012 (between October 2010 to April 2011 and October 2011-April 2012) in the case of white stork.

Migration timing

Both to characterize the timing of passage as well as to allow for comparisons with other observatories, for each migratory soaring bird species we quantified median date of the 5%, 50% and 95% of the passage and length (in number of days) of the central 90% of the passage (Leshem and Yom-Tov 1996, Verhelst *et al*. 2011)

Estimates of the real number of birds from the sample of migratory counts

Estimates of the number of birds migrating over the Strait of Gibraltar in spring and autumn were based on daily counts recorded in two main observatories per season and after applying a spatial and temporal correction for missing birds.

Spatial correction

The most recent and comprehensive surveys of the soaring bird migration along the European shoreline of the Strait of Gibraltar were carried out in the autumns of 1997 and 1998 (SEO/BirdLife 1997 and 1998, Barrios and Doval 2007). In these surveys, 20 different observatories were involved in sampling the visible migration over the Strait, Algarrobo and Cazalla among them. As a result of the analysis of the counts collected in this survey, Algarrobo and Cazalla were identified as the two best observatories for monitoring autumn migration because together these two observatories recorded the largest numbers of birds and these numbers correlated highly with those observed in the total sample of observatories (Barrios and Doval 2007).

Similarly, in the springs of 2008 and 2009 we carried out comprehensive surveys along the European shoreline of the Strait. This survey involved seven observatories simultaneously active twice per week from 1 February to 10 June, including Punta Carnero and Cazalla, the latter two being identified as the best spring observatories in terms of number of birds and correlation with total migration counts (De la Cruz *et al*. 2011).

Assuming that the sum of all birds counted in any of those observatories, 20 in autumn 1997-1998 and seven in spring 2008-2009 respectively, is the total sample of migratory soaring birds crossing the Strait of Gibraltar (or at least which is very close to the total sample), we quantified the proportion of the total migration represented by Algarrobo and Cazalla (autumn migration) and by Cazalla and Punta Carnero (spring migration). From these proportions, we derived estimates of the total annual sample for autumn and spring migration during the period 2009-2012.

Temporal correction

Similarly we quantified a temporal correction of the number of birds from a complete daily survey (from sunrise to sunset) both in spring (once a week from 1 February to 10 June, years 2008 and 2009) and autumn (21 July-16 October 1997) (SEO/BirdLife1997, Programa Migres 2009). Based on these complete daily surveys, we calculated the proportion of birds missed during the counting standard schedule in relation to the total daylight period. From this proportion we could estimate the total daily number of birds migrating over the Strait of Gibraltar both in autumn and spring.

Comparison among migratory and breeding population estimates

Recoveries of ringed, soaring migrating birds show that birds crossing the Strait of Gibraltar mainly come from western European populations although some from Central and North Europe may also follow the south-west flyway across the Strait (Bernis 1966, Bernis 1980a, Diaz *et al*. 1996, SEO/BirdLife 2012). For comparisons between migrating population and breeding population sizes of the different soaring bird species we therefore took into account the estimates of breeding pairs reported by Birdlife International (2004) from three different geographical regions: Western, Central and Northern Europe. Western European populations included birds breeding in Belgium, France, Ireland, Italy, Luxembourg, Liechtenstein, Netherlands, Portugal, Spain and United Kingdom. Central European populations considered breeding pairs from Austria, Croatia, Czech Republic, Germany, Hungary, Poland, Slovakia, Slovenia and Switzerland. Finally, the Northern Europe region included breeding populations from Denmark, Estonia, Finland, Latvia, Lithuania, Norway and Sweden.

Results

Magnitude of the soaring bird migration over the Strait

Up to 46 species of soaring birds were observed in the Strait of Gibraltar in 2009-2012 (Table 1). However, from those only 16 were regularly counted in spring and 20 in autumn. On average, 314.258 migrating soaring birds were observed per autumn and 72.029 per spring (Table 1). Visible migration of soaring birds in the Strait of Gibraltar during spring and autumn passages consists mainly of black kites *Milvus migrans* (49% of total passage in spring; 38% of total passage in autumn), white storks *Ciconia ciconia* (12% of total passage in spring; 23% of total passage in autumn), honey buzzard *Pernis apivorus* (12% of total passage in spring; 18% of total passage in autumn), short-toed eagles *Circaetus gallicus* (11% of total passage in spring; 5% of total passage in autumn), booted eagles *Aquila pennata* (9% of total passage in spring; 10% of total passage in autumn), griffon vultures *Gyps fulvus* (4% of total passage in spring; 3% of total passage in autumn), black storks *Ciconia nigra* (1% of total passage in spring; 1% of total passage in autumn), sparrowhawks *Accipiter nisus* (1% of total passage in spring; 1% of total passage in autumn),and Egyptian vulture *Neophron percnopterus* (1% of total passage in spring; 1% of total passage in autumn). Individuals belonging to these ten species account for more than 99% of the total number of birds migrating over the Strait. Other species also frequently observed, both in spring and autumn, although in smaller numbers were: Montagu's harrier *Circus pygargus*, marsh harrier *Circus aeruginosus*, osprey *Pandion haliaetus*, lesser kestrel *Falco naumanni*, common buzzard *Buteo buteo*, Eurasian hobby *Falco subbuteo*, peregrine *Falco*n *Falco peregrinus* and Eleonora's falcon *Falco* eleonorae (Table 1).

According to the spatial and temporal corrections made in the migration counts, the standard sampling effort made in 2009-2012 covered about 58-65% of the total migration passage. The overall migration passage is estimated at 427.300 soaring birds in spring and 513.500 individuals in autumn (Table 1).

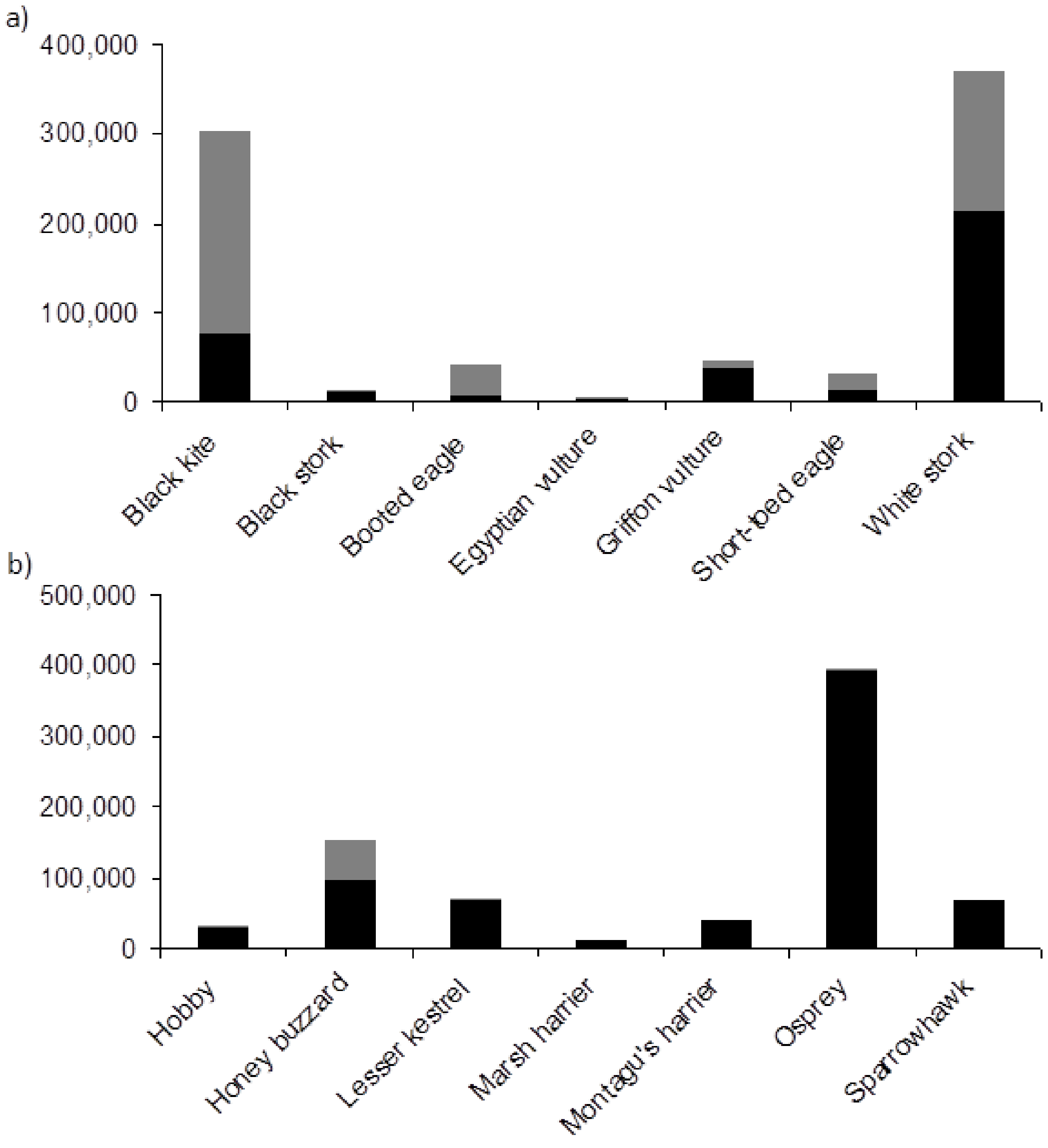
Table 1. *Soaring bird species recorded over the Strait of Gibraltar during spring and autumn migration in 2009–2012. Averaged observed and estimated numbers (based on spatial and temporal corrections; see Methods), coefficient of variation (CV, %), average median date, date of first 5% and first 95% of passage (for species with >10 per year) and length of central 90% of passage (days). Phenology and numbers are only reported for the frequently observed species.*

	Autumn migration								**Spring migration**							
Species	**Counts**	**CV**	**Estimates**	**CV**	**Median date**	**Date of first 5%**	**Date of first 95%**	**Length of central 90%**	**Counts**	**CV**	**Estimates**	**CV**	**Median date**	**Date of first 5%**	**Date of first 95%**	**Length of central 90%**
Accipiter gentilis	< 5															
Accipiter nisus	2,100.75	7.01	3,067.41	8.1	21-Sep	02-Sep	05-Oct	34	407.25	5.97	4,295.20	17.72	02-Apr	08-Mar	01-May	55
Aegypius monachus	< 5															
Aquila adalberti	< 5															
Aquila chrysaetos	< 5															
Aquila clanga	< 5															
Aquila fasciata	< 15															
Aquila nipalensis	< 1															
Aquila pennata	30,840.25	13.4	33,773.80	31.48	18-Sep	24-Aug	03-Oct	41	6,635.75	21.05	21,470.66	34.27	01-Apr	18-Mar	14-May	58
Aquila pomarina	< 15															
Aquila rapax	< 1															
Buteo buteo	85.5	25.9	131.46	29.9	21-Sep	22-Aug	06-Oct	46	45.75	12.3	161.99	13.43	14-Mar	03-Feb	04-May	91
Buteo rufinus	< 5															
Cathartes aura	< 1															
Ciconia ciconia	71,730.00	20.18	156,121.98	23.31	12-Aug	25-Jul	12-Sep	50	8,517.50	29.16	132,608.00	25.1	30-Jan	07-Nov	14-Apr	160
Ciconia nigra	2,703.25	9.42	3,035.65	10.87	21-Sep	08-Sep	03-Oct	26	581.75	40.95	3,538.73	51.84	19-Mar	26-Feb	01-May	65
Circaetus gallicus	16,848.75	23.67	19,559.25	27.33	21-Sep	26-Aug	05-Oct	41	8,168.75	22.18	20,231.73	25.61	10-Mar	24-Feb	27-Apr	63
Circus aeruginosus	440.25	32.22	735.44	37.21	16-Sep	26-Aug	04-Oct	40	209.75	16.35	2,354.62	17.34	29-Mar	23-Feb	10-May	77
Circus cyaneus	< 15				05-Sep	02-Aug	06-Oct	66								
Circus macrourus	< 5															
Circus pygargus	497.75	6.62	1,356.18	7.64	29-Aug	03-Aug	17-Sep	46	177.75	32.41	1,355.39	34.76	09-Apr	24-Mar	25-Apr	33
Coragyps atratus	< 1															
Elanus caeruleus	< 5															
Falco biarmicus	< 5															
Falco cherrug	< 1															
Falco columbarius	< 5															
Falco eleonorae	5	28.28	0	76.59	07-Sep	13-Aug	30-Sep	49	1.5	33.33						
Falco naumanni	277.5	32.64	344.92	37.69	15-Sep	25-Aug	04-Oct	41	156.75	89.06	1,758.69	79.44	02-Mar	05-Feb	07-Apr	62
Falco pelegrinoides	< 1															
Falco peregrinus	20	21.6	20	72.62	19-Sep	08-Aug	01-Oct	55	15.67	60.4			25-Mar	04-Feb	07-May	93
Falco subbuteo	40.5	33.24	40	38.38	28-Sep	12-Sep	06-Oct	25	19.5	90.33	272.55	107.92	24-Apr	12-Apr	25-May	44
Falco tinnunculus	22.67	23.98	39.3	73.94	22-Sep	25-Aug	08-Oct	45	10.33	27.75						
Falco vespertinus	< 5															
Gypaetus barbatus	< 1															
Gyps africanus	< 1															
Gyps fulvus	8,824.00		8,824.00		30-Oct	28-Jul	18-Nov	114	2,534.00	13.23	8,759.70	32.68	08-May	07-Apr	30-May	54
Gyps rueppellii	< 15															
Milvus migrans	119,914.00	10.96	224,585.44	12.66	16-Aug	29-Jul	10-Sep	44	35,723.25	14.47	169,018.66	17.3	15-Mar	20-Feb	10-May	80
Milvus milvus	27	22.83	30	73.29	24-Sep	29-Jul	02-Oct	66	3	0						
Necrosyrtes monachus	< 1															
Neophron percnopterus	2,414.50	5.71	2,482.79	6.59	08-Sep	23-Aug	24-Sep	33	423	11.69	1,282.00	15.63	08-Mar	20-Feb	09-May	79
Pandion haliaetus	75	19.8	92.31	22.86	14-Sep	31-Aug	02-Oct	33	49.75	41.15	841.98	52.3	30-Mar	15-Feb	15-May	90
Pelecanus onocrotalus	< 1															
Pelecanus rufescens	< 1															
Pernis apivorus	57,391.50	8.62	59,332.34	9.96	01-Sep	26-Aug	14-Sep	20	8,348.50	37.15	59,361.96	40.28	08-May	01-May	24-May	24
Terathopius ecaudatus	< 1															
Total	**314,258.17**		**513,572.26**						**72,029.50**		**427,311.87**					

On the whole, the magnitude of the passage is larger in autumn than in spring migration for most of the studied species. However, for black stork, honey buzzard, marsh harrier, sparrowhawk, osprey, lesser kestrel and hobby, the number of migrating birds in autumn is similar or even lower than in spring.

The estimates of the total number of migrating black kites, short-toed eagles and booted eagles observed over the Strait largely exceed the current estimates for their breeding populations in Northern, Central and Western Europe (Figure 2). In contrast, all other species were recorded migrating over the Strait in lower number in relation to their breeding population size according to BirdLife International estimates. Comparisons between breeding individuals and migratory populations in griffon vultures were not straightforward because in this species only juvenile individuals migrate (Griesinger 1996).

Figure 2. *Comparisons between migration population estimates over the Strait of Gibraltar and European breeding population estimates (BirdLife International 2004). a) Species migrating mainly by soaring flight; b) species migrating on a broad front (Newton 2008). Grey bars represent averaged autumn migration estimates for 2009-2012 whereas black bars show the number of breeding individuals in 2000 according to BirdLife International. Breeding individuals from Central, Northern and Western Europe (see Methods). * Migration estimates for griffon vulture and white stork are based on one survey in 2008 and two surveys in 2011-2012, respectively (see Methods). In griffon vulture only juvenile individuals migrate (Griesinger, 1996).*



Timing of the soaring bird migration over the Strait

During spring, the earliest migrant over the Strait of Gibraltar was the white stork, with first passage dates in October and November of the previous year. These dates contrast with those for griffon vultures (late March to early June) and honey buzzards (main passage during May) which are the latest migrants (Table 1). Overall, the order in which the different species migrate over the Strait is similar in spring and autumn except for honey buzzard and, to a lesser extent, for Montagu's harrier and black kite.

Maximum numbers of migrating birds in spring could be observed in February and March, mainly consisting of white storks, black kites, Egyptian vultures, short-toed eagles, marsh harriers, lesser kestrels and ospreys. Furthermore, booted eagles, Montagu's harriers, sparrowhawks and hobbies were the main migrants (in terms of number of birds) crossing the Strait in April.

In the autumn migration, white storks and black kites were the most commonly observed species in July and August, whereas large numbers of honey buzzards, short-toed eagles, booted eagles, black storks and all other most abundant raptor migrants were observed during September and October (Table 1).

The central 90% of the migration passage ranged between 24 (honey buzzard) and 160 days (white stork) in spring and between 20 (honey buzzard) and 114 days (griffon vulture) in autumn. Length of spring migration was larger (27 days on average) than the length of the autumn passage for all species except for griffon vulture and Montagu´s harrier.

Discussion

This study is the first attempt of estimating the real magnitude of soaring bird migration over the Strait of Gibraltar, one of the most important bottlenecks in the entire European–African flyway system and the most important bottleneck in Western Europe for migratory birds. In addition, for the first time, we provide reliable data on number of birds and timing of passage over the Strait both in spring and autumn. Overall, about 135.000-150.000 storks (two different species with regular presence during migration) and 290.000-350.000 raptors

(28 species regularly crossing during migration) can be observed migrating over the Strait Gibraltar.

These numbers are smaller (both in number of individuals and in number of species) than those recorded in other bottlenecks in the south-eastern flyway (e.g., Bosphorus, Batumi, Eilat; Finlayson 1992, Shirihai *et al*. 2000, Newton 2008), but they exceed many times those found in Central Mediterranean Sea (e.g., Messina; Newton 2008). Counts in eastern and southern bottlenecks show the strong barrier effect of the Mediterranean Sea for soaring bird migration. Only those species which are able to migrate frequently by flapping flight, such as honey buzzards, harriers, *Falcons*, sparrowhawks, kestrels and ospreys, are less conditioned by the Mediterranean Sea and usually migrate on a broad front (Meyer *et al*. 2000 and 2003, Newton 2008).

In contrast to the species composition reported for other bottlenecks (i.e. Eilat, Finlayson 1992) differences between spring and autumn species composition are low (Finlayson 1992) in the Strait of Gibraltar. In addition, soaring birds migrating via the Strait are also very similar in terms of species abundance in spring and autumn. The reason behind these results is that the Strait of Gibraltar is the only point of convergence for soaring birds following the south-western flyway. However, number of soaring birds recorded during spring is smaller than the number of birds counted during autumn migration, mainly because the spring migratory population has experienced winter mortality before the next breeding attempt.

Dates of passage are different between seasons within species. Overall, we generally found that autumn migration occurs within a much narrower temporal frame than the spring migration (Bernis 1975a,b). The longer spring migration period has been previously related to the more vague and delayed arrival of immature and non-breeding individuals in this season (Newton 2008). This much narrower autumnal temporal frame allows for a more efficient monitoring of migration because of its shorter duration. Both in spring and autumn, the length of migration is influenced by particular species characteristics and constraints. For instance, honey buzzard, which shows the shortest migration length over the Strait of Gibraltar (Bernis 1980a; present study,) as well as through the south-eastern migration route (e.g., Verhelst *et al*. 2012), has a strong flight and is able to fly in wind conditions unsuitable for other species (Finlayson 1982).

Species composition

The most abundant species both in spring and autumn migration over the Strait are black kite, white stork and honey buzzard. We also found large numbers of short-toed eagles, booted eagles, griffon vultures and Egyptian vultures, in that order. Particularly, numbers of short-toed eagles observed over the Strait are the largest recorded for this species in any other bottleneck over the world. By comparison, forest raptor species such as common and honey buzzards, sparrowhawks, large-sized eagles and, to a lesser extent, harriers and *Falcons*, are of much less importance in terms of the number migrating individuals over the Strait of Gibraltar when compared with central and eastern Mediterranean bottlenecks (e.g., Batumi; Verhelst *et al*. 2012).

Two of the three most abundant raptor species migrating across the Strait of Gibraltar (honey buzzard and black kite) are also the most common migrants over Batumi (eastern Black Sea coast), and Eilat (southern Israel). Of those raptor species shared between eastern observatories (Batumi and Eilat) and Gibraltar bottlenecks, honey buzzard, marsh harrier, Montagu's harrier, sparrowhawk, hobby and peregrine *Falco*n migrate in larger numbers through the East flyway, whereas black kite, Egyptian vulture, booted eagle, short-toed eagle, osprey and lesser kestrel are more abundant through the Strait of Gibraltar.

Migrating soaring birds over the Strait of Gibraltar mainly come from western European breeding populations according to data from ringed birds (Bernis 1966, Bernis 1980a, Diaz *et al*. 1996, SEO/BirdLife 2012). Birds that breed in northern and central Europe, however, may also migrate in a south-west direction and then arrive at the Strait of Gibraltar, or they may follow a south-east migration direction, as is the case of Eastern European populations. Depending on the species, a third alternative route via Messina (Italy) is also possible. The proportion of northern and central European birds following one or another flyway depends on the particular species and populations (Finlayson, 1992). Because the south-eastern flyway via Batumi or Eilat is utilized by birds from a different geographical area compared with those using the western flyway (Verhelst *et al*. 2012) there are significant differences in the composition and abundance of migrating species between the Strait of Gibraltar and the eastern observatories. However, migration timings appeared to keep very constant between both bottlenecks for most migrant soaring bird species. All the timing parameters that are reported in this study (median date of passage, date of first 5% and 95%, and length of the central 90%) are practically the same in both bottlenecks for honey buzzards, booted eagles, Egyptian vultures, sparrowhawks, marsh harriers, lesser kestrels and ospreys. However, black kites and white storks showed earlier passage dates at the Strait of Gibraltar than at Eilat (Krumenacker 2012) and Batumi (Verhelst *et al*. 2012). In contrast, hobby and peregrine *Falco*n showed an earlier passage through Batumi. Furthermore, the length of migration for Montagu's harrier is greater in the Strait of Gibraltar, the dates of first passage being earlier than those recorded in Batumi (Verhelst *et al*. 2012). Previous studies based on recoveries from ringed white storks point out that the latitude of the breeding influences the dates of passage of the different populations (Fernández and Sarasa 1998). Similarly, dates of passage of migrating soaring birds between the southeastern route (Eilat and Batumi) and the Strait (southwestern route) may reflect a similar latitudinal location of the source breeding populations of these species in relation to both bottlenecks.

Migrating and breeding populations

Our spatial and temporal corrections provide with reliable estimates of the real magnitude of soaring bird migration over the Strait. These estimates largely exceed the available numbers for the breeding population size of black kite, booted eagle and short-toed eagle (BirdLife International 2004). These species migrate mainly by soaring flight (Newton 2008), thus they have greater limitations when crossing over water and thus create migration bottlenecks. As they are highly concentrated at the Strait, we can observe a larger fraction of their total migratory population in contrast with species migrating along a broad front (Meyer *et al*. 2000, Newton 2008). Although a soaring raptor, griffon vulture breeding and migrating populations cannot be compared because only juvenile griffon vultures travel to Africa in the autumn (Griesinger 1996). Among the migrating birds there must be adult breeding individuals but also an unknown proportion of floating non-breeders which may be easily overlooked during surveys in the breeding grounds. This is especially the case during autumn migration passage when the migrating population includes adult, non-breeders, immature and juvenile individuals raised in the previous spring. However, this non-breeding population cannot in itself explain differences of such a magnitude.

For species mainly migrating by soaring flight, at least part of the difference between numerical estimates on the breeding grounds (BirdLife International 2004) and those from migrating birds reported here, may arise from underestimates of the non-breeding population. Since the numbers of birds observed at a migration observatory are always partial counts of the total migratory passage (Newton 2008) they should be only a fraction of the total breeding population. In contrast to other soaring bird species with low difficult to survey and with low detectability in their breeding grounds (Palomino and Valls 2011), the European breeding population of white storks is better known. Supporting the reliability of our estimates, migration counts represent only 70% of the total breeding population estimate of the white stork. Migration counts of soaring raptor species that frequently use flapping flight in migration movements (*Falcons*, harriers, ospreys and sparrowhawks) do not provide robust estimates of breeding population size because only a small fraction of the total migratory population can be sighted over the bottleneck during their broad front migration (Meyer *et al*. 2000 and 2003).

Migration bottlenecks for population monitoring

Together with the Strait of Gibraltar, Batumi and Eilat constitute the Western Palearctic's most important bottlenecks for soaring bird migration (Porter and Beaman 1985). Adding up the counts of the most frequently observed species in Batumi (Verhelst *et al*. 2012); Eilat (Leshem and Yom-Tov 1996, Krumenacker 2012) and the Strait, numbers of birds recorded for these species during autumn migration in these bottlenecks (572,000 honey buzzards and 331,000 black kites) are about two times larger than the most recent total estimates of the European breeding population (BirdLife International 2004). However, some migrating soaring birds observed in Batumi may originate from Asian breeding populations. Counts for both stork species are low at Batumi (maximum of 511 white storks observed in 2011 and 604 black storks in 2011) because the main migration passage of these species through the eastern flyway (Finlayson 1992) must take place through the Bosphorus in Turkey (Bjilsma 1987) and Eilat in southern Israel (Krumenacker 2012). Although there are no recent accurate estimates for white and black storks at the Bosphorus, we can use the counts recorded in the western Black Sea bottleneck, Bourgas Bay, in Bulgaria (Michev *et al*. 2011) and Eilat, in northern Israel (Krumenacker 2012), as an indicator of this passage. Adding up the counts of white stork (393,000 individuals) and black stork (7,300 individuals) migrating through Bourgas, Eilat and the Strait, almost the total European breeding population of white stork (95%) and about 40% estimated for the black stork is observed over these three bottlenecks every autumn.

Conclusions

Many of the soaring bird species here presented show low detectability on their breeding grounds and many of them are frequently both logistically difficult and prohibitively expensive to survey and monitor (Fuller and Mosher 1981, 1987). Furthermore, our results clearly indicate an underestimation in the more recent population estimates for many soaring bird species in Europe. One potentially cost-effective method for monitoring regional populations of these species is sampling their numbers during migration (Bildstein *et al*. 2007). We can observe the highest concentrations of most of the European migratory raptor species at the western and eastern ends of the Mediterranean over the Strait of Gibraltar and Eilat and Batumi bottlenecks respectively (Bernis 1980a, Porter and Beaman 1985, Bijlsma 1987, Verhelst *et al*. 2012, present study).

Similarly, the bottlenecks at the Bosphorus and the Strait record a large number of the European population of breeding white and black storks (Finlayson 1992). The information collected with long-term standardized surveys in observatories placed along the Western Palearctic’s migratory flyway will allow us improve our knowledge and understanding of aspects such as timing of passage, relative abundance of the migratory species (Porter and Beaman 1985), population monitoring (Farmer *et al*. 2007) and changes therein (e.g., Gordo and Sanz 2006). However, for species frequently flying by flapping which migrate across a broad front (Newton 2008) such as *Falcons*, harriers, ospreys and sparrowhawks, counts in migratory bottlenecks are only effective for studying the timing of passage since the number of birds observed through direct observation are not a reliable estimates of the total number of birds migrating over Europe.

Acknowledgements

We are grateful to the thousands of people (volunteers and staff) who collected the information presented in this study and to the Board of the Migres Foundation. The data counts from the Strait of Gibraltar analyzed in the study were collected within the field monitoring campaigns 1999/2012 funded by grants of the Consejería de Medio Ambiente from the Junta de Andalucía (Spain). We would also like to thank Andrew Paterson for his kind revision of the language of the manuscript.

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CAPITULO 3. Cambios en la magnitud y composición del paso migratorio de aves planeadoras por el estrecho de Gibraltar: una comparativa entre 1976-2010

Changes in the magnitude and composition of migratory soaring birds passing through the Strait of Gibraltar: a comparison between 1976-2010

Artículo en preparación:

Onrubia A., Martín, B. & Tellería, J.L.. *en preparación*. Cambios en la magnitud y composición del paso migratorio de aves planeadoras por el estrecho de Gibraltar: una comparativa entre 1976 y 2010.

Cambios en la magnitud y composición del paso migratorio de aves planeadoras por el estrecho de Gibraltar: una comparativa entre 1976 y 2010

Resumen

El estrecho de Gibraltar constituye uno de los lugares de concentración de aves migratorias más importantes del mundo al canalizar una porción mayoritaria de las poblaciones de cigüeñas y rapaces de Europa occidental. Desde los 1970s se han desarrollado diversas campañas de censo y desde 1999 cuenta con un programa de seguimiento anual operando con protocolos estandarizados. En este trabajo se comparan las cifras de paso de las campañas de 1976 y 1977 con las realizadas en 1999-2000 y 2011-2012. Esto permite evaluar los cambios en el paso migratorio en un periodo largo de tiempo (35 años) en un contexto de cambio global. Las comparaciones entre los censos muestran un incremento generalizado en el número de aves planeadoras en paso, aunque este aumento parece haberse producido mayoritariamente en la última década. Las especies más abundantes en los años 70 también lo son en la actualidad, aunque la contribución de cada una de ellas al paso total ha cambiado ligeramente entre ambos periodos. En general, hay un aumento significativo de migrantes transaharianos (cigüeña blanca, milano negro, águila calzada, águila culebrera, cigüeña negra, alimoche), algunos presaharianos (gavilán), residentes en dispersión (grandes águilas y buitre leonado), y se producen algunas nuevas incorporaciones, como especies de filiación africana (buitre moteado, busardo moro, halcón borní) y algunos migrantes orientales (águila pomerana, aguilucho papialbo, cernícalo patirrojo). Este patrón contrasta con la estabilidad o disminución de los migrantes presaharianos (cernícalo vulgar, busardo ratonero, aguilucho pálido, esmerejón, azor, milano real) y algunos transaharianos (abejero, aguilucho cenizo, cernícalo primilla, alcotán). Las variaciones en el paso parecen estar propiciadas por cambios en las poblaciones de origen y, en algunos casos, por cambios en los patrones migratorios por acortamiento de la migración o cambios de ruta o distribución.

Abstract

The Strait of Gibraltar is one of the most important places for migratory birds in the world, concentrating a major portion of storks and raptors populations in Western Europe. Since the 1970s several counting campaigns have been carried out and from 1999 an annual monitoring program is operating with standardized protocols. In this work we compared numbers obtained in 1976-1977 campaigns with those made in 1999-2000 and 2011-2012. This allows us to evaluate migration changes in a long period of time (35 years) in a context of global change. Comparisons between censuses show a general increase in the number of soaring birds, although this increase appears to have occurred mainly in the last decade. The most abundant species in the 70s are also at present, although the contribution of each species to the total has changed slightly between the two periods. In general, there is a significant increase in trans-Saharan migrants (white stork, black kite, booted eagle, short-toed eagle, black stork, Egyptian vulture), some pre-Saharan (sparrowhawk), dispersal residents (big eagles and vultures). Also, new additions have occured, as some African species (Ruppell´s vulture, long-legged buzzard, lanner *Falco*n) and some Eastern migrants (lesser spotted eagle, pallid harrier, red-footed *Falco*n). This pattern contrasts with the stability or decrease in pre-Saharan migrants (common kestrel, common buzzard, hen harrier, merlin, goshawk, red kite) and some trans-Saharan ones (honey buzzard, Montagu's harrier, lesser kestrel, hobby). Variations in the passage appear to be prompted by changes in the populations and, in some cases, changes in migration patterns by shortening, rerouting or variation in distribution.

Introduccion

La actividad humana está ejerciendo un fuerte impacto sobre la Tierra y sus repercusiones globales distan mucho de estar bien conocidas y evaluadas. La actual crisis ambiental ha motivado la puesta en marcha de iniciativas de ámbito internacional tendentes a frenar la creciente pérdida de biodiversidad (Myers *et al* 2000). Sin embargo estamos lejos de conocer el impacto que la acción humana ejerce sobre cada una de los millones de especies que habitan la Tierra. Esto ha obligado a centrar los esfuerzos sobre grupos de organismos bioindicadores, cuya respuesta pudiera reflejar los efectos del impacto antrópico sobre los ecosistemas (Andelman & Fagan 2000, Hilty & Merenlender 2000, Rodrigues & Brooks 2007). A este respecto, las aves juegan un papel importante como centinelas ambientales: se trata de organismos bien conocidos y relativamente fáciles de estudiar, se encuentran distribuidos por prácticamente todos los ambientes de la Tierra, ocupan los niveles superiores de las pirámides tróficas, y sus poblaciones responden frecuentemente a los cambios en los ecosistemas (Koskimies 1989, Furness & Greenwood 1993).

Entre los distintos grupos de aves habitualmente empleados como indicadores ambientales destacan las aves de presa, por sus elevadas exigencias ecológicas y por su papel en procesos de bioacumulación de diferentes contaminantes (Sergio *et al*. 2005 y 2006, Gomez-Ramirez *et al*. 2014). También los son las aves migratorias, que precisan de un buen estado de conservación de los múltiples hábitat que utilizan durante sus periplos migratorios (Bildstein 2001, Gregory *et al*. 2005, Sergio *et al*. 2005 y 2006). Estos grupos ejemplifican además los principales problemas de conservación a los que se enfrentan las aves y que incluyen la persecución directa (caza, veneno…), el impacto de infraestructuras viarias o de producción o distribución de energía, o las alteraciones en los hábitats de los que dependen por contaminación, cambio de usos del suelo, cambio climático, entre otros (Bildstein *et al*. 2000, Zalles & Bildstein 2000, Sergio *et al*. 2005, Bildstein 2006). Estos grupos incluyen además muchas especies de gran tamaño, muy populares y con un marcado carácter emblemático que han protagonizado multitud de campañas de sensibilización y numerosos programas de conservación desarrollados en las últimas décadas (Simberloff 1998, Bildstein 2006). Por estas razones son también objeto de diferentes programas de seguimiento de sus poblaciones bien mediante censos periódicos realizados durante la época de cría o en cuellos de botella durante sus migraciones (McCarty & Bildstein 2005, Hardy *et al*. 2006, Bird & Bildstein 2007, Vrezec *et al*. 2012).

El estrecho de Gibraltar es uno de los lugares de concentración de aves migratorias más importantes del mundo, especialmente para las aves planeadoras (Bernis 1980, Porter & Beaman 1985, Finlayson 1992, Zalles & Bildstein 2000). A través del Estrecho se canaliza el paso de la mayor parte de las poblaciones migratorias de cigüeñas y rapaces planeadoras de la ruta occidental del sistema migratorio Paleártico-Africano, entre las áreas de cría de Europa occidental y las áreas de invernada situadas en el norte de Africa (migrantes presaharianos) o al sur del Sahara (migrantes transaharianos) (Bernis 1980, Newton 2008, Martin *et al en prensa*). Es además un lugar con una larga tradición ornitológica y cuenta con numerosos trabajos enfocados a conocer la entidad del fenómeno migratorio (ver por ejemplo Bernis 1980, Tellería 1981, Finlayson 1992). Además, desde 1999 la zona cuenta con un programa de seguimiento anual ("programa Migres") que opera bajo protocolos estandarizados de esfuerzo constante (Programa Migres 2009). Estas circunstancias constituyen una excelente oportunidad para la comparación entre ambos trabajos en un contexto general de cambio global. Trabajos parciales ya se han realizado anteriormente, aunque restringidos a sectores parciales del estrecho (Peñón de Gibraltar) durante la migración primaveral (Bensusan *et al*. 2007) o, aunque referidos también a la migración otoñal, restringidos a un periodo temporal mucho más limitado (i.e. 1999-2014, Martín *et al*. *en prensa*.).

En el periodo 1980-2010 (30 años) han tenido lugar cambios ambientales importantes reflejo de los profundos cambios socioeconómicos y culturales de la actividad humana en esta región del globo (Millennium Ecosystem Assessment 2005). En este periodo se ha registrado un notable incremento de aquellos convenios y normas relativos a la conservación de la naturaleza que tienen su consiguiente reflejo en el aumento de la superficie de áreas protegidas y la puesta en marcha de numerosos programa de protección de especies amenazadas, a la vez que la actividad humana está produciendo cambios profundos en el medio (Tucker & Evans 1997, Millennium Ecosystem Assessment 2005, Goudie 2013). Estos patrones se producen en un contexto de cambio climático que se ha acelerado en los últimos 30 años (IPCC 2014). En estas circunstancias es previsible que las poblaciones de cigüeñas y rapaces migratorias estén respondiendo entre los márgenes impuestos por un medio sujeto a intensos y profundos cambios del hábitat y el incremento de programas y medidas de conservación enfocadas a paliar estos impactos.

El objetivo de este estudio es comparar la magnitud y composición del paso migratorio de aves planeadoras por el Estrecho de Gibraltar en el periodo de

1976 a 2010, empleando como referencia los trabajos pioneros de Bernis (1980) y comparando con los programas de seguimiento actualmente en marcha (Migres, 1999-2012). Se trata de testar si se han producido cambios en el paso de cigüeñas y rapaces en un periodo relativamente amplio de tiempo y determinar los patrones emergentes. Trabajos similares se han realizado con otros grupos de aves (paseriformes y grupos afines –ver Onrubia y Tellería, 2012-) lo cual permite evaluar si los cambios detectados tienen también reflejo en otro grupo de aves migratorias terrestres pero de larga esperanza de vida y entre especies con diferentes nichos ecológicos. Teniendo en cuenta que los números de aves en paso por el Estrecho pueden reflejar tanto cambios poblacionales como cambios en los patrones de migración (Onrubia *et al* 2011, Martín *et al*. 2014, Scholer *et al*. 2015, Martín *et al*. *en prensa*), se explora la relación de estos cambios con las tendencias poblacionales de las poblaciones de origen y las estrategias migratorias de las diferentes especies.

Material y métodos

Debido a su particular localización geográfica y su singular disposición y orografía, el estrecho de Gibraltar (36º 00´29.63´´N 5º 3623.45´´W) recibe un importante contingente de cigüeñas y rapaces migratorias del Paleártico occidental concentrando la práctica totalidad de las poblaciones migratorias de las especies estrictamente planeadoras (cigüeñas, grandes rapaces) y una porción variable de las especies de vuelo más batido (ej. aguiluchos, halcones) (Bernis 1980, Martín *et al*. *en prensa*). En este trabajo hemos considerado como sujeto de análisis la totalidad de especies de cigüeñas y rapaces diurnas en tránsito por el Estrecho, descartando otras especies consideradas planeadoras, como pelícanos, grullas o garzas (Newton 2008), por ser de presencia accidental (pelícanos) o migradores eminentemente nocturnos en el Estrecho.

En el sector español del Estrecho el estudio de la migración diurna de aves planeadoras comenzó en los 1970s y desde 1997 dispone de un programa de seguimiento anual sistemático siguiendo protocolos estandarizados (Bernis 1980, Barrios & Doval 2007, Programa Migres 2009). Los censos de 1970s se basan en observaciones diarias desde siete observatorios comunicados entre sí, operando durante todas las horas de luz, en los que se registraba el total diario de aves en cruce (Bernis 1980). En el caso del programa Migres, los censos se realizan desde dos observatorios (Cazalla y Algarrobo), operando desde las 9:00 hasta las 18:00 (hora oficial). En este caso, para reducir en lo posible los efectos de los dobles conteos de aves circulando por la zona, solamente se han considerado aquellas aves volando en dirección sur con comportamiento de cruce (Barrios & Doval 2007, Programa Migres 2009). En ambos casos, los censos se realizaron por observadores expertos acompañados por ayudantes y con óptica adecuada, prismáticos de 8 a 10 aumentos y telescopios de 20 a 60 aumentos.

Para este trabajo se han considerado los resultados de los censos otoñales de aves planeadoras de las campañas correspondientes a 1976 y 1977, por considerarse las más completas y estandarizadas de las realizadas en esa época según los propios autores (Bernis 1980), y los datos de las campañas correspondientes a 1999-2000 y 2011-2012 del programa Migres. En ambos casos los conteos se realizaron entre el 20 de julio y el 15 de octubre, periodo que recoge aproximadamente el 95% del paso total postnupcial (Programa Migres 2009, Scholer *et al*. 2015) y que corresponde a 88 jornadas de censo. A pesar de que la metodología de trabajo no ha sido idéntica, los datos obtenidos pueden ser comparables con ciertas precauciones, ya que los trabajos previos de diseño del protocolo Migres realizados en 1997 fueron similares a los realizados en 1976-1977 (en términos de días de muestreo y número de observatorios, Barrios & Doval 2007) y se puede estimar la proporción de migrantes total registrada según Bernis (1980), que significan los dos observatorios de Cazalla y Algarrobo. Asimismo, los horarios del programa Migres recogen el 95% del paso diurno diario total (Barrios & Doval 2007, Programa Migres 2009). De esta manera, se pueden obtener datos comparables de aves en migración entre ambos periodos, aunque hay que tener en cuenta que los datos de Bernis (1980) pueden ser ligeramente más exhaustivos a los equivalentes del programa Migres.

Análisis de datos

Para conocer los posibles cambios en el paso de aves planeadoras por el estrecho de Gibraltar se han considerado los resultados de los censos realizados en 1976-1977, 1999-2000 y 2011-2012, correspondientes a un periodo de unos 30 años. Para ello se ha calculado para cada especie la media de los individuos censados para cada bienio y se ha obtenido una tasa de cambio para cada periodo a partir del cociente entre los datos medios de cada bienio en el periodo implicado: 1976-1977 y 1999-2000 (tasa 70s-90s), 1999-2000 y 2011-2012 (tasa 90s-2010s) y 1976-1977 y 2011-2012 (tasa 70s-2010s).

Se ha analizado la relación entre la variación inter-específica en el número de individuos en paso en los bienios 1999-2000 y 2011-2012 con los registrados en 1976-77 mediante un GLM donde se ha utilizado el estatus migratorio (especie de migración pre o trans-sahariana) como factor de clasificación y los numeros de aves en paso como covariante. Igualmente, se ha realizado una comparación por pares (test de la t para muestras dependientes) del número de aves en movimientos entre todos los años analizados. Para satisfacer la suposición de normalidad, se ha realizado una transformación logarítmica de la variable dependiente. El objetivo es determinar si hay algún efecto significativo del estatus migratorio después de controlar por el efecto de la abundancia de 1976-77.

Resultados

Conteos totales

Como resultado del esfuerzo de censo realizado entre 1976 y 2012 se han registrado 34 especies de aves planeadoras correspondientes a dos especies de cigüeñas y 32 de rapaces diurnas. Las cinco especies que acumulan el 97% del total de aves en paso por el Estrecho en 1970s (milano negro, cigüeña blanca, abejero europeo, aguililla calzada y culebrera europea) son las mismas que en los dos periodos posteriores (1990s, 2010s). Entre 1970s y la actualidad, el número total de aves planeadoras prácticamente se ha duplicado, desde los 180.000 ejemplares registrados en 1970s hasta los 310.000 individuos a los que ascienden los conteos en el año 2010 (tabla 1). El aumento general del paso, sin embargo, muestra ciertas divergencias entre especies: del conjunto de 34 especies, 18 aumentan, uno no muestra cambios (estable), tres especies son nuevas, 10 especies disminuyen y tres especies desaparecen. Las tasas de aumento oscilaron entre 1,6 y 10 veces dependiendo de las especies, con las tasas más elevadas registradas en la cigüeña negra y aguililla calzada (10 veces) e incrementos importantes (más de 2 veces) en culebrera europea, aguilucho lagunero, gavilán y milano negro. Por su parte, las disminuciones más importantes ocurren en busardo ratonero, aguilucho cenizo, abejero europeo y alcotán. Además en la última década hacen aparición tres especies nuevas en el tránsito del Estrecho (*G.rueppellii*, *C.macrourus*, *F.vespertinus*).

Del elenco total de especies hay once especies (6 de las más comunes) que muestran aumentos significativos en ambos periodos de tiempo, que son además las que muestran las tasas globales de incremento más elevadas (*C.nigra*, *M.migrans*, *C.gallicus*, *A.nisus*, *A.pennata*, *P.haliaetus*). Por su parte, hay otras once especies (ocho de las más comunes) que se mantienen estables o disminuyen en el periodo 1970s-1990s pero aumentan sensiblemente en el periodo 1990s-2010s, aunque en tres especies, abejero, aguilucho cenizo y alcotán, no llegan a recuperar los niveles originales de los setenta. Solamente tres especies aumentan en el periodo 1970s-1990s pero disminuyen notablemente en la década siguiente (ej. *M.milvus*) y cuatro especies disminuyen sensiblemente en el periodo 1970s-1990s, llegando a desaparecer su paso en ese periodo (*F.columbarius*) o no llegan a recuperarse en la última década (*B.Buteo*, *C.cyaneus*, *F.tinnunculus*).

Tendencias numéricas y efectos del estatus migratorio

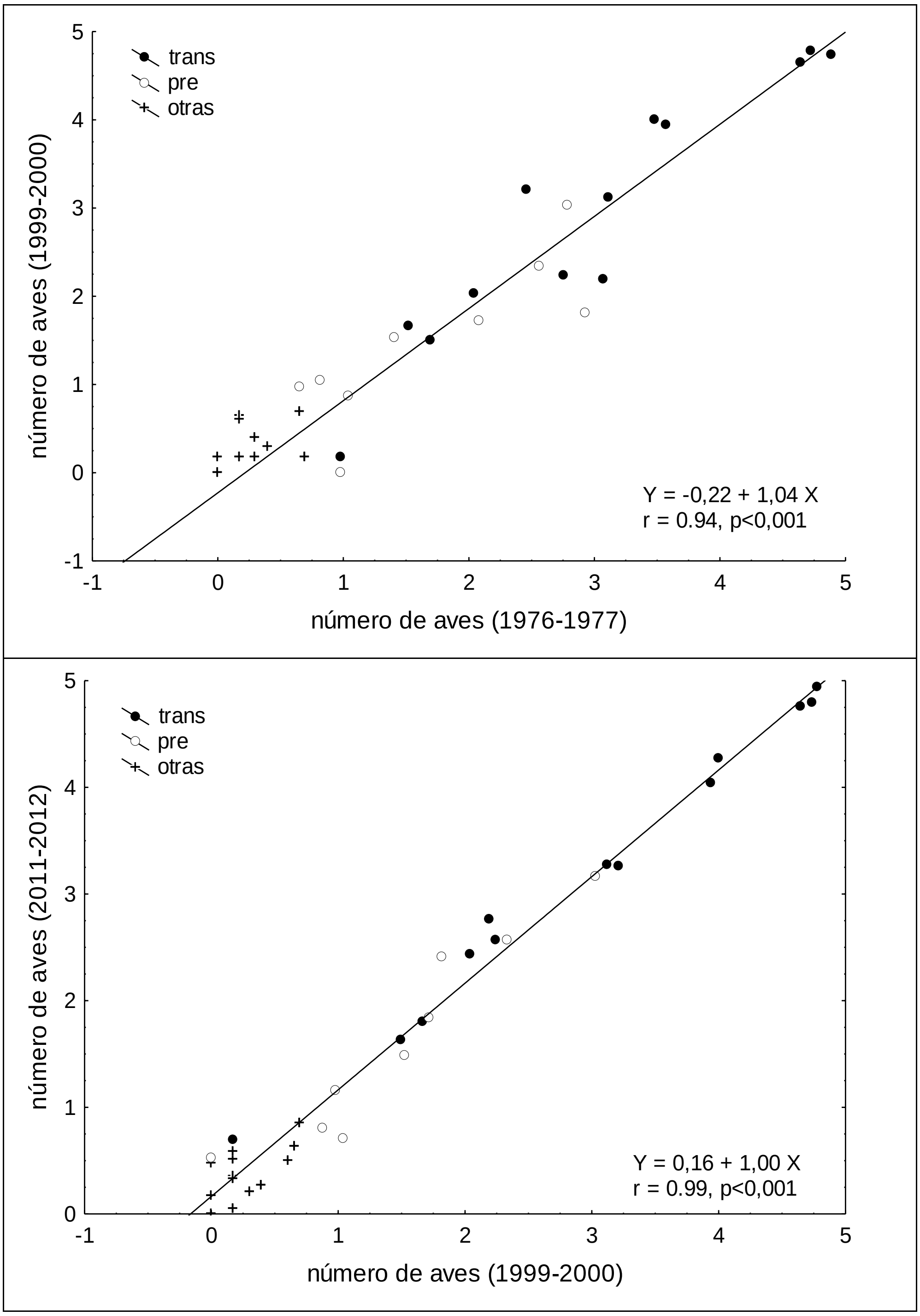
La estructura de la comunidad de planeadoras en paso por el Estrecho difirió poco entre 1976-977 y 1999-2000 dado que la adscripción de indivduos por especie varió poco entre ambos periodos (t=1.13, g.l. 21, p=0,271). Sin embargo, se observó un drástico cambio entre 1999-2000 y 2011-2012, al aumentar sensiblemente los efectivos implicados en estos movimientos (t=4,079, g.l. 21, p<0,001). Es interesante resaltar que este incremento se debió, especialmente, a los migrantes transaharianos (t=4,71, g.l. 12, p<0,001) y no a los cambios en los invernantes pre-saharianos (t=1,55, g.l. 8, p=0,160).

En realidad, la distribución de abundancias entre especies en el periodo previo fue el principal predictor (con una elevada varianza explicada; Figura 1) de las abundancias de especies en el periodo subsiguiente, sin que se detectara un efecto significativo del estatus migratorio de las especies (1976-77 vs. 1999-2000: Status F1,19=0,30, p<0.588; abundancia F1,19=101,94, p<0,001, R2=0,88; 1999-2000 vs 2011-2012.: Status F1,19=2,24, p=0.151; abundancia F1,19=566,85, p<0,001, R2=0,98).

Tabla 1.- *Censos medios anuales (1976-1977; 1999-2000 y 2011-2012) y tasa de cambio entre periodos en el estrecho de Gibraltar.*

	Especies	**1976-1977**	**1999-2000**	**2011-2012**	**Tasa 70s-90s**	**Tasa 90s-2010s**	**Tasa 70s-2010s**
Cigüeña negra	*Ciconia nigra*	285.0	1628.5	2669.5	5.71	1.64	9.37
Cigüeña blana	*Ciconia ciconia*	44187.0	44821.0	75376.0	1.01	1.68	1.71
Abejero europeo	*Pernis apivorus*	76829.0	55219.5	56537.0	0.72	1.02	0.74
Elanio	*Elanus caeruleus*	0.5	0.5	1.0	1.00	2.00	2.00
Milano negro	*Milvus migrans*	53137.5	60639.5	119920.5	1.14	1.98	2.26
Milano real	*Milvus milvus*	24.5	32.5	18.5	1.33	0.57	0.76
Alimoche	*Neophron percnopterus*	1290.5	1328.0	2424.0	1.03	1.83	1.88
Buitre leonado	*Gyps fulvus*	367.0	217.0	584.0	0.59	2.69	1.59
Buitre moteado	*Gyps rueppellii*	0.0	0.0	20.5			
Buitre negro	*Aegypius monachus*	0.5	0.5	0.0	1.00	0.00	0.00
Culebrera europea	*Circaetus gallicus*	3695.0	8699.5	18071.0	2.35	2.08	4.89
Aguilucho lagunero	*Circus aeruginosus*	110.0	108.0	450.0	0.98	4.17	4.09
Aguilucho pálido	*Circus cyaneus*	10.0	6.5	6.5	0.65	1.00	0.65
Aguilucho papialbo	*Circus macrourus*	0.0	0.0	1.0			
Aquilucho cenizo	*Circus pygargus*	1175.5	154.5	509.0	0.13	3.29	0.43
Azor	*Accipiter gentilis*	5.5	10.0	1.5	1.82	0.15	0.27
Gavilán	*Accipiter nisus*	611.5	1070.5	2221.0	1.75	2.07	3.63
Busardo ratonero	*Buteo buteo*	848.0	64.5	64.5	0.08	1.00	0.08
Busardo moro	*Buteo rufinus*	0.5	3.5	12.0	7.00	3.43	24.00
Águila pomerana	*Aquila pomarina*	0.5	3.0	6.0	6.00	2.00	12.00
Águila moteada	*Aquila clanga*	4.0	0.5	0.0	0.13	0.00	0.00
Áquila imperial	*Aquila adalberti*	1.0	0.5	4.5	0.50	9.00	4.50
Águila real	*Aquila chrysaetos*	1.5	1.0	0.5	0.67	0.50	0.33
Aguililla calzada	*Aquila pennata*	3015.0	9941.5	31910.5	3.30	3.21	10.58
Águila perdicera	*Aquila fasciata*	3.5	4.0	13.0	1.14	3.25	3.71
Águila pescadora	*Pandion haliaetus*	32.5	45.5	63.5	1.40	1.40	1.95
Cernícalo primilla	*Falco naumanni*	573.7	173.9	592.8	0.30	3.41	1.03
Cernícalo común	*Falco tinnunculus*	119.3	51.6	51.2	0.43	0.99	0.43
Cernícalo patirrojo	*Falco vespertinus*	0.0	0.5	0.0		0.00	
Esmerejon	*Falco columbarius*	8.5	0.0	0.0	0.00		0.00
Alcotán	*Falco subbuteo*	48.0	30.5	37.0	0.64	1.21	0.77
Halcón de Eleonora	*Falco eleonorae*	8.5	0.5	5.0	0.06	10.00	0.59
Halcón borní	*Falco biarmicus*	1.0	1.5	3.0	1.50	2.00	3.00
Halcón peregrino	*Falco peregrinus*	3.5	8.5	17.0	2.43	2.00	4.86
	Total	186398.5	184270.0	311593.5	0.99	1.69	1.67

Figura 1. *Relación entre los conteos de aves en paso en los tres periodos de estudio. La abundacia por especie han sido transformadas logarítmicamente (log10 (x+1)). Trans se refiere a los migrantes transaharianos, pre a los presaharianos y otras a las especie no consideradas en el análisis por la escasez de resultados.*



Discusión

Las comparaciones entre los censos realizados por Bernis (1980) en 1976-1977 en el Estrecho de Gibraltar y los desarrollados en 1999-2000 y 2011-2012 muestran un incremento generalizado en el número de aves planeadoras en paso, aunque este aumento parece haberse producido mayoritariamente en la última década ya que las tasas de aumento entre 1990s-2010s son superiores a las encontradas en las dos décadas previas (1976-1999) (Tabla 1). Los incrementos más elevados se han encontrado en ambas especies de cigüeñas (blanca y negra) y algunas rapaces (águila calzada, culebrera, gavilán, aguilucho lagunero). Por el contrario, especies como el abejero, aguilucho cenizo y busardo ratonero muestran números sensiblemente inferiores en la actualidad. De las 12 especies más abundantes en paso por el Estrecho (más del 97% del paso), 9 especies presentan cambios positivos en el periodo 1970s-1990s-2010s y 3 especies presentan tendencias positivas en el periodo 1999-2010 pero sin recuperar los niveles de los 1970s (halcón abejero, aguilucho cenizo y cernícalo primilla).

En general los conteos de ambos periodos muestran correlaciones positivas y las especies más abundantes hace 30 años lo siguen siendo también en la última década. No obstante, la abundancia relativa de las diferentes especies que cruzan el Estrecho ha cambiado ligeramente desde 1970 (Bernis, 1980) y ahora hay una mayor proporción de milanos negros, águilas culebreras y calzadas, y cigüeñas blancas y negras, y un menor número de abejeros, cenizos y ratoneros. El abejero europeo era el ave planeadora más abundante en el paso otoñal por el Estrecho en los años 70 (Bernis 1980), y posiblemente también en el primaveral antes de los 80 (Bensusan *et al*. 2007). Sin embargo los milanos negros cruzando por el Estrecho durante la migración se han duplicado desde la década de 1970, tanto en primavera (Bensusan *et al*. 2007) como en otoño (presente estudio) y esta especie es la planeadora más abundante tanto en primavera como en otoño en el paso por el estrecho de Gibraltar.

El hueco de censos existente entre 1978 y 1998 no permite cuantificar las tendencias para un periodo más amplio y no podemos determinar si la tasa de cambio en los conteos de aves migratorias ha sido linear o no en los últimos 30 años. Sin embargo, sobre la comparativa de las cifras medias de paso en 2011-2012 respecto a los periodos previos es evidente un marcado aumento en el número de planeadoras migrando por el estrecho de Gibraltar especialmente en la última década (Martín *et al*. en prensa). Los protocolos de censo no han sido exactamente los mismos en 1976-1977 (Bernis 1980) comparados con los aplicados en fechas recientes (1999-2012), pero como Bernis (1980) realiza un mayor esfuerzo de censo en cuanto a número de observatorios y horario de censo con respecto a los protocolos actuales, es posible que el aumento real haya podido ser superior al detectado en este estudio.

En los últimos 30 años, las tendencias de aves planeadoras en paso por el estrecho de Gibraltar parecen ser marcadamente positivas para la mayoría de las especies, y esto ocurre tanto para la migración primaveral (Bensusan *et al*. 2007) como para la otoñal (presente estudio, Martín *et al*. en prensa). Los cambios detectados son congruentes con los registrados por BirdLife International (Tucker & Heath 1994, BirdLife 2004) para el caso de las poblaciones reproductoras de Europa occidental en periodos equivalentes, salvo para algunas especies como alimoche, águila perdicera, aguilucho pálido, busardo ratonero o esmerejón, en las que se detectan discrepancias. En el caso del alimoche y águila perdicera, BirdLife International indica declives poblacionales en ambos periodos mientras que las cifras de paso por el Estrecho muestran aumentos. En el caso del aguilucho pálido, busardo ratonero y esmerejón, BirdLife International señala tendencias estables o en aumento y el paso en el Estrecho sin embargo disminuye. No obstante, en términos generales puede decirse que los datos de paso por el Estrecho reflejan los cambios poblacionales que tienen lugar en las poblaciones de cigüeñas y rapaces migratorias de Europa occidental, que en general son positivas.

Las poblaciones de aves migratorias que crían en regiones templadas e invernan en los trópicos han sufrido declives prolongados y a menudo severos en las pasadas décadas. Recientes análisis a escala continental europea (Tucker y Heath 1994, BirdLife International 2004) para el periodo entre 1970 y 2000 evidencian este declive (Sanderson *et al*. 2006). En un periodo de 30 años, 48 (40%) de 119 especies migratorias Afro-paleárticas (migradores de larga distancia que crían en Europa e invernan en el Africa subsahariana) mostraron tendencias poblacionales marcadamente negativas. Las aves migratorias parecen ser el grupo más afectado por estos declives poblacionales, dado que no se detectan tendencias similares para especies no migratorias (residentes o migrantes de corto recorrido) nidificantes en los mismos hábitat de Europa. Un combinación de amenazas que incluyen la alteración de los hábitat de cría en Europa, la persecución directa (caza) en el sur de Europa y norte de Africa y la perdida o alteración de los lugares de reposo durante la migración y la invernada, podrían estar detrás de estos declives (Salathe 1992, Sanderson *et al*. 2006, Vickery *et al*. 2014).

El patrón de incremento poblacional de la mayor parte de planeadoras migratorias contrasta con este panorama de declive generalizado de muchos largomigrantes, lo cual indica que los factores implicados son complejos y no afectan igual a todas las especies. En el caso de las especies tratadas, hay que tener en cuenta además que se trata de especies muy populares que han recibido una gran atención en el contexto de la protección de la naturaleza y han protagonizado multitud de iniciativas de conservación activa (Pendleton *et al*. 1987, Stroud 2003, Bird & Bildstein 2007). Sus poblaciones sufrieron fuertes declives en los años 1960s y 1970s como resultado de intensas campañas de persecución directa (caza, veneno…), el efecto de determinados pesticidas (caso del DDT) y por los profundos cambios sufridos en bosques, zonas húmedas y áreas agrícolas de Europa y África (Zalles & Bildstein 2000, Stroud 2003, Kovacs & Burfield 2011). Sin embargo, en respuesta a esos declives y el avance de cierta conciencia conservacionista, desde los años ochenta las cigüeñas y rapaces están protegidas por ley y desde entonces se ha desarrollado una nutrida normativa que ampara su conservación (y la de otras especies emblemáticas) en el marco de la cual se han desarrollado numerosas medidas de protección y gestión. Entre estas destaca la prohibición de su caza, el control en el uso de venenos, la declaración de una amplia red de áreas protegidas que en muchos casos les ampara, la corrección de tendidos eléctricos, la puesta en marcha de medidas mitigadoras en parques eólicos o múltiples planes de recuperación y gestión, o incluso de cría en cautividad y reintroducción (Stroud 2003, Bird & Bildstein 2007). Asimismo, muchas especies se han podido beneficiar de otras circunstancias como ha sido la recuperación de la calidad y cantidad de zonas húmedas o la aparición de nuevas fuentes de alimento como los vertederos (Tortosa *et al*. 2002, Ciach & Kruszyk 2010). No obstante, especies de dieta marcadamente insectívora y/o ligadas a agrosistemas (abejero, aguiluchos cenizo y palido, cernícalo primilla, alcotán) no muestran tendencias positivas y presentan patrones similares a otras especies con similares requerimientos tróficos o ecológicos (Tucker & Evans 1997, Burfield 2005, Kovacs & Burfield 2011), lo cual evidencia que esa recuperación no ha sido paralela en todas las especies.

Los cambios en el paso por el estrecho pueden reflejar cambios poblacionales pero pueden estar reflejando también cambios en los patrones migratorios. Por ejemplo, como consecuencia del cambio climático muchas especies están acortando sus migraciones y otras están cambiando sus rutas o sus patrones de distribución (Newton 2008, Cox 2010, Lehikoinen & Sparks 2010, Pearce-Higgins & Green 2014), lo cual puede tener su reflejo en la composición y entidad del paso por el estrecho. De hecho, los análisis realizados muestran que si bien el paso de planeadoras transaharianas ha aumentado en general en el periodo 1970s-2010s, no ha sido así en el caso de las presaharianas, lo cual contrasta con algunas tendencias positivas de sus poblaciones reproductoras en Europa. Análisis previos muestran como especies como el busardo ratonero están acortado su migración y ya no llegan a los cuarteles de invierno norteafricanos (Martín *et al*. 2014), circunstancia que podría estar ocurriendo en otras especies presaharianas que han rarificado mucho su paso por el estrecho, como es el caso del milano real, aguilucho pálido, cernícalo vulgar y esmerejón. Esta circunstancia también parece estar produciéndose en migrantes transaharianos como se ha evidenciado en ambas cigüeñas, milanos negros, alimoches, calzadas y culebreras que invernan en el norte de Africa o en la península Ibérica en números crecientes (Morganti & Pulido 2012, De Juana & Garcia 2015) y que en el futuro podrían afectar en los números en paso por el Estrecho. Asimismo, nuevas especies han hecho aparición en la última década y el Estrecho recibe ahora un incipiente pero creciente paso de rapaces de filiación africana (buitre moteado, busardo moro, halcón borní…), reflejo de recientes procesos de colonización, y un cierto número de migrantes orientales (águila pomerana, aquilucho papialbo, cernícalo patirrojo …), reflejo de un posible cambio de ruta migratoria, hecho que podría estar produciéndose también en otras especies más comunes como las cigüeñas (Thorup *et al*. 2014).

Conclusiones

Las comparaciones entre los censos realizados en los 1970s en el estrecho de Gibraltar y los desarrollados en 1990s y 2010s muestran un incremento generalizado en el número de aves planeadoras en paso, aunque este aumento parece haberse producido mayoritariamente en la última década. Por su parte, las especies más abundantes en los 1970s también lo son en la actualidad, aunque han cambiado ligeramente la contribución de cada una al paso total. En general hay un aumento significativo de migrantes transaharianos (cigüeña blanca, milano negro, águila calzada, águila culebrera, cigüeña negra, alimoche), algunos presaharianos (gavilán), residentes en dispersión (grandes águilas y buitre leonado), especies africanas (buitre moteado, busardo moro, halcón borní) y algunos migrantes orientales (águila pomerana, aguilucho papialbo, cernícalo patirrojo). Sin embargo, hay una disminución o estabilidad de migrantes presaharianos (cernícalo vulgar, busardo ratonero, aguilucho pálido, esmerejón, azor, milano real) y algunos transaharianos (abejero, aguilucho cenizo, cernícalo primilla, alcotán). Los cambios en el paso parecen estar propiciados por cambios en las poblaciones de origen y en algunos casos por cambios en los patrones migratorios (acortamiento de la migración o cambios de ruta).

Agradecimientos

Queremos expresar nuestro más sincero agradecimiento a todos los compañeros de Fundación Migres y a los cientos de voluntarios y colaboradores que han participado en la recogida de la información presentada en este estudio. Los censos del estrecho de Gibraltar analizados en este estudio dentro de las campañas 1999/2012 fueron financiados por la Consejería de Medio Ambiente de la Junta de Andalucía (España).

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CAPÍTULO 4. Los censos de la migración otoñal como herramienta de seguimiento de las poblaciones de aves planeadoras de Europa continental.

Autumn migration counts as a tool for monitoring continental populations of soaring birds in Europe. An update on the existing estimates of breeding population trends

Este capítulo reproduce el texto del siguiente artículo en revisión:

Martín B., Onrubia A., De la Cruz A. & Ferrer M. *en revisión*. Autumn migration counts as a tool for monitoring continental populations of soaring birds in Europe. An update on the existing estimates of breeding population trends. *Biodiversity and Conservation*.

Autumn migration counts as a tool for monitoring continental populations of soaring birds in Europe. An update on the existing estimates of breeding population trends

Resumen

El seguimiento de la migración puede permitirnos detectar tendencias de la población en grandes áreas geográficas ya que es esperable que el patrón de cambio en los conteos siga el patrón de cambio del tamaño poblacional. Caracterizamos las tendencias recientes de las poblaciones regionales de aves planeadoras migratorias en función de las tasas de cambio en los conteos de migrantes en el estrecho de Gibraltar (España) y en Organbidexka (Francia) durante los últimos 15 años (1999-2013). Las tendencias de los conteos se estimaron mediante el ajuste de un modelo linear generalizado de la serie temporal de conteos de cada especie. Los resultados en Organbidexka se utilizaron para probar las tendencias observadas en el estrecho de Gibraltar. Los números de cigüeñas blancas y negras, milanos negros, águilas culebreras y calzadas, así como de alimoches aumentaron linealmente en el estrecho durante todo el periodo. Por el contrario, los números de abejeros europeos se mantuvieron estables, siendo estas tendencias coherentes con las registradas en Organbidexka. Las mayores pendientes de las tendencias en Organbidexka en comparación con el estrecho sugieren una tendencia creciente en estas especies para pasar el invierno en el sur de Europa. La combinación de los datos recogidos en diferentes observatorios de migración situados en el sistema migratorio Europeo-Africano pueden constituir una poderosa herramienta para medir los rápidos cambios en las tendencias poblacionales y los patrones migratorios de las aves migratorias europeas.

Abstract

Migration monitoring may allow us to detect population trends over large geographic areas because the pattern of change in migrant counts can be expected to follow the pattern of change in population size. We characterize recent regional European population trends of migratory soaring birds from rates of change in migration counts over the Strait of Gibraltar (Spain) during the last 15 years (1999-2013). An additional bottleneck (Organbidexka, France) within the same migratory route and period was also considered. In particular, we estimated count trends by fitting a log-generalized linear model to the time series of each species counts. The counts in Organbidexka were used to test the consistency in the observed trends over the Strait of Gibraltar. Migration counts of White and Black Storks, Black Kites, Short-toed and Booted Eagles as well as Egyptian Vultures increased linearly over the Strait of Gibraltar throughout the 15-year period. In contrast, Honey Buzzard numbers remained stable. Trends were highly consistent with those recorded in Organbidexka. We suggest that the larger slopes for the trends in Organbidexka compared with the Strait reflect an increasing tendency in these species to overwinter in southern Europe. A combination of complementary data sets collected at different bottleneck sites within the European–African flyway system may become a powerful tool to provide important evidence of the migratory patterns and population trends of soaring migrant birds and changes therein all over Europe.

Introduction

Soaring birds and particularly raptors are broadly monitored and a large amount of resources are invested on their research and conservation (Martín and Ferrer 2013). However, many soaring birds exhibit low detectability in their breeding grounds and many of them are frequently both logistically difficult and prohibitively expensive to survey and monitor (Fuller and Mosher 1981, 1987). Therefore, the available information about their abundances at large spatial scales, particularly in the case of forest birds of prey, is incomplete or inaccurate depending on species and breeding areas (Palomino and Valls 2011). More than 90% of the soaring birds in the Palearctic are migratory species (Bildstein 2007). Thus, sampling their numbers during migration offers a cost-effective and efficient method for monitoring regional populations of these species (Bildstein *et al*. 2007) compared to more direct methods such as nest surveys (Lewis and Gould 2000). Only species that concentrate along well-defined narrow fronts during autumn migration can be monitored using visual observation of migration (Farmer *et al*. 2010). Storks and large-winged raptors such as vultures, eagles and buzzards largely rely on thermal updrafts for assisted flight. Therefore they tend to avoid crossing over wide extensions of open water where a lack of such updraughts requires compensation by flapping (Finlayson *et al*. 1976). This leads to the occurrence of large concentrations of soaring birds known as 'bottlenecks', where migration routes converge and large numbers of migrants can be observed (Zalles and Bildstein 2000). The Strait of Gibraltar (southern Spain) has long been recognized as the most important bottleneck in western Europe for soaring bird migration (Bernis 1980, Finlayson 1992). This bottleneck is used by most of west European and Iberian long-distance migrants (Bijlsma 1987). In addition, migrating soaring birds across the Strait are the largest in western Europe at a single site, both in terms of numbers and species (Porter and Beaman 1985, Zalles and Bildstein 2000).

Even in the case of species which concentrate at bottlenecks, visible migration count data cannot be used to directly estimate population sizes because of the different sources of bias in the counts (Bildstein *et al*. 2007). However, for population monitoring, the important consideration is not the actual population size, but the pattern of change through time associated with it. And this pattern of change in migrant counts can be expected to follow the pattern of change in population size (Link and Sauer 1998). Thus migration monitoring may allow us to detect population trends over large geographic areas (Bednarz *et al*. 1990, Dunn and Hussel 1995, Hoffman and Smith 2003) and those trends can be used as an early warning system to identify species of conservation concern.

The objective of this study was to characterize recent regional European breeding population trends of migratory soaring birds from rates of change in migration counts. We aim to discern whether the populations of soaring bird species in Europe have increased or decreased during the last 15 years (1999-2013) and if any trend is detected, to determine which has been the rate of change for the different species. Together with the data collected in the Strait of Gibraltar, we analyzed the rate of change in the migration counts over the same period in an additional migration bottleneck site along the western migration route in the Western Palearctic (Porter and Beaman 1985, Finlayson 1992): Organbidexka, western Pyrenees, France (Filippi-Codaccioni *et al*. 2010). Since observers in Organbidexka and in the Strait of Gibraltar count birds belonging to the same migratory route, comparing the trends in counts between both bottlenecks can be a way of validate the rate of change reported from the Strait of Gibraltar. Therefore, we used data from Organbidexka to test the consistency of the observed trends over the Strait.

Methods

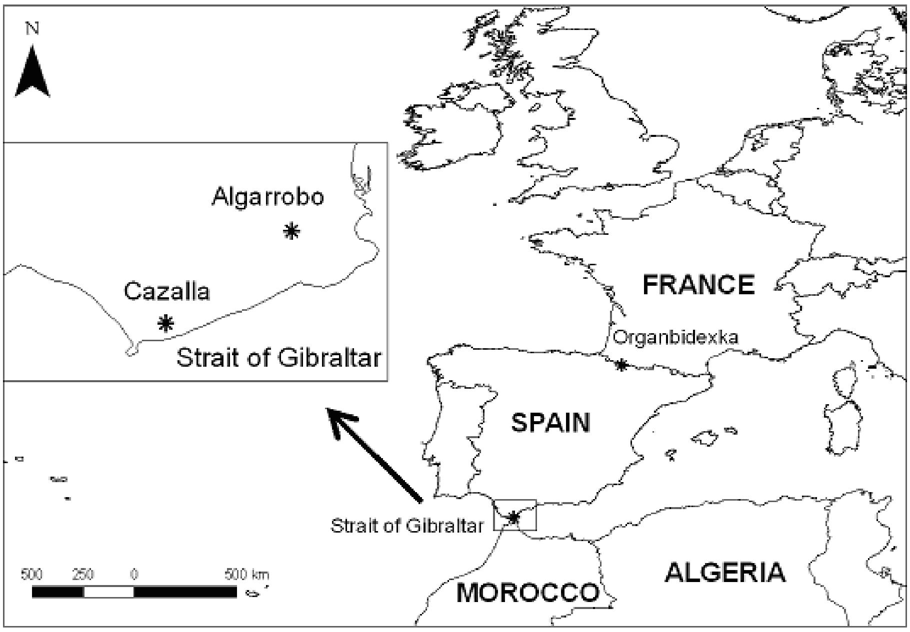
Study species

Since the study of species that migrate over a broad front and which therefore do not concentrate at 'land crossings' and other strategic points is extremely difficult (Porter and Beaman 1985), we focused on the most frequently recorded species of soaring birds that migrate across the Strait of Gibraltar along a well-defined narrow front: White Stork (*Ciconia ciconia*), Black Stork (*Ciconia nigra*), Booted eagle (*Aquila pennata*), Short-toed eagle (*Circaetus gallicus*), Honey Buzzard (*Pernis apivorus*), Egyptian vulture (*Neophron percnopterus*) and Black kite (*Milvus migrans*). We also excluded from the analyses those partial migrant species that do not necessarily travel to Africa for wintering.

Migration bottlenecks

Both the Strait of Gibraltar and Organbidexka are strategic localities where migrating soaring birds concentrate. The Strait of Gibraltar is a short sea-crossing point for soaring birds (14 Km between Europe and Africa) whereas Organbidexka is located on a ridgetop (1,283 m above sea level) in the Pyrenees. Both sites recorded north–south oriented movements of soaring birds (juveniles of the year, as well as older birds included) passing through the site in autumn (Fig 1).

Figure 1. *Sites along the western migration route in the Western Palearctic were the counts were conducted. The Strait of Gibraltar is a short sea-crossing point for soaring migratory birds whereas Organbidexka is located on a ridgetop (1,283 m above sea level). Both sites recorded north–south oriented movements of soaring birds passing through the site*



Data collection protocols

Temporal patterns of relative abundance in count data are only directly descriptive of corresponding patterns in populations if the proportion counted is constant through time. Annual counts were recorded with data collection standardized protocols that are repeated year to year in both bottleneck sites (Filippi-Codaccioni *et al*. 2010, De la Cruz *et al*. 2011). Counts considered for analyses were conducted on an annual basis over the entire autumn at both strategic sites.

- Data collection in the Strait of Gibraltar

Annual counts over the Strait of Gibraltar have been recorded using standardized protocols since 1999 (De la Cruz *et al*. 2011). From 1999 to 2013, counts were conducted during the postnuptial migration between mid-July and mid-October. Numbers of migrants were recorded on a daily basis in two different observatories (Algarrobo 36°5’25’’N, 5°29’02’’W and Cazalla

36°1’58’’N, 5°34’36’’W; Fig. 1). Counts in both sites were conducted simultaneously between late August and mid-October and they were assumed to be independent samples of different flows of migrants (Bernis 1980). In each observatory, counts were carried out by a minimum of four observers with at least one of the observers being a trained ornithologist (De la Cruz *et al*. 2011). All observers were equipped with binoculars. Flight direction of the observed birds was recorded. We only considered individuals for analysis if they were assigned a north-south oriented movement to avoid an overestimation of the number of birds migrating. Counts were not conducted in days with persistent rain or when wind speeds exceeded a Beaufort scale of six. However, under adverse weather conditions in the Strait, such as high speed winds, rain, or low visibility between Europe and Africa, crossing of soaring birds is usually delayed, and birds are forced to wait until weather conditions improve (Shamoun-Baranes 2006, Vansteelant *et al*. 2014).

- *Data collection in Organbidexka*

Annual counts (between 1999 and 2013) in Organbidexka (43°02’19.06’’N, 1°00’21.68’’W; Fig. 1) during the postnuptial migration were obtained from Migraction website (http://www.migraction.net/). The monitoring in this bottleneck consisted of daily counts, from 15 July to 15 November, from sunrise until sunset (Filippi-Codaccioni *et al*. 2010).

Statistical analysis

- *Soaring bird index for migration counts through the Strait of Gibraltar*

We used daily counts of soaring migrant birds to develop species specific-count indeces over the Strait of Gibraltar during autumn. Variance in annual counts produced by observer (number and experience, among others) affects the precision when we are estimating a migratory trend (Francis and Hussell 1998; Dunn 2005). Furthermore, daily migration counts have a highly skewed distribution caused by weather and seasonal variation in the number of migrants (Francis and Hussell 1998). If we apply data collection standardized protocols, we may control this variance but we cannot completely remove the between-year variation in the migrant count data (Dunn 2005). Daily monitoring effort (number of hours of counts per day) was equal across the years. However, seasonal monitoring effort varied among years. Therefore, for each species we identified a seasonal passage window that included days when the middle 95% of the individuals of that species were counted (i.e. the period during which 95% of migrants were observed to pass by the site across all years). Birds counted outside of this seasonal passage window were excluded from the analysis (Farmer *et al*. 2007).

We used multiple regression to derive geometric-mean population indeces that allowed compensation for missing days (Farmer and Hussell 2008). Since daily migration counts are skewed, the geometric mean of the counts is a better indicator of annual abundance than the mean or sum (Dunn and Hussell 1995). We centered each regression at the midpoint in the time series in order to reduce correlation among the polynomial terms (Dunn and Hussell 2009). Following Farmer *et al*. (2007) for the time series of migration counts of each observatory (Algarrobo and Cazalla), the indeces for each species were date-adjusted and estimated by means of the geometric-mean of the daily counts (Francis and Hussell 1998; Farmer and Hussell 2008) as follows:

$$\ln(N_{ij}+1) = a_0 + \sum_{j=1}^{J} a_j Y_j + \sum_{k=1}^{4} b_k i^k + e_{ij}$$

where N_{ij} was the number of birds of one species counted during day i in year j; Y_j was a series of J dummy variables which were set equal to one when year $=j$ and were zero in all other years; i^k were first through fourth order terms in date; a_0 was the intercept estimated by the regression; a_j and b_k were coefficients estimated by the regression representing the effects of each independent variable on $\ln(N_{ij}+1)$; and e_{ij} represented unexplained variation. The regression model was one-way ANCOVA, with year terms as factors and the other independent variables as covariates (Farmer *et al*. 2007). This index eliminates the bias due to those days when data were not collected (Farmer and Hussell 2008). Since previous studies found that a date-adjusted index performed best than a date-weather adjusted index we did not included weather variables as covariates in our regression models for index calculation (Farmer *et al*. 2007). Then, we calculated the estimated geometric-mean count (back-transformed) for each day in each year following Farmer and Hussell (2008):

$$(index)_j = e^{(\ln(N_{ij}+1)+V/2)} - 1$$

where V was the variance estimated by the regression.

Sites that are close one each other but not so close as to observe the same birds, such as Cazalla and Algarrobo, are probably counting birds belonging to the same population. Therefore, we could measure a pooled annual index for these both sites and estimate trends as if they were a single site (Hussell and Ruelas Inzunza 2008).

- Population trends through Gibraltar and Organbidexka

Since a trend may be defined as the geometric mean rate of population change over the time (Link and Sauer 1997, 1998), if the trend is linear, the geometric mean rate of change can be estimated by fitting a linear regression to the logarithm of the annual counts (Farmer and Hussell 2008). We estimated magnitude and significance of the trends in annual counts by fitting log-linear models by Generalized Least Squares (GLS). GLS generalizes ordinary least squares to the case where the residuals have a normal distribution with an arbitrary covariance matrix. In these extended linear models the errors are allowed to be correlated in such a way that we can directly model temporal autocorrelation.

Log-generalized linear models of annual indeces from the Strait of Gibraltar against year were fitted for each species. Log transformation of the annual counts allowed us to achieve a more approximately normal variable (Miller 1997) before applying simple linear regression. Trends in counts over Organbidexka, however, were estimated by fitting a log-generalized linear model to the annual raw counts of each species. Because Migraction website only provides annual count data we could not estimate soaring bird indeces for data from Organbidexka. Although trends estimated using annual raw counts results in less accurate estimating of population trends than those derived from the indeces, there is a high correlation among geometric-mean indeces and annual counts (Farmer *et al*. 2007) when daily and seasonal monitoring efforts are controlled. Thus even with this simple method, and in spite of the loss of precision, we can detect trends in migration counts (Farmer *et al*. 2007) that can be useful to assess the validity and robustness of the results obtained over the Strait of Gibraltar.

The annual rate of change over the study period (1999-2013) for each species and bottleneck was then measured from the coefficient of the year variable in the regression models, and multiply by 100. This result represents the annual % change in the population, linear change in the log scale (Dunn and Hussell 2009). We use the term "trend" as a description of an overall tendency (Link and Sauer 1997).

Temporal correlation among regression residuals is a violation of stochastic independence and can affect the conclusions drawn from statistical inference. Temporal autocorrelation (ACF) and partial temporal autocorrelation (PACF) functions for all the regression models (those based in count indeces over the Strait of Gibraltar and those based on raw counts through Organbidexka) were inspected in order to identify the form of the temporal autocorrelation by means of significant autocorrelation at any time lag. In case any significant autocorrelation was detected, we account for temporal autocorrelation using ARIMA models (autoregressive moving average models; Box and Jenkins 1983). We used Akaike’s information criteria (AIC; Akaike 1973) to identify the most robust (i.e. that model including variables which have the strongest impact on outcomes) and parsimonious (avoiding over-fitting) among the different ARIMA models that we tested. The model with the lowest AIC was considered most robust and parsimonious. If several models had low and similar AIC values (Delta AIC<2) then we selected the most parsimonious one (Burnham and Anderson 2002).

Results

Trends in 1999-2013

The inspection of quantile-quantile plots of the residuals of our GLS models showed that data lied close to the 1:1 line in all the species and in both bottlenecks, which represents a good agreement between the distribution of our count data and the expected distribution (Gordon *et al*. 2015).

The inspection of the temporal autocorrelation functions (ACF and PACF) for the regression models showed no significant autocorrelation at any time lag for most of the species. However, we detected a temporal dependency in the case of White Storks migrating over the Strait of Gibraltar, and for Booted Eagles and Black Storks through Organbidexka. Autoregressive models of order 2 AR(2) (linear model which predicts the value at the present time using the value at two previous time steps) and two moving average terms MA(2), properly modeled the autocorrelation structure of White Stork. An AR(1) model (a linear model which predicts the value at the present time using the value at the previous time) was enough to take into account the temporal autocorrelation in Booted Eagle data through Organbidexka. According to AIC values, Black Stork AR(1) model did not improve the robustness of the final model thus we used a model without temporal correlation structure to estimate the trend in the counts of Black Stork through Organbidexka (Table 1).

Table 1. *Model selection among different ARIMA structures for models with temporal autocorrelation in the residuals. (a) White Stork in the Strait of Gibraltar; (b) Booted eagle in Organbidexka; (c) Black Stork in Organbidexka.*

(a)	**Df**	**log.Lik**	**AIC**	**Delta AIC**
AR(2)MA(2)	7	-7.51	29.02	0.00
AR(2)	5	-12.21	34.42	5.41
AR(1)	4	-13.28	34.55	5.54
.	3	-15.38	36.76	7.74
AR(2)MA(1)	6	-12.55	37.09	8.08

(b)	**Df**	**log.Lik**	**AIC**	**Delta AIC**
AR(1)	4	-1.48	10.97	0.00
.	3	-3.98	13.95	13.95

(c)	**Df**	**log.Lik**	**AIC**	**Delta AIC**
.	3	3.17	-0.34	0.00
AR(1)	4	3.76	0.48	0.82

Trends for the Strait of Gibraltar based on annual indeces of migratory counts and trends for Organbidexka based on raw annual migratory counts are shown in Table 2. Overall, almost all the species studied showed significantly increasing trends from 1999 to 2013 in both bottleneck sites. These included White Stork, Black Stork, Short-toed eagle, Booted Eagle and Black Kite. Increases in migratory counts of Black Storks through the Strait of Gibraltar, however, were non-significant. Contrastingly, Honey Buzzard migratory counts were stable over the years in both sites (Table 2). Low number of birds observed over Organbidexka did not allow us to estimate a reliable population trend for Egyptian Vultures in this bottleneck over the period of study.

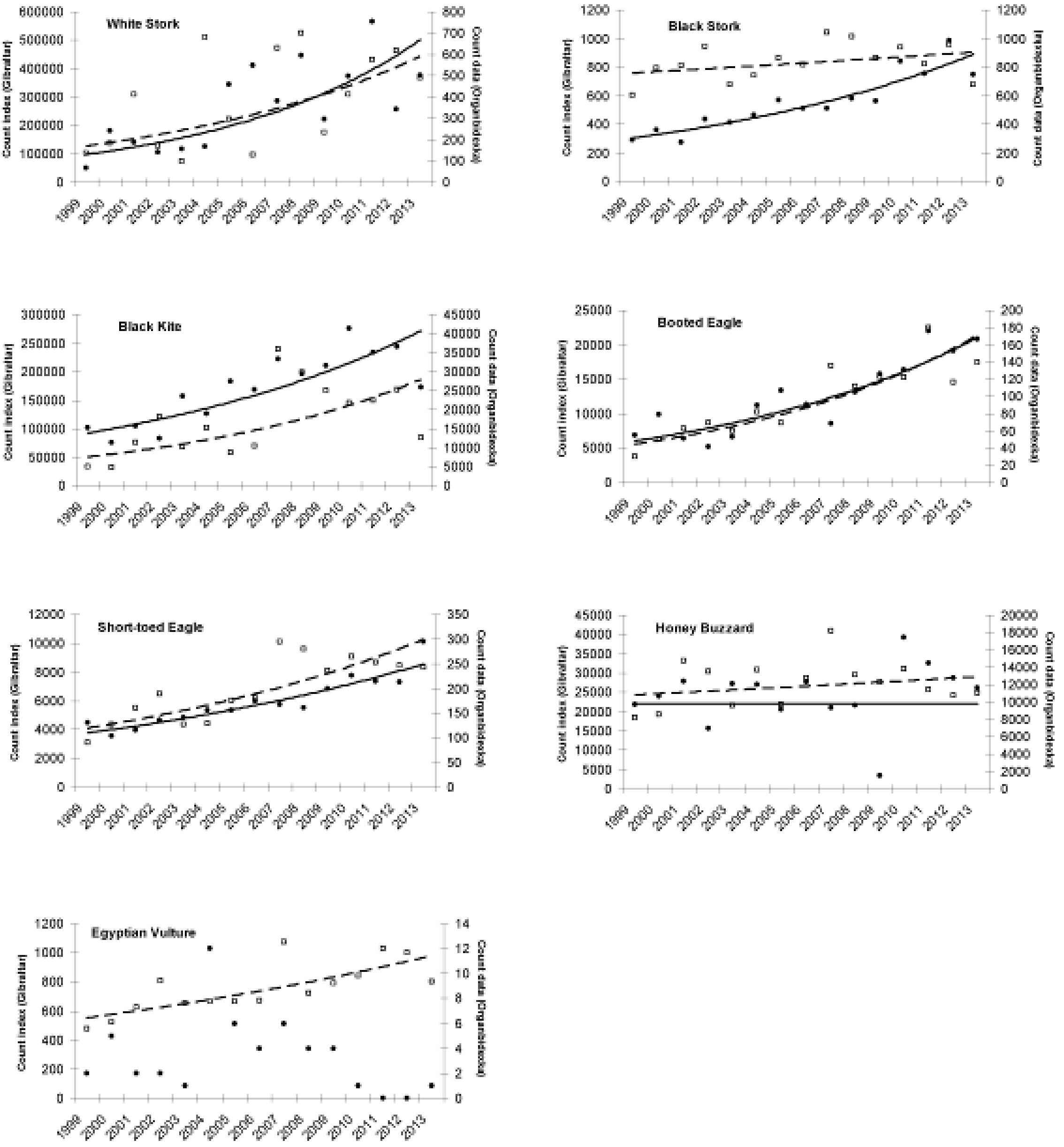
Table 2. *Log-generalized linear regression models to the time series of annual indeces (Strait of Gibraltar) and raw counts (Organbidexka) for each species. * Model for White Stork through the Strait of Gibraltar and Booted eagle through Organbidexka included temporal correlation structure (see Table 1). **Mean annual counts and SE are referred to the 95% seasonal passage window (see Methods).*

Species	**Bottleneck site**	**Mean annual counts****	**SE annual counts****	**year**	**SE year**	**t-value**	**p-value**	**% annual change**
White Stork	Gibraltar*	56670.80	23631.12	0.089	0.004	19.83	<0.001	8.88
	Organbidexka	354.53	199.47	0.117	0.027	4.38	0.001	11.67
Black Stork	Gibraltar	2283.47	513.86	0.013	0.009	1.37	0.194	1.25
	Organbidexka	552.53	202.97	0.077	0.008	9.39	<0.001	7.72
Booted eagle	Gibraltar	21987.73	9639.55	0.096	0.013	7.71	<0.001	9.64
	Organbidexka*	99.33	43.46	0.093	0.020	4.77	<0.001	9.33
Black Kite	Gibraltar	94799.80	26386.29	0.093	0.028	3.32	0.006	9.30
	Organbidexka	25498.60	9260.79	0.077	0.013	5.72	<0.001	7.70
Egyptian vulture	Gibraltar	1922.60	558.53	0.041	0.009	4.48	0.001	4.09
	Organbidexka	3.33	3.13					
Honey Buzzard	Gibraltar	60072.40	11951.36	0.012	0.013	0.97	0.351	1.25
	Organbidexka	10807.20	3561.14	0.000	0.035	0.01	0.993	0.03
Short-toed eagle	Gibraltar	12792.60	4489.86	0.066	0.012	5.30	<0.001	6.56
	Organbidexka	172.33	49.97	0.059	0.006	9.94	<0.001	5.86

Figure 2 shows the back-transformed slope of the log-generalized linear regression models to the time series of annual indeces (Strait of Gibraltar) and raw counts (Organbidexka), allowing for the visual comparison in the magnitude of the trends among species and bottlenecks. White Stork showed the largest rate of change both throughout the Strait and throughout Organbidexka. The positive trend in Booted Eagle and Short-toed Eagle numbers was similar between the Strait of Gibraltar and Organbidexka. White Storks, Black Kites and Booted Eagles exhibited the largest increases both in the Strait and Organbidexka. Contrastingly, Black Stork showed the largest discrepancy in the magnitude of the population trend between both bottelenecks: a markedly positive trend over Organbidexka whereas the trend over the Strait of Gibraltar was only slight and non-significant during the study period.

Summarizing trends across both migration sites indicates considerable agreement among sites for all species (Fig 2) although trends over Organbidexka are mostly steeper compared to those over the Strait of Gibraltar, particularly in the case of Black Kite and Black Stork.

Figure 2. *Annual trends in migration counts for seven species of soaring birds over two different bottlenecks through the western migration route (Organbidexka, France and the Strait of Gibraltar, Spain). Trends are measured as the back-transformed slope of the log-generalized linear regression models to the time series of annual indeces (Strait of Gibraltar; white squares and dashed line) and raw counts (Organbidexka; black dots and solid line).*



Discussion

Soaring bird population trends in Europe

There is a wide variety of evidence that many populations of long-distance migrant birds breeding in temperate regions have been declining from 1970 to 2000 (Sanderson *et al*. 2006). This pattern seems to be independent of the breeding habitat or phylogeny. These population declines have been related to habitat loss or degradation in the breeding, wintering (Berthold 2001, Newton 2004), and stop-over areas (Berthold 2001), as well as to direct (McCulloch *et al*. 1992, Berthold 2001), and indirect persecution (Tucker *et al*. 1990, Sergio *et al*. 2004, Smart *et al*. 2010), and climate change (e.g. Both *et al*. 2001, 2006, Moller *et al* 2008, Saino *et al* 2010). The trends derived in the present study from autumn migratory counts, however, suggest that most of the soaring migrant birds breeding in northern, western and central Europe have increased their populations, some of them even largely, throughout the 15-year period from 1999 to 2013. These results markedly contrast with the existing population trends estimated for these species which predicts stable or even negative trends for most of them (BirdLife International 2004). One of the main causes associated to soaring bird declines in Europe and particularly to birds of prey is direct persecution (Stroud 2003). In contrast to mediaeval periods when raptor species were highly valued in Europe and protected for *Falco*nry (Ratcliffe 1993), the starting of game rearing in the 19th century led to widespread persecution of these species. Several soaring birds were driven close to extinction during the 19th and early 20th centuries in Europe and many of their populations were at or near historically low levels as a result of a combination of human-induced factors such as hunting, the use of poisons and pesticides (i.e., DDT), and the adverse consequences of land-use changes (Newton 1979). During the first half of the 20th century, decreases over Europe affected all the vulture species (Egyptian vultures included) and all the eagles except the Booted Eagle and the Black Kite (Ferguson-Lees 1963). In contrast with the past, soaring birds and particularly raptors are now highly valued by important sectors of society. They were some of the first bird species with strict protection under national and international law (Stroud 2003). This fact, together with the stepwise eradication of pesticides, the ban for poison in the first half of the 20th century and the mitigation of raptor electrocution on power poles (Guyonne and Ferrer 1999) opened the door to the recovery of these species in Europe.

Our findings support a marked recovery of the European breeding populations of migratory soaring birds from central, northern and western Europe in recent years. Counts of migrants over the most important bottleneck along the western migratory route, the Strait of Gibraltar, show large and linearly increases in White and Black Storks, Black Kite, Short-toed and Booted Eagles as well as Egyptian Vulture numbers over the last 15 years. In contrast, Honey Buzzard numbers remained stable for the same period. Trends in migration counts for these species were highly consistent between different bottleneck sites along the western migration route which supports increases in breeding bird numbers not only in the Iberian populations but also in those populations located north to the Pyrenees traveling from northern and central Europe.

Migrant populations can be influenced by factors taking place in the wintering and breeding areas as well as throughout the migration routes (Newton 2004), thus determining the cause of any population change in this species is difficult. In addition, different factors or combinations of these factors may have different implication for different species. However, there are a number of possible causes of the observed increases in breeding populations of European soaring birds. Together with the legal protection of these species, the retrofitting of dangerous power lines (Ferrer 2012), the eradication of pesticides and the ban for poisoning baits (Stroud 2003), positive population trends may be connected to the increase in mean winter temperatures in Europe (i.e. climate change), and the new artificial sources of food provided by humans (Newton 2008). The Short-toed Eagle is a reptile specialist which is becoming more abundant according to its trends in migration counts both over the Strait of Gibraltar and Organbidexka. Reptiles depend of external heat sources to regulate their body temperature, and thus climate is a key factor affecting their distribution and abundance (Pough *et al*. 2001). As a results of a warming in the cooler northern ranges, which provides new opportunities for colonization, models predict the expansion of nearly half of the European reptile species against only a 5% of the reptile species expected to contract their distribution (Araujo *et al*. 2006). These changes in reptile distribution ranges are expected to benefit those species that feed on them such as Short-toed eagles. On the other hand, carrion and edible rubbish are now more readily available affecting all the scavengers. White Storks, Kites and Vultures frequently feed on the litter of rubbish and garbage dumps. For instance, garbage dumps have been identified as an important food resource for migrating kites and even of secondary importance during the breeding season (Blanco 1994). In contrast to the latter species, Honey Buzzard is a true insect-eater that largely confines its attention to wasps and bees. The absence of a positive trend in this species in spite of the reduction of direct and indirect persecution nowadays is likely linked with the decreases in insect populations, and particularly bees, that are going on across Europe (Pettis *et al*. 2013).

Other authors have reported that birds with small relative brain size and high resource specialization have suffered larger population declines compared to other species (Shultz *et al*. 2005). Soaring birds, however, are large-bodied species with long-life expectancy and, presumably, with a high ability to learn and adapt (Martin *et al*. 2014). In addition, soaring birds and particularly raptors, in temperate regions are frequently generalist species that can adapt to a large variety of environments and they show tolerance to small-to-moderate habitat alterations (Rodríguez-Estrella *et al*. 1998). We suggest that, in contrast to other long-distance migrants (Sanderson *et al*. 2006), rapid adaptation of these species to climate change (Martin *et al*. 2014) and other antropogenic factors of recent appearance allow them successfully grow in numbers even under the current global change scenario. Thus the impact of increasing temperatures and recent land-use changes across Europe on soaring bird migrants may be less negative than previously expected. The ability of these species to cope with environmental changes, however, should be monitor in the medium-long term to guarantee that population trends maintain their positive rates (or reach the stability) and ensure that new declines do not take place again.

Wintering in Europe: an increasing trend

Shortening of the migratory route linked to climate change has been reported for several migratory species breeding in temperate regions all over the world (Visser *et al*. 2009). More specifically, from the 1980s a growing proportion of the European migratory population of White Stork (Máñez *et al*. 1994; Marchamalo 1995; 2002), Booted Eagle (Sunyer and Viñuela 1996) and Black

Stork (Cano *et al*. 2014) winters in the Iberian Peninsula. Wintering White Storks in Spain in 1995 were about 7,500 birds whereas more recent census in 2004 recorded up to 31,200 birds (Fernández-Cruz 2005). Some of these wintering White Storks breed in Spain but they also come from breeding areas in France, Germany and the Netherlands (Fernández-Cruz 2005). Among others, reasons for this recent change in migratory behaviour are linked to the use of garbage dumps as a novel important food resource (Molina and Del Moral 2005). Similarly, Black Kites wintering in Spain are frequently observed in rubbish dumps (Palomino 2012). However, as this species is frequently associated to Red Kites during winter (Kabouche 2004), its presence within the flocks is often overlooked and their wintering population trends are unknown in Spain (Palomino 2012).

The effectiveness of long-term, standardized counts of diurnal migrants for monitoring population trends has been debated (e.g. Titus and Fuller 1990; Allen *et al*. 1996) because a pattern in counts is reflective not only of corresponding pattern in population sizes, but also of corresponding patterns in the proportion of animals counted. If a pattern in counts exists, i.e. changes in migratory behaviour such as percentage of birds remaining north of the count site (Viverette *et al*. 1996), however, changes in the proportion counted could easily be misinterpreted as population change (Link and Sauer 1998).

We suggest that the observed difference between trends in migratory counts in Organbidexka (Pyrenees) and the Strait of Gibraltar (i.e. larger slopes for the trends in Organbidexka) for Booted Eagle and, particularly, for Black Kite, White Stork and Black Stork is, on the one hand, reflective of this increasing tendency in these species to overwinter in southern Europe. For these species, trends in migratory counts over the Strait of Gibraltar show a lower increase because a fraction of the central, northern and western European breeding population does not cross over the Strait and remains in the Iberian Peninsula during the winter. On the other hand, increases in breeding population size may be different among countries and regions. For instance, those species with large population size may have already reached the carrying capacity of the environment in the Iberian Peninsula and be suffering density-dependent effects (Huntley *et al*. 2007) that are not present in northern populations. If that were the case, populations of these species which are north of the Pyrennes might be experiencing larger positive trends compared to Iberian ones.

Breeding and migratory population trends

In the past 15 years, trends of migratory soaring birds passing through the Strait of Gibraltar have been markedly positive for most of the species, and this is true both for spring (Bensusan *et al*. 2007) and autumn migrants (present study). Based on migration counts, recent publications have reported large inconsistencies between current population estimates in the breeding grounds (BirdLife International 2004) and the migratory population of many European soaring bird species (Bensusan *et al*. 2007, Verhelst *et al*. 2012). Soaring birds frequently show low detectability in their breeding grounds (Palomino and Valls 2011). Moreover, a well coordinated regional monitoring of raptors in Europe is lacking (Vrezec *et al*. 2013) and monitoring schemes for these species in Europe are frequently focused on rare species. Therefore, a broad coverage monitoring of the complete species range across Europe is only achieved for restricted-range species. As a consequence, the available information about the abundance of common and widespread species in Europe (i.e. Honey Buzzard), and particularly species breeding predominantly in southern and eastern Europe (i.e. Booted Eagle, Short-toed Eagle, Egyptian Vulture) is still incomplete or inaccurate depending on breeding areas (Vrezec *et al*. 2013). On the other hand, among the migrating birds there are both immature (non-breeders) and adult individuals. This proportion of floating non-breeders is frequently unknown since monitoring in the breeding areas is usually focused on breeding individuals. Thus, the divergence between the estimates on the breeding grounds reported by BirdLife International (2004) and those of migrating birds may arise from underestimates of the non-breeding fraction of the population in the breeding areas. Nevertheless, the high level of consistency found between bottleneck sites in detecting population trends of migratory soaring birds strongly support the fact that breeding populations of these species in Europe have largely increase at least in the last 15 years in Europe. More research is needed to find out if this recovery of the populations is a recent phenomena or it has taken place before 1999.

Conclusions

Determination of long-term population trends for species potentially threatened by global changes as are long-distance migrants is a key issue in conservation nowadays but these trends are seldom easy to establish. The Strait of Gibraltar is unquestionably one of the more important bottlenecks in the entire European–African flyway system, and is the most significant in Europe for the autumn migration of several key species. Counts of visible migrants at the Strait provide a cost-effective population-monitoring tool for European soaring birds. Although numbers of birds observed at the Strait are only partial counts of the total migratory passage, the information collected with long-term standardized surveys allow us monitoring changes in population sizes (e.g. Gordo and Sanz 2006) and can be used as an early warning system to identify species of conservation concern. A combination of complementary long term data sets of standardized observations at different bottlenecks along the western migratory route (e.g. Falsterbo –Sweden-, Organbidexka –France- and the Strait of Gibraltar –Spain-) or even along different migratory routes within the European–African flyway system (e.g. Bosphorus –Turkey-, Bourgas –Bulgaria-, Batumi –Georgia-, Eilat –Israel-; Bijilsma 1987) may become a powerful tool to provide important evidence of the migratory patterns and population trends of these species and changes therein all over Europe.

Acknowledgements

We are grateful to the thousands of people (volunteers and staff) who collected the information presented in this study and to the Board of the Migres Foundation. The data counts from the Strait of Gibraltar analyzed in the study were collected within the field monitoring campaigns 1999/2012 funded by grants of the Consejeria de Medio Ambiente from the Junta de Andalucia (Spain). We would like to thank the editor and two anonymous referees for providing us with comments and suggestions which help to improve the manuscript.

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CAPITULO 5. Efectos del cambio climático en el comportamiento migrador del busardo ratonero

Effect of climate change on the migratory behavior of the common buzzard

Este capítulo reproduce el texto del siguiente artículo:

Martín B., Onrubia A. & Ferrer M. 2014. Effect of climate change on the migratory behavior of the common buzzard *Buteo buteo*. *Climate Research*, 60:187-197.

Effects of climate change on the migratory behavior of the common buzzard *Buteo buteo*

Resumen

Examinamos el comportamiento migrador otoñal del busardo ratonero *Buteo buteo* a partir de las recuperaciones de 2157 individuos anillados en Europa a lo largo de los últimos 50 años, así como de los censos de aves migratorias en Suecia y España entre 1976 y 2008. Un modelo linear generalizado mostró evidencias de un acortamiento de la distancias recorridas entre la época de cría y la de invernada en los últimos 50 años. Este acortamiento en las distancias de migración se relacionó con las anomalías en la temperatura del hemisferio norte y dependiente de la región de cría, siendo las poblaciones del norte de Europa las que más han reducido su migración. Estos cambios en las distancias no estuvieron acompañados con cambios en las direcciones de migración. Entre 1976-1977 y 1999-2008 se ha producido una reducción significativa del número de ratoneros que cruza el estrecho de Gibraltar (España) igual que ha ocurrido en Falsterbo (Suecia) entre 1975 y 2007. Un análisis de regresión por cuartiles de la serie de datos del Estrecho revela que el paso medio y final de los ratoneros es hasta siete días más temprano en 2008 que en 1999. Estos cambios en el comportamiento migrador del busardo ratonero en Europa podrían tener consecuencias ecológicas y evolutivas para las diferentes especies del género *Buteo* en Europa, ya que la distribución invernal del ratonero de estepa *Buteo buteo vulpinus* en el centro y este de Europa parece verse afectada por la distribución de los busardos ratoneros (*B.b.buteo*) de Europa occidental, los cuales están extendiendo sus áreas de cría hacia el norte.

Abstract

We examined the autumn migratory behavior of the common buzzard *Buteo buteo* from recoveries of 2157 ringed individuals across Europe over the last 50 yr, as well as from birds migrating through Sweden and Spain between 1976 and 2008. A generalized linear model analysis showed evidence of a shortening of the distance between areas of common buzzard breeding and wintering over the last 50 yr. The ability of common buzzard populations to shorten their migration distance was related to temperature anomalies in the Northern Hemisphere and depended on the breeding region, with northern European populations shortening their migration distance to the greatest extent. Changes in migratory distances were accompanied by no apparent shift in migratory direction. A significant reduction in the annual number of common buzzards migrating through the Strait of Gibraltar (Spain) occurred between 1976−1977 and 1999−2008. Similar decreases in the number of migrating common buzzards were observed in the annual passage at Falsterbo (Sweden) between 1975 and 2007. Furthermore, a quantile regression analysis of the time series record of migrating common buzzards at the strait revealed that median- and late-passage common buzzards crossed up to 7 d earlier in 2008 than in 1999. Shifts in migratory behavior in the European common buzzard may have ecological and evolutionary consequences for the different species of the genus *Buteo* in Europe, since the winter distribution of the steppe buzzard *Buteo buteo vulpinus* in central and eastern Europe appears to be affected by the distribution of common buzzards (*B.b.buteo*) from western Europe, which are extending their breeding range northwards.

Introduction

Growing evidence supports human-driven climate change over the last 40 yr (Oreskes 2004). Migratory birds subject to a wide range of environmental conditions are particularly likely to be affected by climate change (Fiedler *et al*. 2004). Changes in migratory behavior under the influence of climate change have become evident in a wide range of bird species at many sites in the Northern Hemisphere (Newton 2008) and also in the Southern Hemisphere (Beaumont *et al*. 2006). Many species have changed their migration phenology by advancing arrival times at their breeding grounds (e.g. Bradley *et al*. 1999, Inouye *et al*. 2000). In addition, many migratory birds have shortened their migration routes (e.g. Viverette *et al*. 1996, Duncan 1996) as climate has changed and human activities have increased food availability at higher latitudes in their wintering range (Martínez & Sánchez-Zapata 1999, Pandolfino & Wells 2009). As a consequence, the wintering areas of many bird species are moving north (La Sorte & Thompson 2007, Visser *et al*. 2009). Data available on autumn migration shifts, however, are less abundant, with some species advancing and others delaying their date of departure from breeding areas (Lehikoinen *et al*. 2004), probably depending on species-specific annual strategies (e.g. Smallegange *et al*. 2010). For instance, migratory timing responses to climate change are expected to be weaker in larger species compared with smaller ones (Austin & Rehfisch 2005), because smaller species should be more sensitive to annual variations in food resources and temperature. However, this hypothesis remains to be confirmed since most studies on climate change responses have been biased towards small migratory passerines (Sokolov *et al*. 1998, Tøttrup *et al*. 2006) and fewer have examined large bird species (but see Duncan 1996, Viverette *et al*. 1996, Pandolfino & Wells 2009, Filippi-Codaccioni *et al*. 2010, Lehikoinen *et al*. 2010, Zduniak *et al*. 2010).

In the present study, we examined the autumn migration routes (distance and direction) of the medium-sized raptor, the common buzzard *Buteo buteo*, from recoveries of ringed individuals across Europe over the last 50 yr. The common buzzard is one of the most common and widely distributed raptor species in Europe. Its nominate subspecies (*B.b.buteo*) is a short-distance migrant (Cramp & Simmons 1980), with part of its population moving south and southwest in autumn (Thévenot *et al*. 2003). We evaluated 4 hypotheses predicting shifts in the migratory behavior of the common buzzard under the influence of climate change. As a response to new climate conditions, (1) we expected that the common buzzard would change its autumn migration phenology by advancing its departure time from the breeding grounds. To test this first hypothesis, we assessed the changes in autumn passage dates of common buzzard over the last 30 yr in Spain. As a shorter migration distance helps birds save energy while reducing mortality risk during migration (Hedenström 2010), (2) we hypothesized that a reduction in migratory propensity or even a complete shift to sedentariness in common buzzard populations would occur. To test this second hypothesis, we assessed whether changes in autumn-migrating common buzzards counted in Sweden and Spain over the last 30 yr were consistent with a reduction in migratory propensity. (3) We also hypothesized a trend towards wintering at sites located at increasingly higher latitudes in Europe (i.e. shortening of the migration distance), related to warmer temperatures in the last decades. To test this hypothesis, we investigated the relationship among long-term temporal changes in habitat conditions, temperature variations in Europe, and the distance of migration of common buzzard to different latitudes. To avoid a misleading interpretation of the results, (4) we explored the hypothesis that the adoption of new wintering areas (involving migrations in different directions) may also lead to changes in the migration distance of common buzzards. We discuss our findings in line with the different ecological and life-history characteristics of the species.

Materials and methods

Study species

The common buzzard has resident, partially migratory and migratory populations, with some migrants reaching northwest or even west Africa (Thévenot *et al*. 2003). Migratory behaviour of the common buzzard *Buteo buteo buteo* in Europe is more probable with increasing latitude. Island populations are sedentary, including British populations (Global Raptor Information Network 2014). The European population of the common buzzard is estimated at 690 000 to 1 000 000 pairs (Ferguson-Lees & Christie 2001), and between 1980 and 2006 populations have undergone a moderate increase (PECBMS 2009, BirdLife International 2011).

Changes in passage dates and numbers

- Strait of Gibraltar (Spain)

Large-winged raptors such as vultures, eagles and buzzards largely rely on thermal updraft for assisted flight. Therefore, they tend to avoid crossing over wide extensions of open water where a lack of such up draughts requires compensation by flapping. This leads to the occurrence of large concentrations of soaring birds known as ‘bottlenecks’, where migration routes converge and large numbers of migrants can be observed (Zalles & Bildstein 2000). The Strait of Gibraltar (southern Spain) has long been recognized as an important bottleneck area for soaring bird migration (Bernis 1980). We analyzed data on the number of migrating common buzzards counted during autumn migration (20 July−20 October) and collected at 2 different observatories (1 sampling point at each site) in the Strait of Gibraltar: Algarrobo (36° 5’ 25” N, 5° 29’ 02”

W) and Cazalla (36° 1’ 58” N, 5° 34’ 36” W) from 1999−2008. Binoculars (10 × 42 magnification) were used at all watch sites to detect the birds. Counts were carried out by trained volunteers (3 to 4 observatory) supervised by an expert ornithologist. Additional data about autumn migration numbers of common buzzards in the Strait of Gibraltar are available for 1976−1977 in Bernis (1980). We compared these migration numbers recorded in 1970s with those collected in the 2 decades later (1999−2008) in order to detect trends in the number of autumn migration birds. Both sources of data were collected with the same counting method and similar sampling effort in terms of daily monitoring hours and overall duration of the survey. Data collected in 1976 and 1977, however, belonged to 8 different watch sites (1 sampling point at each site), including Algarrobo and Cazalla (see above). According to an exploratory survey in 1997, the Algarrobo and Cazalla sites account for 47% of the total common buzzards recorded at the 8 original watchsites used by Bernis in 1976−1977. Therefore, we compared 47% of the annual total of birds counted by Bernis in 1976−1977 with those numbers of autumn migrants counted at Cazalla and Algarrobo in subsequent years (1999−2008) in order to standardize the sampling effort between both periods.

The total hours of observation varied slightly from day to day and among years. Additionally, the total number of days of observation also differed among years. In order to avoid the effect of changes in coverage, we identified a seasonal passage window for common buzzard at each site, defined as the period during which 95% of migrants were observed to pass by the site (all years combined). Similarly, we also identified a daily passage window as the hours of the day during which 95% of individuals were counted at each watch site. Common buzzard recorded outside of the daily and seasonal passage windows were excluded from analysis (Farmer *et al*. 2007).

- Falsterbo (Sweden)

The Falsterbo observatory (southwestern Sweden; 55° 22’ 40” N, 12° 48’ 37” E) is also located in an important bottleneck area for soaring bird migration. Since 1973, annual standardized counts of migrants (counts of visible migration) have been conducted from 11 August−20 November by the National Monitoring Programme of the Swedish Environmental Protection Agency (Kjellén & Roos

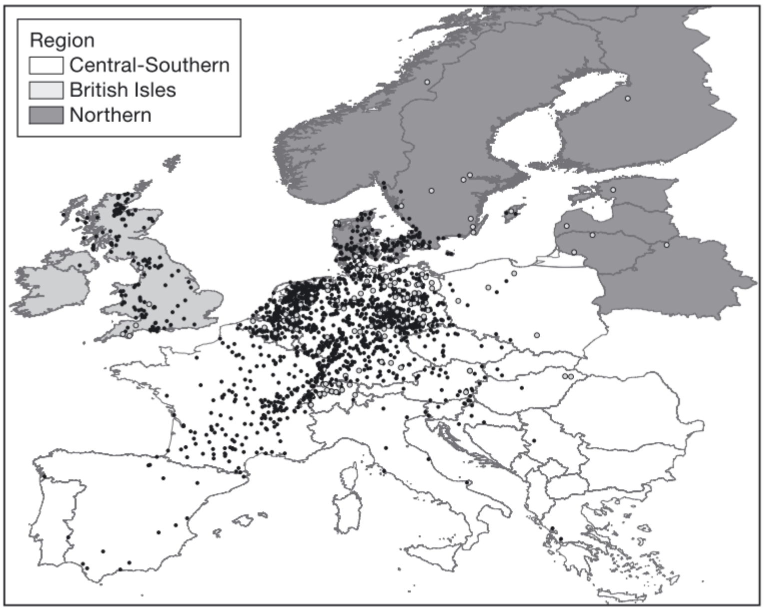
2000, Lindström at al. 2011). Data on species-specific counts are available at www.falsterbofagelstation.se/.

We considered the number of migrating common buzzards at Falsterbo from 1975−2007. In order to adjust for any population trend that may affect the number of birds counted, we weighted these numbers according to the estimated breeding population of the species in Sweden by dividing the annual number of migrating birds by an index related to the breeding population size recorded each year (based on indices derived by Lindström *et al*. 2011). These weighted numbers are an estimate of the ‘migration probability’.

Changes in migration direction and distance

Mean departure direction and distance were quantified for common buzzards ringed as adults or nestlings in different areas of Europe (British Isles, northern, central and southern Europe). We obtained recovery information (distance and direction) on 25 116 different birds ringed for 50 yr (period: 1959− 2009) from the European Union for Bird Ringing database (EURING). Distribution of the recoveries was spatially variable but consistent over time. Common buzzard range covers most of Europe and extends into Asia (Ferguson-Lees & Christie 2001). Almost the entire breeding range of the species within Europe was covered (Fig. 1).

Figure 1. *Spatial distribution of recoveries of the European common buzzards Buteo buteo (n = 2157) considered in the analysis. Black dots: recoveries between 15 November and 31 January; grey dots: recoveries between 20 April and 15 July (see 'Materials and methods')*



Recovery distances and directions were based on the loxodromic distance (distance on a constant compass bearing) between ringing and recovery locality (Imboden & Imboden 1972). Birds were only included in the analysis if the recovery date was accurate to at least 2 wk and if the accuracy of the recovery coordinates were within a 50 km radius or less, according to the EURING database. We also omitted all records containing detectable errors and inaccuracies. After the removal of potentially inaccurate and misleading data, and the restriction to birds that could be associated with wintering or breeding areas, 2157 recoveries remained. Ring recoveries came mainly from dead birds (83%), but also from birds reported alive (17%). We averaged all the ringing records (distance and direction) involving a bird in the same season when >1 record was available for 1 particular bird. Migration periods were defined according to Cramp (1985) and Del Hoyo *et al*. (1994).

Records were considered to reflect autumn migration movements if the birds were ringed between 20 April and 15 August and recovered between 15

November and 31 January. Records from birds ringed in the wintering area and recovered during the following spring (spring migratory movements) were also considered. Nevertheless, in order to get comparable measures of migration direction in the case of ‘spring migration’ records, the migration directions were corrected by adding 180° to the original value (Reichlin *et al*. 2009). We took into consideration records of birds that were ringed and recovered in the same year, as well as recoveries made in a later year under the assumption of fidelity to the breeding and wintering areas (Glutz von Blotzheim *et al*. 1989, Newton 1990, Selás 2001; see ‘Results’).

Statistical analysis

-Changes in passage dates

Since migration occurs during an extended period, quantile regression (Cade & Noon 2003) was used to estimate trends in the 10th, 25th, 50th, 75th and 90th percentiles (phases of migration) of the distribution of autumn migration dates over the Strait of Gibraltar from 1999 to 2008. Quantile regression coefficients measured the estimated per year change for each percentile. To make it easy to compute an integer difference between one calendar date and another calendar date, prior to analyses, each date was transformed into a Julian day. Julian day is the continuous count of days since the beginning of the Julian Period. The estimated shift in passage dates (Julian day) for all migratory phases between 1999 and 2008 was calculated as the number of years (n = 10) × regression coefficient (Kovács *et al*. 2011).

-Changes in passage numbers

The number of birds counted at Falsterbo was regressed against years of observation in order to detect any trend in the number of migrating birds. We also assessed whether differences between the standardized annual number of migrating birds in the Strait of Gibraltar in 1976− 1977 and 1999−2008 were statistically significant using a U-test (n 1 = 2, n 2 = 8).

-Changes in migration direction

We tested whether migratory direction showed a temporal trend from 1959−2009. Firstly, uniformity of directions was tested with the Rayleigh test of uniformity (Jammalamadaka & SenGupta 2001). Finally, we fitted a regression model for the migratory direction as a response variable against the year of recovery and an additional model against the migratory distance. As ‘direction’ is a circular random variable, circular-linear regression coefficients were measured in both cases (Mardia & Jupp 2000).

Since shorter migration distances exhibited more variable directions (see Fig. 4a) only migration distances >100 km were considered in order to reduce noise from sedentary birds without a clear movement direction. The analyses of circular data were carried out using the software Oriana (Kovach 2011).

-Changes in migration distance

The dependent variable measuring migration distance was analyzed with generalized linear models (GLM). Since the distance provided by the EURING database is truncated or rounded to its integer value, we estimated the models with a negative binomial (log link) model structure (Breslow & Clayton 1993) using the package MASS (Venables & Ripley 2002) in R (R Development Core Team 2011). We included (1) common buzzard European population trend, (2) habitat change, (3) recovery year, (4) annual temperature anomaly, (5) breeding region, (6) age at recovery, (7) quadratic and (8) interaction terms as predictors in the model (Table 1). The following is a description of how such predictors were measured.

1. Population trend: we quantified a national common buzzard population trend (between 1990 and 2000) based on data from BirdLife International (2004). This trend was measured based on data corresponding to each European country where the recorded bird bred. We estimated the trend as the number of breeding pairs in 2000 divided by the number in 1990 (Visser *et al*. 2009).

2. Habitat change: in addition, we estimated a national trend in common buzzard habitat change in Europe based on data from CORINE land cover 1990, 2000 and 2006 projects (CEC 1994, Bossard *et al*. 2000, Büttner *et al*. 2002, EEA 2007). Common buzzard density is negatively related to farmland availability and positively related to woodland availability (Sergio *et al*. 2005). We measured a trend in forest cover in the breeding areas between 2000 and 2006. To quantify this trend we compared CORINE land use databases

covering 2 periods (1990−2000 and 2000−2006). The rate of change within each period was measured as the difference between forest cover gains and forest-cover losses per country. Finally, we quantified the trend in the forest cover per country as the slope between forest cover change in 1990−2000 and forest cover change in 2000−2006.

3. Recovery year: we included recovery year as a fixed effect to account for temporal trends in the migrating distance over the study period.

4. Temperature anomaly: surface air temperature gives one of the clearest signals of global and regional climate change, especially in recent decades (Jones *et al*. 1999). We included the North Hemisphere annual land temperature anomaly as an additional predictor. Temperature anomaly was downloaded from www.ncdc.noaa.gov/monitoringreferences/faq/anomalies.php. The term temperature anomaly means a departure from a long-term average which is the reference value. A positive anomaly indicates that the observed temperature was warmer than the reference value, while a negative anomaly indicates the opposite. Anomalies were provided as departures from the 20th century average (1901−2000).

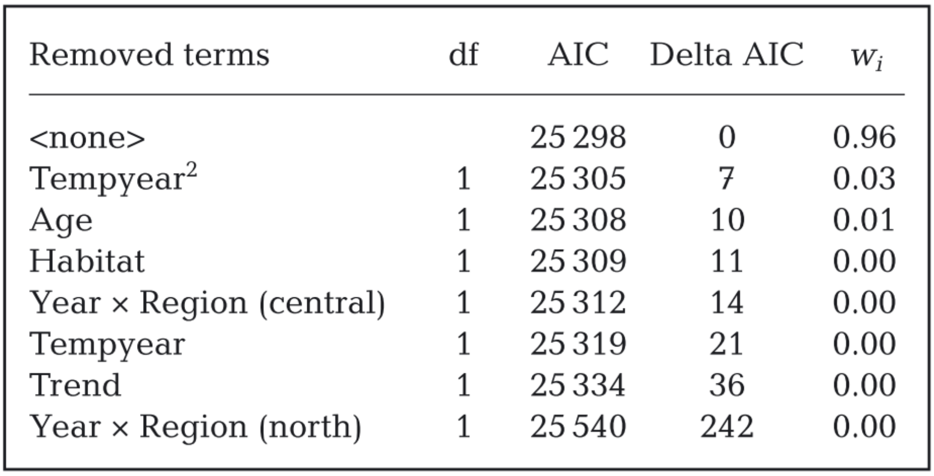
5. Breeding region: to account for differences in migratory behavior due to the different latitudinal geographical zones of the ring recoveries, we included a factor describing the region where the recorded birds breed with the following levels: northern Europe, central-southern Europe and British Isles (see Fig. 1). Since common buzzards are sedentary on islands, the 'British Isles' was the reference level for comparisons between regions. Southern Europe was omitted as an independent region level from the analysis, as the sample size from that area was very small (Fig. 1). From a preliminary analysis, we observed that longitude of the breeding population did not affect the trend in the migration distance; thus, we did not include longitudinal geographical zones in the model.

6. Age at recovery: a preliminary non-parametric analysis (U-test; Lehmann 1975) showed a negative relationship (Spearman rank correlation) between age at recovery and migration distance ($n = 2157$, $r s = -0.14$, $p < 0.001$); thus, age was included in the model as an explanatory variable. The U-test did not show statistical differences ($p > 0.05$) in migration distance, temperature anomaly, population trend, or habitat change between sexes ($n = 164$, $p > 0.05$).

7. Non-linear terms: since the relationship between temperature anomaly and migration distance was described by a second-order polynomial, we included annual temperature anomaly in the model as a quadratic term.

8. Interaction terms: to determine if the breeding region effect on migration distance changed over time, we included the interaction term between region and year in the model.

Table 1. *Buteo buteo. Model selection using a backward stepwise procedure by Akaike's information criterion (AIC). wi : Akaike weight for each model*



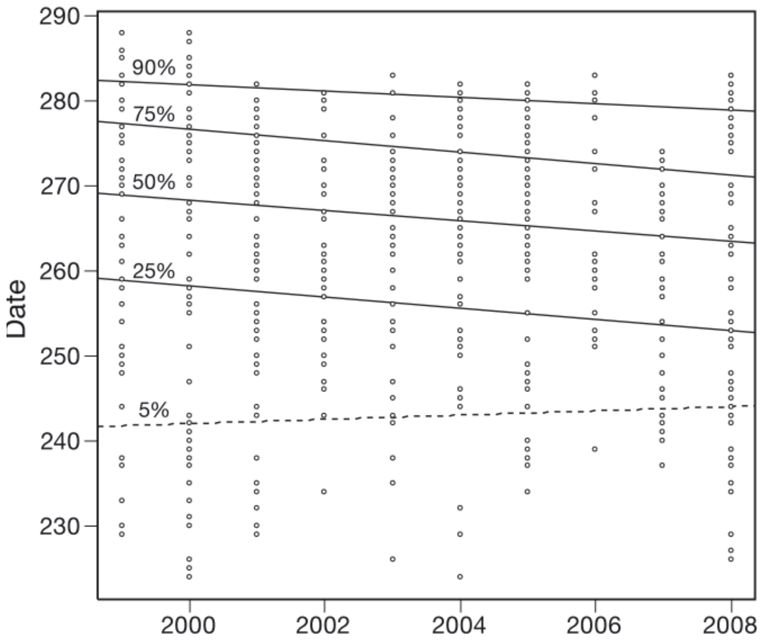
Removed terms	df	AIC	Delta AIC	w_i
<none>		25 298	0	0.96
$Tempyear^2$	1	25 305	7	0.03
Age	1	25 308	10	0.01
Habitat	1	25 309	11	0.00
Year × Region (central)	1	25 312	14	0.00
Tempyear	1	25 319	21	0.00
Trend	1	25 334	36	0.00
Year × Region (north)	1	25 540	242	0.00

Results

Changes in passage dates

The overall duration of migration through the Strait of Gibraltar has shortened over the years. For the 10th percentile of timing of migration, no significant change in passage dates was detected. However, the slopes for the 25th, 50th, 75th and 95th percentiles of timing of migration showed that the passage period of the common buzzards *Buteo buteo* has advanced 6−7.5 d during the period 1999−2008 (Fig. 2).

Figure 2. *Buteo buteo. Regression plot of the quantiles (10, 25, 50, 75, 90%) for passage dates against year at the Strait of Gibraltar, 1999−2008. Lines were fitted by quantile regression (solid: significant at the 5% level; dashed: non-significant). The estimated quantile regression line for the 50% quantile shows the trend in the median passage date over the period*

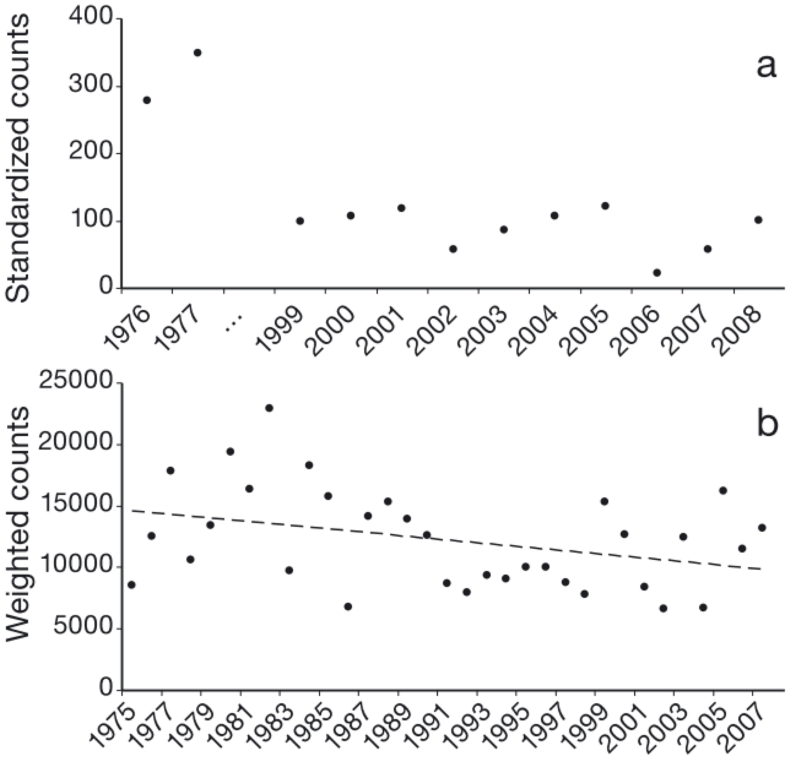


Changes in passage numbers

Differences in annual number of migrating birds between periods 1976−1977 and 1999−2008 in the Strait of Gibraltar were statistically significant (Z = 2.15, p < 0.031; Fig. 3a).

Similarly, the trend in the numbers of migrant common buzzards at Falsterbo was significantly negative after breeding population size adjustment (Fig. 3b, r = −0.35, p = 0.044). The inspection of the temporal autocorrelation function of the residuals of the regression model showed no significant autocorrelation at any time lag. In addition, increases in both wintering (r = 0.42, p = 0.013) and breeding (r = 0.50, p = 0.002) common buzzard populations in Sweden were statistically significant during the study period (1975−2007).

Figure 3. *Buteo buteo. (a) Changes in annual number of common buzzards migrating through Strait of Gibraltar between 1976−1977 and 1999−2008 (see 'Materials and methods'). (b) Number of common buzzards counted during autumn migration at Falsterbo, Sweden, over the period 1975−2007 (r = −0.35, p = 0.04). Dashed line: regression fit. Annual number of migrating birds was weighted using breeding population indices derived from Lindström et al. (2011)*

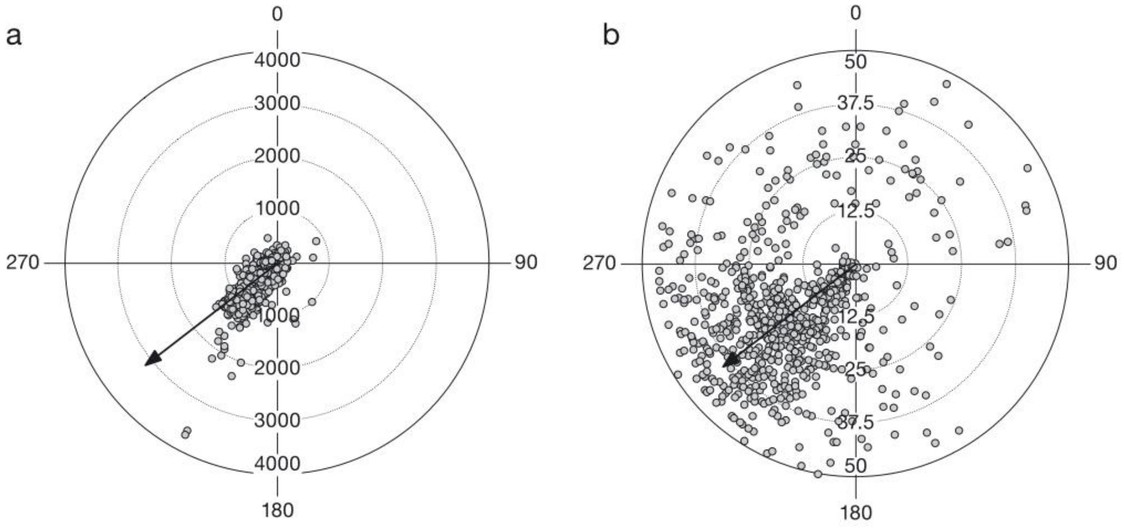


Changes in migration direction

Birds ringed in the wintering area and recovered during the following breeding period provided about 10% of the total records. Less than 1% of the total recoveries considered in the analysis belonged to birds with >1 record yr −1. All recoveries for 1 bird in the same year were located within a distance of 5 km. In addition, our assumption of fidelity to the breeding and wintering areas was supported by results from birds (n = 36) with several records (2 to 8 different recoveries depending on the bird) in subsequent years. Recoveries in subsequent years for 1 bird were always within a distance of <16 km.

A preliminary analysis of the autumn migration direction showed no differences in the direction among regions. The mean direction for common buzzards during autumn migration was 240.45° (±85.31°). The Rayleigh test of uniformity showed data were not distributed uniformly and there is evidence of a preferred direction (Z = 235.04, $p < 0.0001$). The relationship between direction and migration distance was significant (Fig. 4a). In addition, a significant but very weak temporal trend was detected on migratory direction between 1959 and 2009 according to a circular-linear regression test (n = 2157, r = 0.13, $p < 0.001$; Fig. 4b).

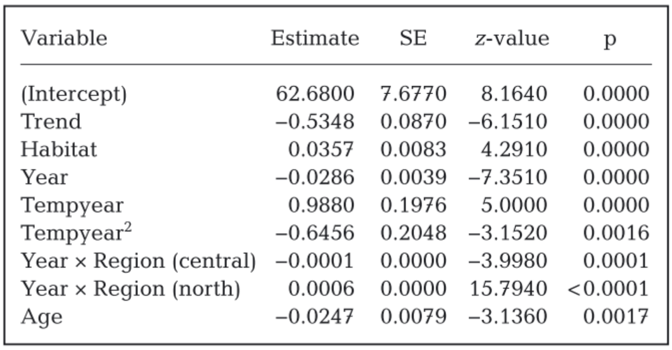
Figure 4. *Buteo buteo. Circular-linear regression. (a) Migratory direction against migration distance (r = 0.33, p < 0.001). (b) Migratory direction against recovery year (r = 0.13, p < 0.001). To facilitate the interpretation of the results, year was rescaled (year 1959 = 0; year 2009 = 50). Only migration distances >100 km were included (see 'Materials and methods'). The position around the circular axis represents the circular variable, while the position on the concentric grid represents the linear value. The black arrow indicates the mean migratory direction over the study period (1959−2009)*



Changes in migration distance

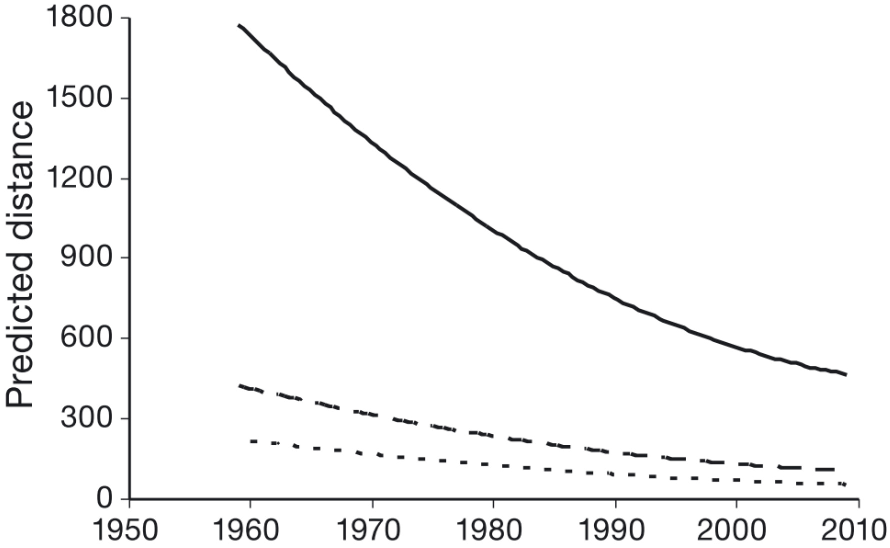
After fitting the final GLM model (Table 1), examination of the deviance residuals against year showed the independence between residuals and time and the absence of a significant temporal correlation. In addition, an inspection of the spatial correlogram of the residuals of the best-fit model predicting migration distance showed there was no correlation pattern. According to the best-fit model (Table 2), the age of the bird had an effect on the recovery distance, with younger birds moving longer distances. Population and habitat changes were significant factors affecting migration distance. Shorter migration distances were associated with positive common buzzard population trends, whereas longer migration distances were related to positive trends in forest-cover gains. In addition, we found support for a reduction in migration distances of common buzzards in Europe during the years 1959−2009. However, this reduction depended on the region of the different breeding populations, since the effect of year on migration distance is affected by breeding region (Table 2, see the interaction term year × region). Northern Europe and the central-southern European associations between recovery year and migration distance are significantly different from those of the British Isles. The estimate of the northern Europe year regression slope indicates that it is steeper than that of central-southern Europe, while the British Isles line is less steep than that of central-southern Europe (Fig. 5).

Table 2. *Best-fit generalized linear model of the recovery distance (km) for the common buzzards Buteo buteo ringed in Europe between 1959 and 2009*



Variable	Estimate	SE	z-value	p
(Intercept)	62.6800	7.6770	8.1640	0.0000
Trend	−0.5348	0.0870	−6.1510	0.0000
Habitat	0.0357	0.0083	4.2910	0.0000
Year	−0.0286	0.0039	−7.3510	0.0000
Tempyear	0.9880	0.1976	5.0000	0.0000
Tempyear^2	−0.6456	0.2048	−3.1520	0.0016
Year × Region (central)	−0.0001	0.0000	−3.9980	0.0001
Year × Region (north)	0.0006	0.0000	15.7940	<0.0001
Age	−0.0247	0.0079	−3.1360	0.0017

Fig. 5. *Buteo buteo. Predicted values for migration distance from the best-fit model against year for a given value of the other predictors: trend = 1, habitat = 1, tempyear = mean (tempyear), age = 3. Solid line: northern Europe; dashed line: central-southern Europe; dotted line: British Isles*



Discussion

Changes in passage dates

Human-induced global changes affect wildlife species by modifying migratory behavior. Among those shifts, phenological changes in migratory patterns are the most commonly reported effects of global change on bird migration (Møller *et al*. 2008). Our analysis of the time series record of the common buzzards *Buteo buteo* migrating through the Strait of Gibraltar revealed that the timing of autumn passage has advanced significantly between 1999 and 2008. According to these results, common buzzards in median and later phases of migration cross the strait 6−7 d earlier than they did in the previous decade. Median dates of autumn migration also show an advancing trend in relation to climate change in other raptor species (e.g. Filippi-Codaccioni *et al*. 2010, Lehikoinen *et al*. 2010) and in many migrating passerines (Tøttrup *et al*. 2006).

The observed advance in passage dates, however, seems to contradict results found by Kjellén & Roos (2000). Those authors detected a delay in the autumn migration peak of common buzzards at Falsterbo (south Sweden) when comparing birds observed in the 1940s and 1950s with those observed in late 1990. Similar delays in mean autumn passage dates to those observed in Falsterbo have also been found for our study species at Organbidexka (southwestern France) (Filippi-Codaccioni *et al*. 2010). Different trends in the timing of autumn migration in the Strait of Gibraltar and at Falsterbo and Organbidexka may arise from different causes. Firstly, common buzzards migrating through Falsterbo and through the Strait of Gibraltar may belong to different populations that may be constrained by different environmental pressures and, consequently, exhibit different passage dates. Secondly, it is inexact to designate migration as occurring simply earlier or later, because some raptor species display a bimodal phenological distribution due to different passage dates between males and females or between adults and juveniles (e.g. Yosef *et al*. 2002). Therefore, changes in the distribution of passage dates may be related to population- or individual-based responses (see the comments on age and migratory behavior below).

Passage date is not the only migratory trait of common buzzards that has changed in recent decades. An additional response detected is a reduced migratory propensity. This species was the most common migrant in the early 1940s at Falsterbo (Kjellén & Roos 2000), but their numbers diminished markedly after 1950. Furthermore, according to our results, autumn migration at Falsterbo showed a clear reduction in the number of migrating birds between the 1980s and the following decade. Reduction in the number of birds has previously been associated with population declines, mainly as a consequence of habitat changes (Kjellén & Roos 2000). However, although the number of migrating common buzzards at Falsterbo has decreased, the number of resident individuals (i.e. overwintering buzzards) in Sweden has shown a significant increase during the past 20 yr (Lindström & Svensson 2007). Similar results have been observed during autumn migration in the Strait of Gibraltar, where we found a significant reduction in the number of migrating birds after 1976. Significant declines in migrant common buzzards in the Strait of Gibraltar have also been detected during spring migration; here a few hundred birds were counted before the 1980s, contrasting with <10 birds observed in recent years (Bensusan *et al*. 2007). Since the overall population of common buzzards in

Europe has exhibited a stable, moderate increasing trend during the last decades (PECBMS 2009), the decrease observed in the number of migrating birds cannot be interpreted as a consequence of a decline in breeding population numbers. Thus, a decrease in migrating birds may only be explained by a reduction in the migratory activity or by changes in the migratory directions of European common buzzards, with fewer birds currently traveling to South Europe and North Africa to winter.

Changes in migration direction

In accordance with previous studies, our analysis of the autumn migration routes of common buzzard showed a southwesterly direction (Fransson & Pettersson 2001, Strandberg *et al*. 2009a), and changes in migratory distances in European common buzzard were accompanied by no apparent shift in migratory direction.

Changes in migration distance

In the present study, we found evidence of a shortening of the distance between breeding and wintering sites of European common buzzard between 1959 and 2009. Many previous studies have reported marked associations between bird migration and long-term regional weather trends (Miller-Rushing *et al*. 2008).

Our results indicate that longer distances of migration are associated with negative and small temperature anomalies, while large positive anomalies are related to a reduction in the migration distance. Migration can be expected to occur only if survival is larger for migrating birds than for birds remaining at their breeding sites over the whole year (Lack 1954). The reduction observed in migratory behavior (i.e. shortening of the migration distance) is probably a consequence of the greater survival probabilities during the winter as winter weather conditions become milder (Berthold 1999). In addition, resident individuals may advance their reproductive activities before migratory individuals arrive at their breeding grounds and, consequently, gain benefits in terms of fitness. Moreover, in long-lived birds with deferred sexual maturity and retarded-return in juveniles, as with the common buzzard (Glutz von Blotzheim *et al*. 1971, Melde 1983), a shift from a migratory to a sedentary lifestyle would, as a consequence, bring an advance in first breeding age. As a result, an increase in population size should take place (Ferrer *et al*. 2011). According to our findings, there is an additional explanation for the observed tendency of common buzzards towards wintering at more northerly sites in Europe: an increase in habitat availability due either to climate change or land-use changes (Newton 2008).

The propensity to shorten migration distance among European common buzzard populations depends on their breeding regions, with northernmost populations shortening their migration distance to the greatest extent. Climate warming is expected to increase population growth and carrying capacity if populations are located close to the coolest limit of a species' distribution, where climatic conditions are becoming more suitable for the species (Jiguet *et al*. 2010). Species occurring at high latitudes and exhibiting wide thermal tolerance, such as the European common buzzard, may live in climates that are currently cooler than their physiological optima; thus, climate warming should enhance their fitness (Deutsch *et al*. 2008). Our findings are also supported by previous studies that document a northward shift in the wintering distribution areas of common buzzard in the last 30 yr (Strandberg *et al*. 2009a,b). With regard to the other variables that explain changes in migration distance of European common buzzards, age is an important predictor in our model. The social-dominance hypothesis (Gauthreaux 1982) proposes that in short-distance migrants, such as the European common buzzard, subordinate individuals are forced to leave breeding areas in winter because of competition from more dominant birds (Schindler 2002). Therefore, juveniles should be more migratory than adults, because adults are presumably dominant over juveniles. For instance, in southern Sweden the proportion of juveniles among wintering common buzzards is low, whereas it is significantly higher in migrating birds (Kjellén 1994). Correspondingly, a high proportion of individuals among all the common buzzards recorded in the Strait of Gibraltar are juveniles (1.6 juveniles adult -1 ; authors' unpubl.data).

Ecological and evolutionary consequences

Shifts in migratory behavior in European common buzzard presumably imply ecological and evolutionary consequences. Among others, changes in the breeding density of common buzzards in Europe could affect prey abundance in those areas where the species is now breeding or resident. Additionally, the steppe buzzard subspecies (*Buteo buteo* vulpinus) that occurs in North and East Finland is a long-distance migrant that winters south of the equator (Mebs & Schmidt 2006). The winter distribution of steppe buzzard in central and eastern Europe appears to have been affected by the distribution of the short-distance migrant or resident common buzzards from western Europe up to the 1990s (Morozov 2007). However, hybridization of steppe and common buzzards is common in Finland and probably also in North Sweden (Dick Forsman pers. comm.). Given the northern expansion of the European range of common buzzards (Lehikoinen *et al*. 2009), an increase of genetic exchange between the 2 subspecies of B. Buteo could occur. Genetic monitoring of these populations would provide information on the extent to which hybridization is occurring.

A shortening of the migration distance in this wide spread and common partial migrant species represents a highly likely scenario for other species of migratory raptors, and of birds in general. Our results support data that behavioral responses such as northward shifts in winter range and advances in passage dates are also possible in large, long-lived species (see also Duncan 1996, Viverette *et al*. 1996, Pandolfino & Wells 2009, Filippi-Codaccioni *et al*. 2010, Lehikoinen *et al*. 2010, Zduniak *et al*. 2010). Considering that habitat alteration is progressing under the influence of climate change and human activity (Newton 2008), long-lived species such as the common buzzard and other raptors could be able to learn from previous experience, and therefore to adjust their behavior to these new conditions even faster than smaller birds with shorter life expectancies. It remains unclear, however, whether these behavioral responses will be sufficient to cope with climate change and what ecological implications they will have for these and other species.

Acknowledgements. This research was funded by grants of the Consejería de Medio Ambiente from the Junta de Andalucía (Spain). We thank all the volunteers and staff that made monitoring in the Strait of Gibraltar possible. We also thank Andrew Patterson for his kind revision of the language of the manuscript.

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CAPITULO 6. Presencia inusual de rapaces migratorias orientales en el Estrecho de Gibraltar

Unusual presence of Eastern migratory raptors in the Straits of Gibraltar

Este capítulo reproduce el texto del siguiente artículo:

Onrubia A., Muñoz A.R., Forsman D., Ramírez J. & De la Cruz A. 2010. Presencia inusual de rapaces migratorias orientales en el Estrecho de Gibraltar. *Migres, Revista de Ecología*, 1: 47-54.

Presencia inusual de rapaces migratorias orientales en el Estrecho de Gibraltar

Resumen

En la primavera de 2008 se registró la presencia inusual de varias especies de rapaces de migración típicamente oriental en el Estrecho de Gibraltar. Los registros obtenidos mediante observaciones sistemáticas y estandarizadas, junto a otros no sometidos a protocolos específicos de censo, suman catorce aves de cuatro especies diferentes: siete cernícalos patirrojos *Falco vespertinus*, cinco águilas pomeranas *Aquila pomarina*, un aguilucho papialbo *Circus macrourus* y un águila de estepa *Aquila nipalensis*, aunque esto podría ser solo una fracción del paso real. Se exploran varias hipótesis para explicar este hecho y se sugiere que las condiciones meteorológicas reinantes en el norte de África, con vientos persistentes y fuertes del este coincidiendo con los picos de migración de estas especies, podrían haber propiciado la deriva hacia el oeste de una porción de migrantes. El patrón encontrado en el águila pomerana podría deberse también a un paso regular y minoritario por la ruta occidental de la fracción invernante en África occidental.

Abstract

During the spring of 2008 we detected in the Strait of Gibraltar the unusual presence of several species of raptors that typically migrate through the oriental flyway. The standardized records, obtained by systematic observations, and considering others not under specific monitoring protocols, total 14 birds of four different species: seven Red-footed *Falcons Falco vespertinus*, five Lesser Spotted Eagles *Aquila pomarina*, one Pallid Harrier *Circus macrourus*, and one Steppe Eagle *Aquila nipalensis*, although this could be only a fraction of the total amount of eastern migrants crossing the Straits. We explore several hypotheses to explain this unusual occurrence and suggest that the prevailing weather conditions in northern Africa, with strong and persistent winds from the east coinciding with the peak migration of these species, might have facilitated the westward drift of a portion of migrants. In the case of the Lesser Spotted

Eagle it could be a regular, although minority, migration pattern used by those birds wintering in West Africa.

Introducción

La concurrencia de dos grandes barreras geográficas orientadas de este a oeste, el mar Mediterráneo y el desierto del Sahara, junto a la existencia de otras barreras menores (p.ej. la cordillera alpina) han propiciado la existencia de dos grandes ejes migratorios en el contexto del sistema Paleártico-Africano (Moreau 1972, Berthold 1993, Newton 2008). Aunque la mayoría de las aves exhiben una extraordinaria capacidad para realizar grandes desplazamientos (Alerstam 1990), la imposibilidad de disponer de enclaves adecuados para el reposo y engorde durante el cruce de las citadas barreras, o la incapacidad de volar grandes distancias sobre el mar en el caso de la mayoría de aves planeadoras, explican la dificultad del tránsito directo sobre estas barreras (Alerstam 1990, Berthold 1993, Bildstein, 2006, Newton 2008). De este modo, un contingente mayoritario de las aves que nidifican en el Paleártico occidental rodea el tramo central del Mediterráneo y el Sahara por el Próximo y Medio Oriente hacia el este y sur del continente africano o el sur de Asia (ruta oriental) o por la península Ibérica hacia el oeste de África (ruta occidental), siendo la ruta central por Italia de menor entidad (Finlayson 1992, Bruderer *&* Liechti 1999, Corso 2001, Leshem & Yom-Tov 1996, Zalles & Bildstein 2000).

La ruta oriental recoge las aves migratorias del centro y este del Paleártico y supera notablemente a la ruta occidental tanto en número de especies como en cantidad de aves en paso (Moreau 1972, Leshem & Yom-Tov 1996, Bruderer *&* Liechti 1999, Shirihai *et al*. 2000, Zalles & Bildstein 2000). En el caso de las aves planeadoras, esta ruta exhibe los valores más elevados de individuos en paso para la mayoría de especies (cigüeñas, pelícanos, rapaces, etc.) y dispone de varias exclusivas que sólo migran por esa ruta (migrantes orientales) (Leshem & Yom-Tov 1996, Shirihai *et al*. 2000, Zalles & Bildstein 2000, Bildstein 2006). Por su parte, el contingente migratorio occidental es importante aunque de menor entidad y no dispone de especies exclusivas, aunque destacan los números de algunas de ellas, como por ejemplo *Circaetus gallicus*, *Neophron percnopterus*, *Circus pygargus* y *Gyps fulvus* (Zalles & Bildstein 2000). Aunque esporádicamente se detectan migrantes orientales en nuestras latitudes (Díaz *et al*. 1996), la presencia de estas especies en nuestro marco geográfico ibérico tiene consideración de rareza y constituyen una noticia ornitológica (De Juana 2006). La distribución estival de estas especies se circunscribe al sector más oriental del Paleártico (Cramp 1980).

En la primavera de 2008 se registró la presencia de varias rapaces de migración oriental en el Estrecho de Gibraltar, lo cual coincidió con un elevado número de citas de alguna de estas especies en la península Ibérica (varias decenas en el caso de *Falco vespertinus*, Andy Paterson, com.pers.).

Lo inusual del registro ha motivado la elaboración de esta nota, donde se describe el patrón encontrado en el Estrecho y se exploran y discuten las posibles causas de este acontecimiento.

Métodos

La fuente principal de datos proviene del esfuerzo de seguimiento de la migración primaveral realizado durante los años 2007, 2008 y 2009 por el Programa Migres, proyecto de la Consejería de Medio Ambiente de la Junta de Andalucía coordinado y desarrollado por Fundación Migres. La base del seguimiento es el conteo de planeadoras desde observatorios fijos con un protocolo de esfuerzo constante, con jornadas diarias de 5-6 horas de observación continua (Programa Migres 2010).

En el año 2007 se han realizado conteos en 39 jornadas de las cien posibles repartidas entre el 7 de febrero y el 18 de mayo. Las observaciones se han realizado en 3 observatorios (Punta Paloma, Cazalla y La Hoya) que vienen a cubrir un 40% del frente del Estrecho (figura 1). En el año 2008 se han realizado conteos sistemáticos entre el 15 de enero y el 30 de mayo. De 136 jornadas posibles, se han realizado conteos el 73% de los días en Cazalla, observatorio que controla aproximadamente un 13% del frente español del Estrecho, y en el 35% de los días en 6 observatorios repartidos regularmente por el frente del Estrecho y que vienen a controlar más de un 80% de éste (figura 1). En el año 2009 los conteos se han realizado entre el 1 de febrero y el 15 de mayo. Se han realizado 89 jornadas de conteo de 103 posibles en dos observatorios (Cazalla y Punta Carnero), y 24 jornadas en 6 observatorios simultáneamente (figura 1).

Figura 1. *Localización de los observatorios utilizados para el seguimiento de la migración primaveral en el Estrecho de Gibraltar en el Programa Migres.*

A esta información se han añadido registros no sistemáticos realizados por ornitólogos en el área del Campo de Gibraltar y recogidos en la base de datos que sirve de origen para la elaboración del Noticiario Ornitológico del Estrecho que coordina la Fundación Migres (Ramírez 2010). Estas observaciones no están sometidas a protocolos de esfuerzo controlados y tienen por tanto una validez limitada para el estudio del fenómeno migratorio. No obstante, la elevada presencia de ornitólogos de distinta procedencia en el área y la existencia de cauces eficaces de recogida y canalización de esos datos, permiten disponer de una información adicional interesante para interpretar los datos existentes.

Por otro lado, se han revisado trabajos ornitológicos recopilatorios del área del Estrecho realizados en el último siglo (Irby 1898, Bernis 1980, Finlayson, 1992, Barros y Ríos 2002), así como en el contexto peninsular (Díaz *et al*. 1996, De Juana 2006), prestando atención al estatus indicado en dichas obras sobre estos migrantes orientales. Esta información permite disponer de una perspectiva temporal de enorme valor para evaluar adecuadamente el carácter inusual de la presencia de estas especies.

Finalmente se han revisado los mapas sinópticos y condiciones meteorológicas diarias ofrecidos por el Servicio Nacional de Meteorología y webs especializadas (http://www.meteored.com) a lo largo de las primaveras de 2007, 2008 y 2009 para conocer las condiciones meteorológicas imperantes a escala local y regional.

Resultados

Como resultado del esfuerzo de seguimiento sistemático de la migración (Programa Migres) se han contabilizado 20.463 rapaces en la campaña primaveral de 2007, 77.511 rapaces en el 2008 y 98.460 en 2009. De estos totales, 5 corresponden a migrantes orientales: 3 águilas pomeranas en (1 en 2008 y 2 en 2009), 1 aguilucho papialbo en 2008 y 1 cernícalo patirrojo en 2008. En conjunto los migrantes orientales suponen una ínfima fracción del total de rapaces en paso (0,002-0,0038%). En 2008 los migrantes orientales suponen aproximadamente 4 de cada cien mil rapaces que cruzan el Estrecho y en 2009 son 2 de cada 100.000. En 2007 no se registran rapaces de migración oriental.

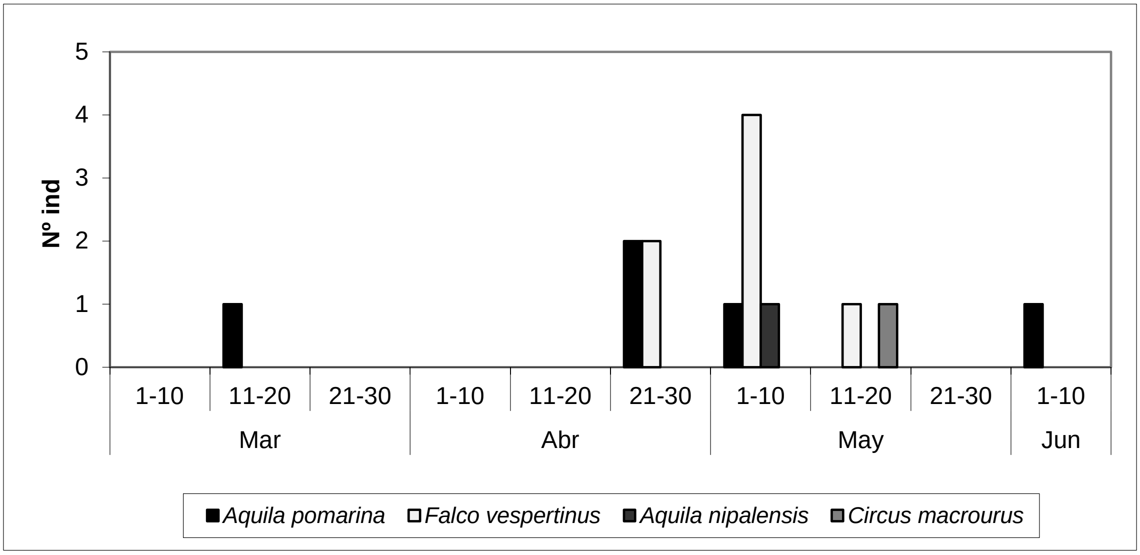
Considerando las observaciones no sistemáticas, se añaden 11 registros de migrantes orientales que se corresponden con 1 águila de estepa, 4 águilas pomeranas y 6 cernícalos patirrojos, todas ellas realizadas en el año 2008.

El conjunto de avistamientos sistemáticos y no sistemáticos supone 16 registros de rapaces orientales, dominados por el águila pomerana (7 aves) y el cernícalo patirrojo (7 aves). Del total de registros, 14 tienen lugar en 2008 y sólo 2 en 2009 (3 a 2 si consideramos los datos recogidos de manera sistemática). La campaña 2008 presenta unos valores relativamente elevados de migrantes orientales respecto a 2007 y 2009.

Los registros de águila pomerana (5 en 2008 y 2 en 2009) se distribuyen desde finales de marzo hasta principios de junio, con mayoría en abril (4 aves). Los registros de cernícalo patirrojo, todos de la temporada 2008, se localizan entre el 29 de abril y el 16 de mayo.

Si tenemos en cuenta todos los registros realizados en 2008, la mayoría (12 aves) se concentran a finales de abril y primera quincena de mayo (figura 2). Únicamente dos registros de águila pomerana escapan a este patrón.

Figura 2. *Distribución por periodos de diez días de los contactos de rapaces de migración oriental registrados en el Estrecho de Gibraltar en la primavera de 2008.*



Discusión

Todas las especies de migrantes orientales citadas en este trabajo, con la excepción del águila de estepa, han sido citadas previamente en la zona aunque con carácter raro o muy escaso. Irby (1898) cita la presencia de *Falco vespertinus* en el entorno de Tánger durante los meses de abril y siempre ligado a la presencia de grupos de langostas. Bernis (1980) registra la presencia ocasional de una posible águila pomerana durante la migración otoñal y Cramp (1980) cita la entrada frecuente de cernícalos patirrojos por Marruecos y el oeste de Europa, a veces en números elevados, con sucesos posteriores de cría en sectores occidentales alejados de sus zonas habituales de distribución. Finlayson (1992) indica la presencia esporádica de aguilucho papialbo y cernícalo patirrojo en la zona. Por su parte, Barros y Ríos (2002) recogen algunas citas de águila pomerana y cernícalo patirrojo en el Estrecho.

La existencia de citas históricas y recientes de estas especies orientales hace pensar que la presencia de éstas en la zona es algo relativamente habitual y ya conocido dentro de la rareza del hecho. En este sentido, los registros efectuados en estos últimos años podrían ser el resultado de un mayor esfuerzo prospectivo y de una mejor cobertura por parte de un plantel de ornitólogos cada vez más numeroso, mejor formado en identificación y con mejores medios ópticos y materiales (ver De Juana 2006). No obstante, los datos del año 2008 destacan por la concentración de un elevado número de registros (14 aves) y por la variedad de especies (4), hecho absolutamente inusual. A esto se une el registro de un ejemplar de *Aquila nipalensis* en 2008, que supone la primera cita de la especie en la península Ibérica (De Juana 2006). El esfuerzo de la campaña 2009 es notablemente superior al de 2008 y sin embargo registra menos rarezas orientales tanto en individuos como en especies.

Por su parte, el número de registros de cernícalo patirrojo en la península Ibérica entre finales de abril y principios de junio de 2008 aglutina varias centenas de individuos y es la más elevada registrada en las últimas décadas, con mucha diferencia (Andy Patterson, com.pers.). Este hecho viene a corroborar que la primavera de 2008 fue excepcional en cuanto a avistamientos de rapaces de migración oriental, especialmente cernícalos patirrojos.

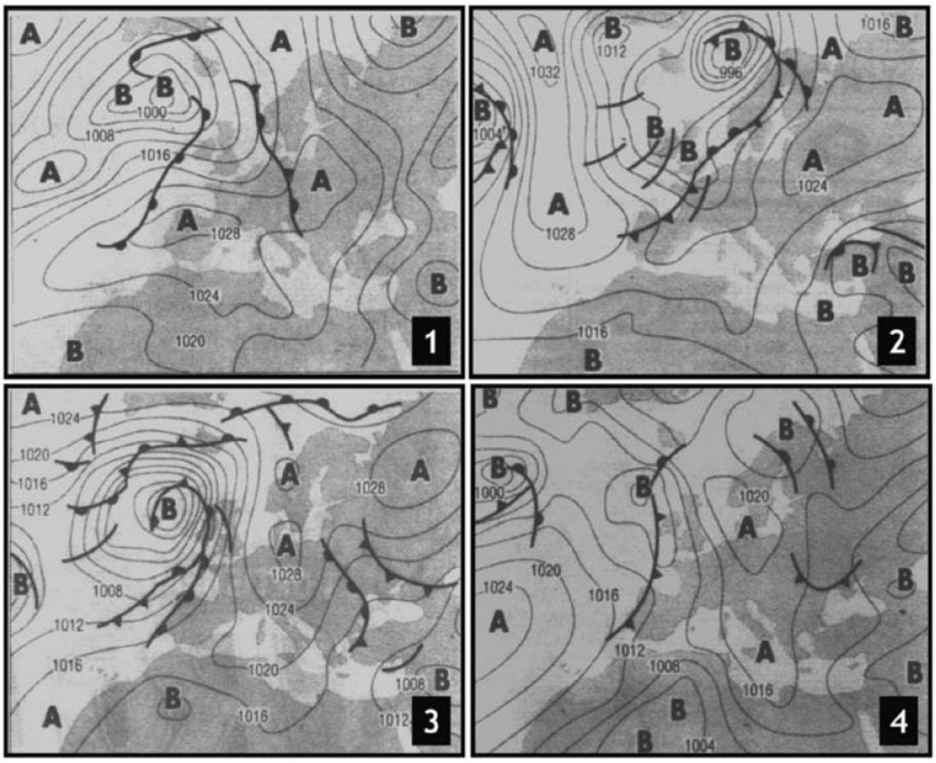
Sin embargo, esta abundancia de registros en Iberia es de mucha mayor magnitud que los encontrados en el Estrecho. A este respecto, hay que tener en cuenta que los esfuerzos prospectivos del Programa Migres suponen una cobertura representativa pero baja del montante total de la migración en el Estrecho durante la primavera: se censa en el mejor de los casos el 70-80% de los días y durante un número limitado de horas (entre el 40 y el 60% de las horas de luz), y sólo un tercio de los días se alcanza una cobertura espacial satisfactoria. Los registros así conseguidos son solo una fracción del montante total de aves que cruzan el Estrecho. Además, rapaces de los géneros *Falco* y *Circus* no se concentran especialmente en el Estrecho y son capaces de atravesar grandes distancias sobre el mar (Meyer *et al*. 2000 y 2003), de manera que la fracción detectada aquí es solo una muestra del total de aves que cruzan el Mediterráneo occidental.

Sobre las posibles causas de esta inusual concurrencia, se han descrito diversos motivos posibles que explican la presencia de aves migratorias fuera de sus rutas típicas: expansión distributiva, existencia de rutas secundarias pero minoritarias en la población, fallos en la manifestación del programa migratorio interno, condiciones ambientales en las zonas de invernada, o efectos de deriva durante la migración debido a agentes meteorológicos especiales, como vientos fuertes (Bernis 1966, Berthold 1993, Alerstam 1990, Elkins 1995 y 2005, Newton 2008).

Todas las especies indicadas presentan declives moderados o fuertes de sus poblaciones en las últimas décadas (BirdLife International 2004), lo que descarta posibles procesos expansivos. Los registros efectuados en el Estrecho de Gibraltar coinciden con los picos de migración de estas especies en otros puntos de similar latitud, como Italia (Cramp 1980, Corso 2001, Corso *&* Cardelli 2004) o Israel (Shirihai *et al*. 2000), lo que indica que no se trata de un hecho fortuito o anómalo en su patrón fenológico. La concurrencia de un número relativamente elevado de aves en unas fechas muy concretas de 2008 (figura 2) tanto en el Estrecho como en la península Ibérica, Baleares y Canarias, y la ausencia en los años 2007 y 2009, así como en los registros históricos, apuntan a una circunstancia puntual en ese año y no a una estrategia regular. Una excepción a esto es el águila pomerana, que registra individuos también en 2009 y en un periodo más extenso (marzo a junio), lo que apunta a la posibilidad de que en el caso de esta especie exista un paso regular aunque minoritario, como parece ocurrir durante la migración postnupcial (Ramírez *et al*., en prep.). Por su parte, la concurrencia de migrantes de distinta ecología trófica que incluyen consumidores de invertebrados (*Falco vespertinus*, *Circus macrourus*), de pequeños vertebrados (Aquila pomarina) o vertebrados de tamaño mediano (*Aquila nipalensis*) (Cramp 1980, Newton 2008), descartan la posibilidad de una relación específica con los ciclos de langostas (*Locusta migratoria*, *Schistocerca gregaria*…) o de otras presas (térmitas, roedores, tejedores...) en el Sahel.

La exploración de las condiciones meteorológicas reinantes en esas fechas arroja datos relevantes. Entre finales de abril y principios de mayo de 2008 se produjo la confluencia de un anticiclón en el sur de Europa con una zona de bajas presiones en el norte de África – Sahara central, Libia, Túnez…- (figura 3). Estas condiciones provocaron la existencia de vientos fuertes laterales de dirección este-oeste, que afectaron principalmente al sector central y occidental del mediterráneo. La persistencia de estas condiciones durante un periodo prolongado de tiempo (unos 15 días aproximadamente) y su coincidencia con los picos de migración de estas especies en este sector, en un momento además crítico como es el tránsito sobre el mar a través del Canal de Sicilia, puede explicar la presencia inusual de rapaces de migración más oriental en el Estrecho y la península Ibérica. En el caso del cernícalo patirrojo o del aguilucho papialbo, su presencia podría verse también favorecida por la existencia de una migración en lazo con rutas en primavera más occidentales que las otoñales (Cramp 1980, Corso & Cardelli 2004, Newton, 2008).

Figura 3. *Mapas sinópticos que indican la posición de centros de altas (A) y bajas (B) presiones en Europa y norte de África el 24 de abril de 2008 (1), 27-abr-2008 (2), 3-may-2008 (3) y 8-may-2008 (4).*



Teniendo en cuenta que los efectos de deriva por el viento son una de las principales causas de desvío de los migrantes de sus rutas, incluidas las aves planeadoras (Alerstam 1990, Berthold 1993, Liechti 2006), y analizando las condiciones meteorológicas reinantes en esas fechas, se sugiere que la presencia de migrantes orientales en el Estrecho puede estar relacionada con esa circunstancia. No obstante, algunos registros de águila pomerana en el Estrecho podrían estar relacionados con una estrategia de paso específica y no necesariamente propiciada por factores meteorológicos concretos.

Agradecimientos

A los compañeros de la Fundación Migres que han participado en los censos de aves en el Estrecho de Gibraltar. Un revisor anónimo aportó comentarios que mejoraron la versión inicial del manuscrito.

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CAPITULO 7. Migración otoñal del águila pomerana en el estrecho de Gibraltar: accidental o regular?

Autumn migration of lesser spotted Eagle Aquila pomarina in the Strait of Gibraltar: accidental or regular?

Este capítulo reproduce el texto del siguiente artículo:

Onrubia A., Muñoz A.R., Arroyo G.M., Ramirez J., De la Cruz A., Barrios L., Meyburg B.U., Meyburg C. & Langgemach T. 2011. Autumn migration of Lesser Spotted Eagle *Aquila pomarina* in the Strait of Gibraltar: accidental or regular? *Ardea*, 99: 113-116.

Autumn migration of lesser spotted Eagle *Aquila pomarina* in the Strait of Gibraltar: accidental or regular?

Resumen

El águila pomerana migra hacia sus cuarteles de invernada siguiendo el corridor del Mediterráneo oriental. Entre 1998 y 2009 se han registrado 47 águilas pomeranas en el estrecho de Gibraltar en el curso de un programa de seguimiento de la migración de aves. Todas las observaciones se realizaron entre el 6 de agosto y el 12 de octubre (media 16 septiembre, mediana 12 septiembre). Sobre 13 pomeradas datadas la edad, 10 fueron no juveniles. De 86 pomeranas marcadas con emisores satelitales en el límite occidental de su área de distribución, seis siguieron la ruta occidental y tres de estos alcanzaron África a través del estrecho de Gibraltar. La presencia del áquila pomerana en nuestro área de estudio, a pesar de los números bajos, indica la existencia de una ruta menor a través de la península Ibérica.

Abstract

The Lesser Spotted Eagle (LSE) migrates to its winter quarters via the eastern Mediterranean corridor. During 1998 to 2009, 47 LSEs have been registered in the Strait of Gibraltar during a monitoring program of bird migration. All observations were made between 6 August to 12 October (mean 16 September, median 12 September). Of thirteen age-identified LSEs, ten birds were non-juveniles. Six out of 86 LSEs fitted with a satellite transmitter at the western limit of its distribution followed the western route. Three of those birds reached Africa via the Strait of Gibraltar. The presence of LSE in our study area, albeit in small numbers, indicates the existence of a minor migration route across the Iberian Peninsula.

Introduction

The Lesser Spotted Eagle *Aquila pomarina* (hereafter LSE) is a medium-sized migratory raptor that breeds mainly in central and eastern Europe. The breeding population consists of approximately twenty thousand pairs (BirdLife

International 2004). The birds leave the breeding grounds from early September to early October and most of them return during April. The species winters in eastern and southern Africa, south of the Equator (Ferguson-Lees & Christie 2001).

The LSE migrates to the winter quarters following the eastern Mediterranean corridor, through the Caucasus, Turkey and the Middle East (Bijlsma 1987), a route that has been confirmed by means of satellite telemetry (e.g. Meyburg *et al*. 1995). In the Central Mediterranean the species is considered rare on migration (Kisling *et al*. 1994). There are few published records in the western Mediterranean. In Spain, recent observations were restricted to the Balearic Islands and Doñana (De Juana 2006, Rüegg 2007). For the Strait of Gibraltar there is a single possible observation in October 1976 (Bernis 1980). The species is listed as Rare by the Spanish Rarities Committee (Clavell *et al*. 2005). In Morocco, it is an accidental visitor, with one record only (a subadult on 18 April 1996; Thévenot *et al*. 2003).

The aim of this study is to demonstrate its regular occurrence and autumn migration pattern in the Strait of Gibraltar. We also present the first records of satellite tracked birds migrating through the Iberian Peninsula and northwestern Africa.

Methods

The Strait of Gibraltar is located at the southernmost point of the Iberian peninsula. The Strait is an approximately 20 km-long channel that connects the Atlantic Ocean and the Mediterranean Sea and that separates Europe from Africa (Fig. 1). This short sea-crossing makes the Strait an important migration bottleneck, channelling the majority of thermal-using migratory raptors of Western Europe. At this site, we monitored raptor migration from July to October 1998–2009. Daily censuses were carried out between 7:00 and 16:00 UTC during 68–87 days per year (on average 77 days/year), depending on weather conditions. Three strategic vantage points with a good view along the northern coast of the Strait were used for counting (Fig. 1). At least two observers per watch site continuously scanned the sky with binoculars; a telescope was used to aid identification. For each migratory raptor we recorded time, species, number of birds, direction, and age and sex (when possible).

Climatic conditions were measured every second hour; when wind speed exceeded 60 km/h (c. 7 Bt) we interrupted the survey.

Figure 1. *Breeding range of Lesser Spotted Eagle (modified from Riede 2004), study area and observatories used in the monitoring program. Altitudinal lines (m) are indicated.*

All records used in this study refer to positive identifications by experienced birdwatchers. We considered juveniles to be birds in fresh plumage with a wing band formed by the pale tips of the upper primary and greater coverts, and non-juveniles (either adults or immatures) as those in active moult or in worn plumage with uniformly coloured remiges (see Forsman 2007 for detailed information).

As supplementary information we used the data provided by a long-term project in which 74 birds (39 adults and 35 nestlings) were fitted with satellite transmitters (PTTs) in 1992–2009, the majority in Germany at the north-western edge of the species' breeding range (Meyburg & Meyburg 2007). From 2004 onwards the devices deployed were GPS enhanced PTTs. The tags were programmed to record a GPS fix every hour, transmitting information on flight altitude, speed and direction. Additionally, in 2009 twelve young Latvian Lesser Spotted Eagles, taken to Germany as part of a translocation project (Meyburg *et* *al*. 2008), were fitted with PTTs and released into the wild at a hacking station some 60 km north of Berlin.

Results

From 1998 to 2009 a total of 47 LSEs were observed, with annual sightings (Fig. 2). The birds were observed between 6 August and 12 October, with an average and modal date of passage of 16 and 12 September respectively (Fig. 3). The peak of migration occurred between 5 and 24 September (55% of all records). Most of the birds (n = 35) were observed in the central area of the Strait of Gibraltar (Cazalla and Tráfico observatories, Fig. 1), where the largest survey effort was conducted.

The birds passed between 7:00 and 16:00 h (UTC), the majority (64% of n = 47) between 9:00 and 12:00 h. Of thirteen age-identified LSEs, ten birds were non-juveniles.

Figure 2. *Number of Lesser Spotted Eagles registered at the Strait of Gibraltar during autumnal migration counts in 1998–2009 (n = 47).*

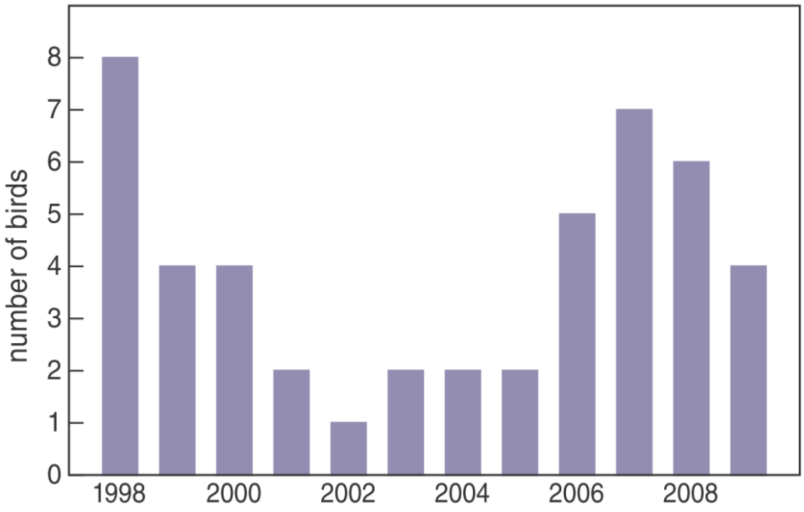
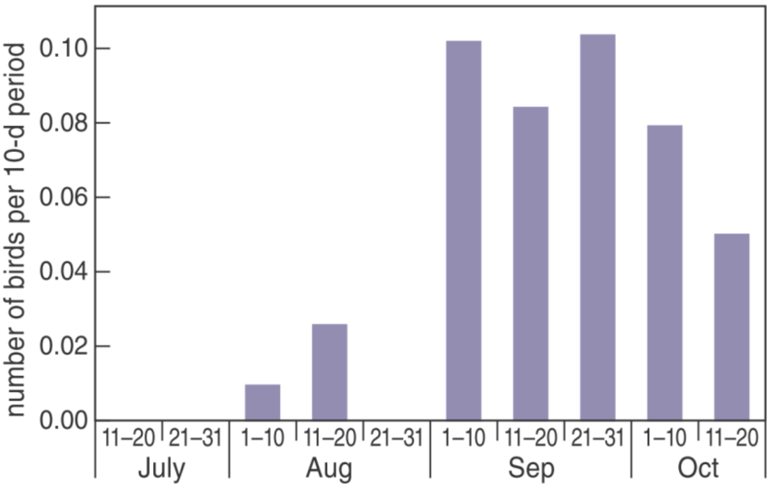


Figure 3. *Seasonal pattern of Lesser Spotted Eagle passage at the Strait of Gibraltar (mean number/10-day, n = 47), summed for 1998–2009.*



Satellite tracking

Four out of 74 German LSEs fitted with a satellite transmitter followed the western route. Two of those birds reached Africa via the Strait of Gibraltar. A third LSE tried to cross the Mediterranean Sea from Cape Gata (Andalusia, Spain) to Cape Viejo (Morocco), but failed during this attempt. Another young bird took the western route but it was tracked only as far as France.

Of those birds crossing the Strait, the first was marked as a nestling on 23 July 2008 some 50 km ESE of Rostock (Germany). It left the nest on 11 August and a week later was still observed in the company of the parents. After migrating through Germany and France, it flew southwards along the Spanish Mediterranean coast to reach the Strait of Gibraltar on 6 October where it remained until 29 October (where it was observed and photographed by T. Chodkiewicz *et al*., pers. comm.). A first attempt at crossing the Strait on 27 October was aborted when within 6.5 km of the open sea at a height of 758 m (at 14:00 h). The actual crossing occurred on 29 October, departing from Spain some 7.2 km ENE of Tarifa. The bird was tracked as far as eastern Ivory Coast where the signal was lost. The second bird was fitted with a PTT transmitter as a nestling on 24 September 2009 near Templin, some 70 km north of Berlin. It departed from the breeding area on 14 September 2009. On 1 October, around 16:00 h (UTC), the bird reached Tarifa, but continued its migration parallel to the Atlantic coast until it reached a point some 55 km northeast of Lisbon on 7 October. The bird then veered towards Gibraltar and crossed the Strait on 9 October.

In 2009, two out of 12 young Latvian Lesser Spotted Eagles translocated into Germany followed the western route. The first young eagle began its autumn migration on 11 September and spent the night of 8/9 October 9 km north of Algeciras. The following morning it resumed migration at about 07:30 h and at 10:00 h was located 2 km north of the coast (4.9 km southwest of Algarrobo). At 11:00 h it had covered 32 km and had crossed the Strait. The second young Latvian eagle also began its migration on 11 September 2009. On 29 September it arrived at Cape Gata. At about 13:00 h it attempted to cross the Mediterranean in a southerly direction. Until 18:00 h it flew with a speed of 30–36 km/h, coping with a SE to ESE cross-wind of 11–15 km/h. South of the coast its flight altitude gradually decreased from 500 m to 100 m a.s.l. At 18:00 h the bird was clearly exhausted and continued flying a few metres above the waves for another 4 km with a speed of 35 km/h, before apparently drowning 12 km west off the coast near Mellila.

Discussion

The regular presence of LSE, albeit in small numbers, suggests an unknown migration route via the Iberian Peninsula and the Strait of Gibraltar. The number of birds crossing to Africa via the Strait of Gibraltar is probably underestimated, mainly due to methodological and identification problems. Information from satellite tracking further suggests that these birds originate from the western limit of its breeding distribution, mainly northeastern Germany and western Poland, possibly including Central Slovakia, southwest Hungary and northern Croatia. The wintering sites of these birds are still a mystery. The bird tracked as far as Ivory Coast might still have been migrating at the time of its loss. At present, there is no information to suggest that West Africa is a regular wintering site of any importance (Ferguson-Lees & Christie 2001), nor that it has been in the recent past when LSE was slightly more common in the western parts of its breeding range (Brown *et al*. 1982).

We show that the species has occurred annually in the Strait of Gibraltar at least since 1998, which makes a revision of its status in the western

Mediterranean necessary, particularly for the Iberian Peninsula and Morocco. Furthermore, the presence of non-juveniles birds shows that the movements are not just naive juveniles on the wrong track. These results suggest two alternative hypotheses: 1) this route might be of recent origin, or 2) it is a relict of a once frequently used route, when the range of LSE expanded well into West Europe and numbers were higher (e.g. Meyburg *et al*. 2004). This route may have implications for the conservation of this endangered species, and it should be considered in the European recovery plans of the species, especially those focused on the dwindling westernmost populations (which are most likely to be involved in the western route).

Acknowlegdments: The Programa Migres, on which the present study is based, is promoted by the Consejería de Medio Ambiente (Junta de Andalucía). We thank all volunteers that participated in the programme. The satellite tracking was financed in 2007 and 2008 by Deutsche Bundesstiftung Umwelt and Deutsche Wildtier Stiftung. We particularly acknowledge Rob G. Bijlsma for many helpful comments.

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CAPITULO 8. Movimientos primaverales del buitre moteado *Gyps rueppellii* por el estrecho de Gibraltar

Spring movements of Ruppell´s vulture *Gyps rueppellii* across the Strait of Gibraltar

Este capítulo reproduce el texto del siguiente artículo:

Ramírez J., Muñoz A.R., Onrubia A., De la Cruz A., Cuenca D., Gonzalez J.M. & Arroyo G.M. 2011. Spring movements of Rüppell´s Vulture *Gyps rueppellii* across the Strait of Gibraltar. *Ostrich*, 82 (1): 71-73.

Spring movements of Ruppell´s vulture *Gyps rueppellii* across the Strait of Gibraltar

Resumen

El buitre moteado o de Ruppell (*Gyps rueppellii*) es una especie de distribución africana. Sin embargo en los últimos 15 años se ha registrado su presencia en la península Ibérica donde es considerado una rareza. Durante el programa de seguimiento de la migración primaveral en el estrecho de Gibraltar realizado en 2007 se registraron nueve ejemplares jóvenes o inmaduros alcanzando las costas ibéricas entre abril y junio, siempre integrados en grupos de buitres leonados (*Gyps fulvus*), si bien las cifras reales podrían ser muy superiores a tenor del esfuerzo de censo realizado. Estos datos evidencian una arribada significativa de buitres moteados a la península Ibérica, que podrían estar formando una vía de dispersión a larga distancia desde el Sahel, acompañando a los buitres leonados ibéricos durante sus movimientos dispersivos. Estos movimientos podrían ser la antesala de la colonización de la península Ibérica por parte de esta especie.

Abstract

Rupell´s vulture (*Gyps rueppellii*) is a species restricted to the Africa continent in its distribution. However in the last 15 years it was registered in the Iberian peninsula where it is considered a rarity. During the monitoring program of spring migration ran in the Strait of Gibraltar in 2007, nine juvenile or immature individuals were recorded reaching the Iberian coast between April and June, always within groups of griffon vultures (*Gyps fulvus*), although the actual numbers could be greater considering our survey efforts. These data show a significant arrival of ruppell´s vulture in the Iberian peninsula, which could be forming a new long-distance route from the Sahel, accompanying the Iberian griffon vultures during their dispersion. These movements could be the prelude to colonization of the Iberian peninsula by this species.

Article

Rüppell’s Vulture *Gyps rueppellii* is an endemic from a relatively narrow belt of arid sub-Saharan Africa from southwestern Mauritania, Senegambia and Guinea east to Ethiopia, and thence to central Tanzania (Ferguson-Lees and Christie 2001). This species has suffered a population decline in most of its distribution area, mainly in West Africa (Thiollay 2006), which led the Rüppell’s Vulture to be included in the IUCN Red List as Near Threatened (IUCN 2007).

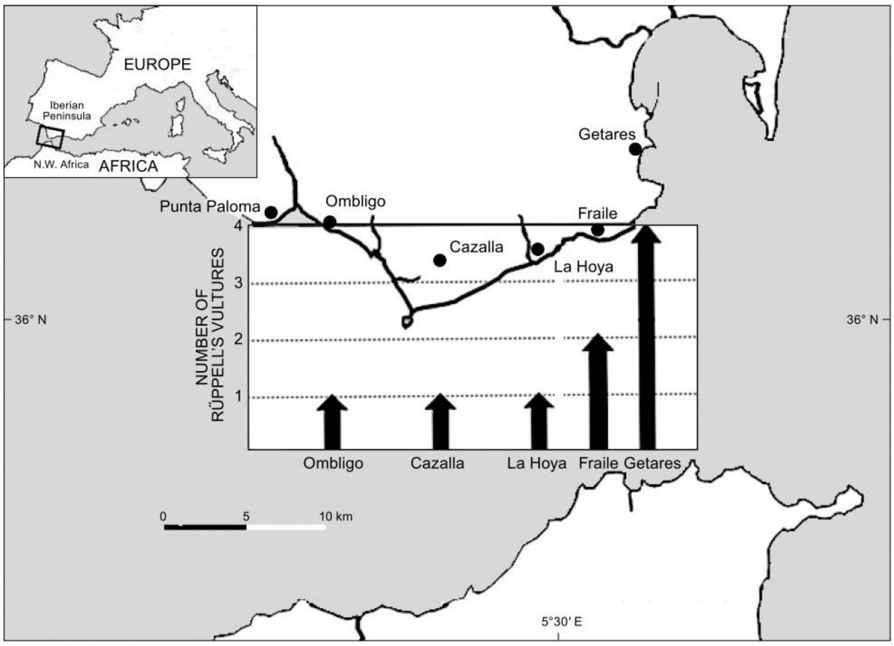
Generally, Rüppell’s Vulture is considered as non-migratory (Cramp and Simmons 1980), although daily foraging movements of up to 150–200 km have been recorded (see Ferguson-Lees and Christie 2001). However, in the last 15 years the species has been recorded far away from its breeding colonies reaching the Iberian Peninsula and north-eastern South Africa (Ferguson-Lees and Christie 2001, De Juana 2006, Kemp and Kemp 2006). In the case of the Spanish records these movements have been suggested as regular yearly movements of Rüppell’s Vulture, probably associated with Griffon Vultures Gyps fulvus crossing the Strait of Gibraltar (De Juana 2006). Currently, the numbers of this near-threatened species entering into Europe remains unknown.

The aim of this paper is to evaluate the numbers of Rüppell’s Vultures arriving to the European continent during spring migration via the Strait of Gibraltar, which connects the western end of the Mediterranean Sea to the Atlantic Ocean, and Europe to Africa, and supports the largest migration of raptors in the Western Europe–West African flyway (Zalles and Bildstein 2000).

Spring raptor migration was counted in the Strait of Gibraltar from February to June 2007 from six equidistant coastal lookouts located along the northern shoreline of the Strait (Figure 1). From early February to late May migration was monitored regularly from three fixed observatories, called La Hoya, Cazalla and Punta Paloma, but during June the observations were not regular and only sporadic records of vultures arriving were available. These sporadic observations were made from three other observatories called Ombligo, El Fraile, and Getares. Regular monitoring included countings three days a week from 9:00 to 15:00 solar time. This six-hour observation period was extended only in those cases in which big flocks of arriving vultures were detected. In order to avoid double counts or birds flying around from an unknown origin, only Rüppell's Vultures positively identified and reaching the European coast coming from the African continent were considered.

Nine Rüppell's Vultures were observed crossing the Strait of Gibraltar and arriving in the European continent from Morocco. Eight of them reached the European coast across the eastern half of the strait, and only one by the western half (Figure 1). Observations of Rüppell's Vultures were recorded during April, May and June, with one, four and four birds, respectively. These birds arrived from 11:00 to 15:00 (UTC). All the birds that were aged were juveniles or inmatures, and they were always seen in flocks together with Griffon Vultures. Observed Rüppell's Vultures represents 0.55% of the total number of vultures counted (n = 1 626).

Figure 1. *Study area and observatories (black dots) used to monitor the spring migration. Arrows show the number of Rüppell's Vultures observed in each observatory*



According to Ferguson-Lees and Christie (1980), the Rüppell's Vulture disperses several hundreds of kilometres north and south in the Sahel and savanna of West Africa, in response to drought and rains. Nevertheless, De

Juana (2006) suggested long-distance movements of Rüppell’s Vultures to Europe through the Strait of Gibraltar, probably coming with Griffon Vultures. Our spring records confirm De Juana’s hypothesis and, furthermore, could indicate that the number of Rüppell’s Vultures crossing the Strait of Gibraltar is of a magnitude unsuspected until now. Taking into account the limitations of our monitoring program, counting for only three days a week and considering the difficulties in identifying the species, these results probably underestimate the total number of Rüppell’s Vultures arriving to the Iberian Peninsula during spring across the Strait of Gibraltar.

The crossing behaviour of soaring raptors in the Strait of Gibraltar depends mainly on the prevailing wind direction. The birds converge on the eastern end of the Strait under westerly winds and on the western end under easterly winds (Bernis 1980). During spring migration the Griffon Vultures normally cross the Strait of Gibraltar under conditions of moderate westerly winds, using the shortest crossing distance and reducing energy consumption during the sea crossing. The vultures avoid the crossing of the Straits under strong and easterly winds.

The Spanish population of Griffon Vulture consists of approximately 25000 pairs (Del Moral 2009). The breeding populations are resident whereas young birds are migrants or vagrants (Bernis 1983, Griesinger 1996, Griesinger 1998), although little is known about the migration of this species and their wintering ecology in Africa. Most of the Iberian juveniles disperse from breeding areas during October, probably in order to locate feeding resources and also to avoid competition for food with adults. This dispersal results in young birds reaching even the Sahel, south of the Sahara, where ringed birds have been recorded in Gambia, Senegal, Mali, Chad and Niger (Díaz *et al*. 1996, Barlow and Wacher 2005, Terrasse 2006). There are also migration records in the middle of the Sahara Desert, in the border-region between Western Sahara and Morocco, Mauritania, Niger and Senegal (Cramp and Simmons 1980, Mundy *et al*. 1992, Thévenot *et al*. 2003). In Africa both Rüppell’s Vultures and Griffon Vultures are highly gregarious forming communal feeding and roosting groups (Mundy *et al*. 1992), with some Rüppell’s Vultures associating with the flocks of migratory Griffon Vultures, a fact that was verified in Senegal during February 2007 (JR pers. obs.). These incorporations could be mediated by conspecific attraction and could facilitate the northern movement of the African species, especially during those years with extreme drought conditions.

Our records show an obvious association between the arrival of Griffon Vultures and Rüppell's Vultures during spring migration. The spatiotemporal pattern of movements detected and the number of birds involved could imply the formation of a long-distance dispersal pattern of Rüppell's Vultures to the Iberian Peninsula, associated with the migration of Griffon Vulture. The Strait of Gibraltar in southern Spain is a migration bottleneck for the Griffon Vultures migrating to and from Africa each year, with an increasing passage of vultures in the last decades (Bildstein *et al*. 2009). Furthermore, these movements could also imply an expansion of the distribution range of the Ruppell's Vulture, as a probable early step for the establishment of this African vulture in the European continent as a breeding species. There is already some evidence of adult Rüppell's Vultures occupying breeding colonies of Griffon Vultures in the Iberian Peninsula, during 1999 and 2008, and exhibiting breeding behaviour (e.g. Costa *et al*. 2003). The increasing number of Spanish records of vagrant Rüppell's Vultures, the vast majority being juveniles or inmatures, occur around the Strait of Gibraltar (Gutiérrez *et al*. 2010), area with a population of more than 2 000 breeding pairs of Griffon Vultures. In this context the Strait of Gibraltar becomes a potential focal point for the settlement of the African species in Spain. Another African raptor, the North African Long-legged Buzzard Buteo rufinus cirtensis, has followed a similar pattern and has recently started to breed in southern Spain (Elorriaga and Muñoz 2010).

Determining if climate change is responsible for this recent, although regular, entrance of Rüppell's Vulture into Europe requires the continuation of monitoring programs of the migration, as well as the surveillance of the European breeding colonies of Griffon vultures to confirm the reproduction of the species and the consequent occupation of the newly favourable habitats in Europe.

Acknowledgements — Funding for the monitoring Migres Program was provided by the Consejería de Medio Ambiente, Junta de Andalucía. The Asociación Eólica de Tarifa funds the monitoring of vulture migration across the

Strait of Gibraltar. We are grateful to Ara Monadjem and two anonymous reviewers for valuable comments on earlier versions of the manuscript. We also would like to acknowledge Rafael Benjumea and Joaquín Mazón for their help in the field work.

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CAPITULO 9. Variabilidad de los cambios en la fenología migratoria otoñal de las aves planeadoras en el sur de España

Variable shifts in the autumn migration phenology of soaring birds in southern Spain

Este capítulo reproduce el texto del siguiente artículo:

Scholer M.N, Martín B., Ferrer M., Onrubia A., Bechard M.J., Kaltenecker G.S. & Carlisle J.D. *en prensa*. Variable shifts in the autumn migration phenology of soaring birds in southern Spain. *Ardea*.

Variable shifts in the autumn migration phenology of soaring birds in southern Spain

Resumen

A pesar de que los cambios en los patrones migratorios de las aves son uno de los efectos ecológicos más evidentes del cambio climático, existen pocos estudios relativos a los cambios en la fenología migratoria de migrantes transaharianos de vida larga. En este trabajo utilizamos los censos de migración otoñal en el sur de España para analizar la magnitud y dirección de los cambios fenológicos de seis especies comunes de aves planeadoras. Aunque muchos métodos recientes para estudiar los cambios fenológicos se basan en series temporales continuas, estos datos no suelen estar disponibles por múltiples razones. Hemos utilizado un análisis de correlación cruzada para comparar los datos recientes de paso desde 1999 a 2011 con datos de censos realizados en 1976-1977. Los cambios encontrados en los calendarios de paso son específicos de cada especie. Así como cigüeñas blancas *Ciconia ciconia* y milanos negros *Milvus migrans* parecen haber retrasado el paso, cigüeñas negras *Ciconia nigra*, águilas culebreras *Circaetus gallicus* y abejeros europeos *Pernis apivorus* han adelantado el paso, mientras aguilillas calzadas *Hieraaetus pennatus* no muestran cambios aparentes.

Abstract

While alteration of the migratory habit of birds is widely regarded as one of the most evident ecological effects of climate change, studies reporting shifts in migration phenology for long-lived, long-distance migrants have been few. Using time series of count data collected in southern Spain during autumn migration, we examined the magnitude and direction of phenological shifts for six common species of soaring birds. Many current methods for investigating phenological change rely on continuous data sets; however, these data may be unavailable for a variety of reasons. We used a cross-correlation analysis, which allowed us to compare recent data on the timing of migration from 1999-2011 to a historic data set collected during 1976-1977. The direction of

phenological shifts for autumn migration was species-specific. White Storks *Ciconia ciconia* and Black Kites *Milvus migrans* appeared to delay passage, Black Storks *Ciconia nigra*, Short-toed Eagles *Circaetus gallicus*, and European Honey Buzzards *Pernis apivorus* advanced their migratory timing, and we found no clear phenological change for Booted Eagles *Hieraaetus pennatus*.

Introduction

The biological consequences of climate change for birds are now well documented for a wide range of taxa and species (Møller *et al*. 2010). In particular, studies addressing avian migration behavior in response to these changes have grown rapidly in recent decades (Gordo 2007, Newton 2008). An estimated 2600 bird species of 141 families undergo some type of seasonal migration (Cox 2010). The capacity of these diverse migrants to adjust to altered environmental conditions is therefore likely to vary across geographic regions and depending on the species' life history strategy. A complete picture of the impact of climate change on bird migration therefore necessitates understanding how species with varied life history traits and distributions are adjusting their migratory behavior.

Although many studies report a trend towards earlier spring arrival in migratory birds, our understanding of how climate change influences other parts of the annual cycle remains less clear (Jenni & Kéry 2003, Gordo 2007, Cox 2010). For example, in contrast to spring migration, fewer data exist for shifts in autumn migration with some species showing advances in their departure while others appear to be experiencing delays (Gordo 2007). Furthermore, the majority of these studies have focused on short-lived passerines as model species (Jenni & Kéry 2003, Mills 2005, Jonzén *et al*. 2006, Tøttrup *et al*. 2006), yet our understanding of the effects of climate change on large, long-lived species of soaring birds, such as raptors and storks, remains largely unexplored (Lehikoinen & Sparks 2010).

In this study, we examine changes in autumn migration phenology for a suite of soaring birds. Data collected from long-term, standardized monitoring programs along migratory routes are perhaps the best data available for studying phenological trends and various modeling techniques have been designed to characterize changes in bird migration (see Knudsen *et al*. 2007 for a review).

Here, we take advantage of the standardized monitoring of soaring birds in southern Spain by comparing annual time series of count data from a historical data set 1976-1977 and from 1999-2011. We examine the magnitude and direction of phenological shifts using cross-correlation analysis by comparing the synchrony of count data between three different time periods for each study species: 1970s-2000s, 1970s-2010s, and 2000s-2010s. Cross correlation analysis is appealing because it allows for comparisons between years, regardless of whether data were collected during the period separating each time series. Such “snap shot” approaches can be useful in cases where observatories are unable to conduct or use count data from a particular year (i.e., incomplete time series for financial or logistical reasons or due to incongruities in data collection) or only a historical data set exists for long term comparisons, such as in our study.

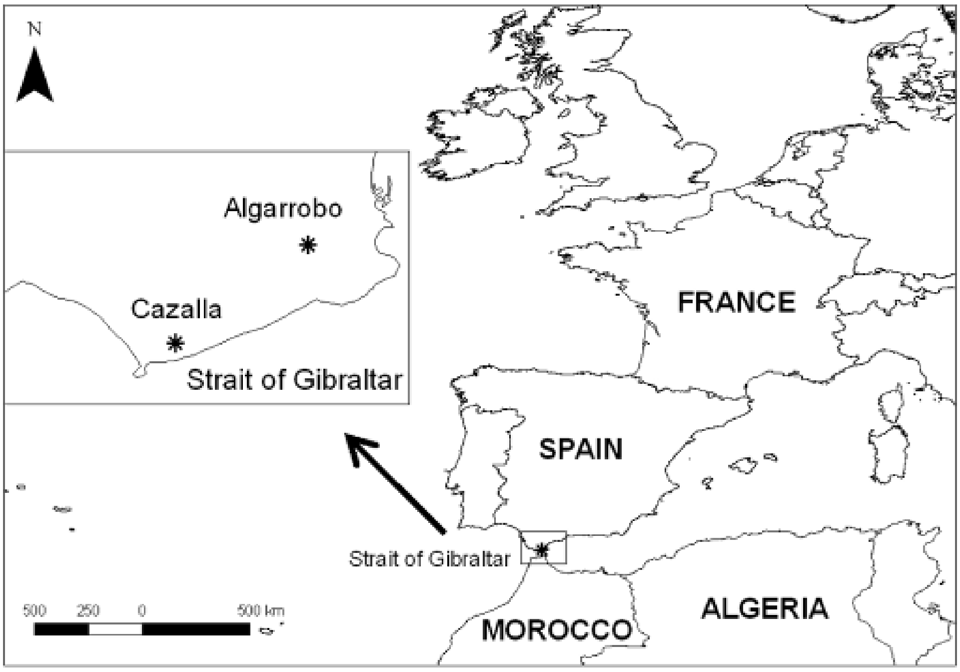
The few studies that have examined autumn migration of European soaring birds report that most species are advancing their departure timing (Filippi-Codacciuoni *et al*. 2010, Lehikoinen 2011, Jaffré *et al*. 2013). We therefore predicted that soaring birds would advance their passage date and that advancements would be most pronounced between the 1970s and 2000s. We based this assumption on trends in global surface temperatures that suggest the majority of climate warming took place before 2000 (Solomon *et al*. 2010) and several well recognized benefits to early departure by long-distance migrants. For example, arriving earlier would allow birds to locate optimal winter territories resulting in better body condition for spring migration (Newton 2008). There is also evidence suggesting that single brooded species, such as the soaring birds we studied, may advance the timing of autumn migration when spring migration is also advanced (Jenni & Kéry 2003, Jaffé *et al*. 2013).

Methods

Study area

We conducted our study in the area of the Strait of Gibraltar (hereafter the Strait) located in the southern extreme of Spain. This portion of the Mediterranean Sea is the shortest distance between continental Europe and North Africa (approximately 14 km) and acts as an obligatory crossing point for the majority of soaring birds migrating from Western Europe. Movements of soaring birds crossing the Strait are strongly governed by the prevailing weather conditions with westerly winds giving rise to higher concentrations of birds following the Mediterranean coast, but along the Atlantic coast when winds are easterly (Bernis 1980). Furthermore, the migration routes of different species vary, making the Atlantic side optimal for viewing some species while others concentrate further east along the Mediterranean. We therefore collected count data for migratory soaring birds at two different observatories positioned near the coast of the Strait: Algarrobo, 54.7’37’’S, 6.25’21’W, which is situated near the town of Algeciras along the Mediterranean, and Cazalla, 54.10’4’’S, 6.33’30’’W, located closer to the Atlantic coast (Figure 1).

Figure 1. *Location of the two observatories in southern Spain where migrations counts of soaring birds were conducted.*



Study species and data collection

Long-term, standardized monitoring efforts unequivocally offer the best data available for characterizing bird migration and, importantly, allow for analysis of complete seasonal distributions (Knudsen *et al*. 2007). We used count data for soaring birds during autumn migration from a baseline dataset collected in 1976 and 1977 (Bernis 1980) and a long-term dataset from 1999-2011. For all years, postnuptial migration counts were conducted daily from approximately 0800-1700, Central European Time, beginning in mid-July and ending in mid-October. In 1976-1977, counts were carried out at both observatories by a minimum of four volunteers with at least one of the volunteers at each site being a trained ornithologist (Bernis 1980). Based on this study a similar methodology detailed in Barrios and Doval (2007) allowed for standardized surveys of soaring birds at both Algarrobo and Cazalla from 1999 until present. Under suboptimal weather conditions in the Strait (e.g., high winds, rain, or low visibility between Spain and Africa) soaring birds will often delay their crossing until conditions improve. Therefore, all birds detected were assigned cardinal values for their direction of origin and destination. We only considered individuals for analysis if they were assigned a southern trajectory (i.e., indicating they were likely going to attempt to cross the Strait) to minimize the possibility of over-estimating the number of birds migrating. Counts were not conducted on days with persistent precipitation or when wind speeds exceeded 6 Beaufort.

Up to 30 species of soaring birds can be regularly counted in the Strait each year. For our analysis, we considered species that 1) could easily and accurately be identified by observers and 2) were most abundant during the autumn migration. We did this to both minimize possible differences in the count data introduced by observer bias as well as maximize our effective sample size. We thus included White Storks *Ciconia ciconia*, Black Storks *Ciconia nigra*, Short-toed Eagles *Circaetus gallicus*, Booted Eagles *Hieraaetus pennatus*, Black Kites *Milvus migrans*, and European Honey Buzzards *Pernis apivorus* (hereafter Honey Buzzards). This list is representative of a suite of long-lived and large-bodied European breeding species which annually migrate south of the Sahara desert.

Air temperature data

We obtained mean annual surface air temperature data from the National Center for Environmental Prediction and National Center for Atmospheric Research Reanalysis dataset (Kalnay *et al*. 1996). We used the R package RNCEP (Kemp *et al*. 2012) to aggregate data from grid cells at a resolution of 2.5˚longitude x 2.5˚latitude for all of Spain.

Modeling shifts in phenology

To assess whether phenological timing differed between years, we analyzed time series for soaring birds counted from 1976-1977 and 1999-2011. We first pooled data from both observatories for all birds with a southern trajectory. We then created a relative frequency distribution of species abundance by dividing daily totals for each species by the total number of birds observed for that species during the season. For comparison years, we identified three time periods of interest that we refer to as the 1970s, 2000s, and 2010s time series, which were calculated by averaging counts between adjacent years for 1976-1977, 1999-2000, and 2010-2011, respectively. To further reduce noise and irregularities, we applied a Gaussian kernel smoothing technique to the frequency distribution using the R package KernSmooth (Wand 2014). Kernel smoothing uses a bandwidth parameter to estimate the optimal degree of smoothing for a kernel density estimate. Larger bandwidths create smoother estimates that may obscure local features of the distribution while small bandwidths may lead to spurious estimates caused by “spikes” in the density estimate (Wand & Jones 1995). Our motivation for smoothing was to allow for 1) missing days in our dataset due to inclement weather conditions, 2) variation in sampling effort, and 3) a more flexible interpretation of between-year variation in the phenological distribution (Knudsen *et al*. 2007). The latter of these issues is of particular importance when dealing with soaring bird migration. As some species display bimodal phenological distributions attributed to the difference in passage of adults and juveniles or males and females, analysis of raw data makes it difficult to identity a single overall shift between two relative frequency distributions (Knudsen *et al*. 2007). Assuming that the variation in the smoothed count data was a proxy for the species’ phenology, we calculated separate time series for each year and for each species using the script itall.R (Shumway & Stoffer 2006).

We used a cross-correlation analysis to explore the spatial relationship between two time series x and y as described by Cassel *et al*. (2000) using the crosscovariance function

$$C_{xy}(h) = \frac{1}{N(h)} \sum_{i=1}^{N(h)} (x_{i+h} - \bar{x})(y_i - \bar{y}) \qquad [1]$$

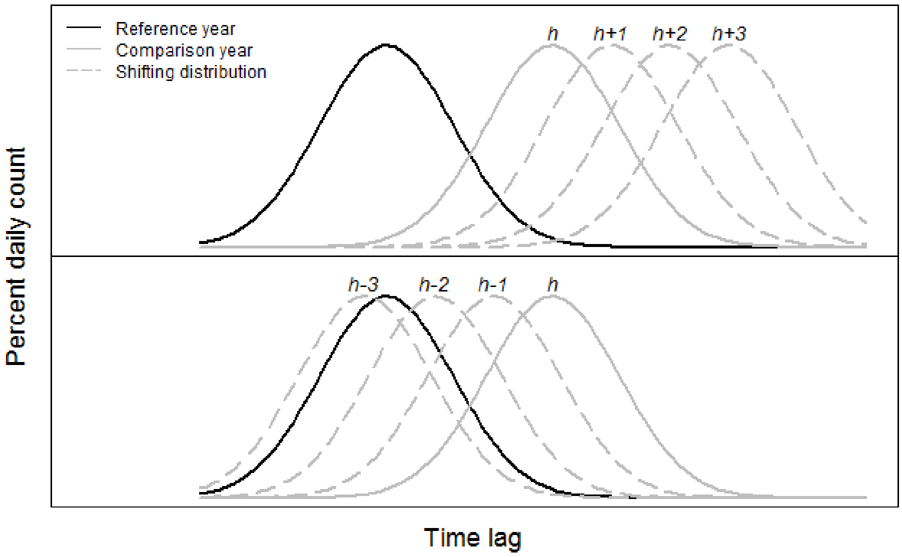
where $N(h)$ is the number of pairs of sample points at a lag distance h apart, x_{i+h} and y_i are measurements x and y at locations $i+h$ and i, respectively, and i and h are vectors. The cross correlation function $\gamma_{xy}(h)$ was used to visualize the spatial correlation between our three time periods of interest and was calculated as follows:

$$\gamma_{xy}(h) = C_{xy}(h)(\sigma_x \sigma_y)^{-1} \qquad [2]$$

with the standard deviations σ_x and σ_y of x and y, respectively (Cassel *et al.* 2000).

Using the *ccf* function in *itall.R* (Shumway & Stoffer 2006), we explored the cross correlation between paired daily abundance (percentage) estimates for soaring birds by setting the most historic time period as a reference and shifting the other temporally until the most parsimonious correlations between abundances were found (Figure 2). The aim was to determine the degree of synchrony between distribution counts of adjacent years and if the degree of coupling (synchronous or lagged) was constant over the last decade. In other words, we sought to identify whether counts from one year “peaked” at a different time(s) and, if true, how far ahead or behind these peaks lagged in reference to the historic time period. We considered lags up to ± 20 days for time series comparisons between the 1970s-2000s, 1970s-2010s, and 2000s-2010s to assess if phenological shifts in migration have occurred in the past four decades and whether the magnitude of those shifts differed. As high inter-annual variation may mask changes in the phenology, we also compared smoothed time series for 1976-1977, 1999-2000, and 2010-2011 to explore how variation in phenology between consecutive years compares to analysis of longer time frames. We calculated 95% confidence intervals around the mean daily abundance of birds for determining significance of cross-correlation time lags. All analyses were carried out in R ver. 3.0.3 (R Development Core Team 2014).

Figure 2. *This heuristic demonstrates our use of the cross correlation function to assess variation in migration timing between two years. The frequency distribution of a comparison year is shifted ahead (A) and behind (B) a reference year by a time lag distance h (e.g., weeks, days, hours) until the maximum overlap between distributions is found. In this case, shifting the distribution by a lag distance of h - 3 results in the most parsimonious correlations, suggesting that migration has advanced in relation to the reference year.*



Results

Between 1976 and 2011, more than 3.5 million birds were counted crossing the Strait of Gibraltar. During this time, mean air surface temperatures in Spain increased from 13.95 to 14.58°C and the majority of this warming occurred before 1999 (Table 1). Generally, shifts in migration were detected between comparisons with the 1970s time series when annual rates of change were greatest for soaring bird passage (Table 1). Figures 3 demonstrate long term shifts in the autumn migration phenology for each of the six study species. Figures 4 illustrate the inter-annual variation in migration timing calculated from adjacent years.

Table 1. *Summary of the annual rate of change (Δdays year-1 relative to a reference time period; see Methods) in migration of soaring birds for time series comparisons between the 1970s, 2000s, and 2010s. The corresponding annual change in mean air surface temperature (°C) across Spain is shown below each time period.*

Species	Time series comparisons		
	1970s-2010s Δ0.017 °C year^{-1}	1970s-2000s Δ0.027°C year^{-1}	2000s-2010s Δ0.027°C year^{-1}
White Storks *Ciconia ciconia*	-0.417	-0.375	0.154
Black Storks *Ciconia negra*	0.250	0.208	0.231
Short-toed Eagles *Circaetus gallicus*	0.056	-0.083	0.231
Booted Eagles *Hieraaetus pennatus*	0.000	-0.167	0.077
Black Kites *Milvus migrans*	-0.111	-0.167	0.000
Honey Buzzards *Pernis apivorus*	0.083	0.125	0.077

Figure 3. *Frequency distributions for the daily proportion of birds counted based on yearly totals of White Storks, Black Storks, Short-toed Eagles, Booted Eagles, Black Kites, and Honey Buzzards crossing the Strait of Gibraltar, Spain, during autumn migration.*

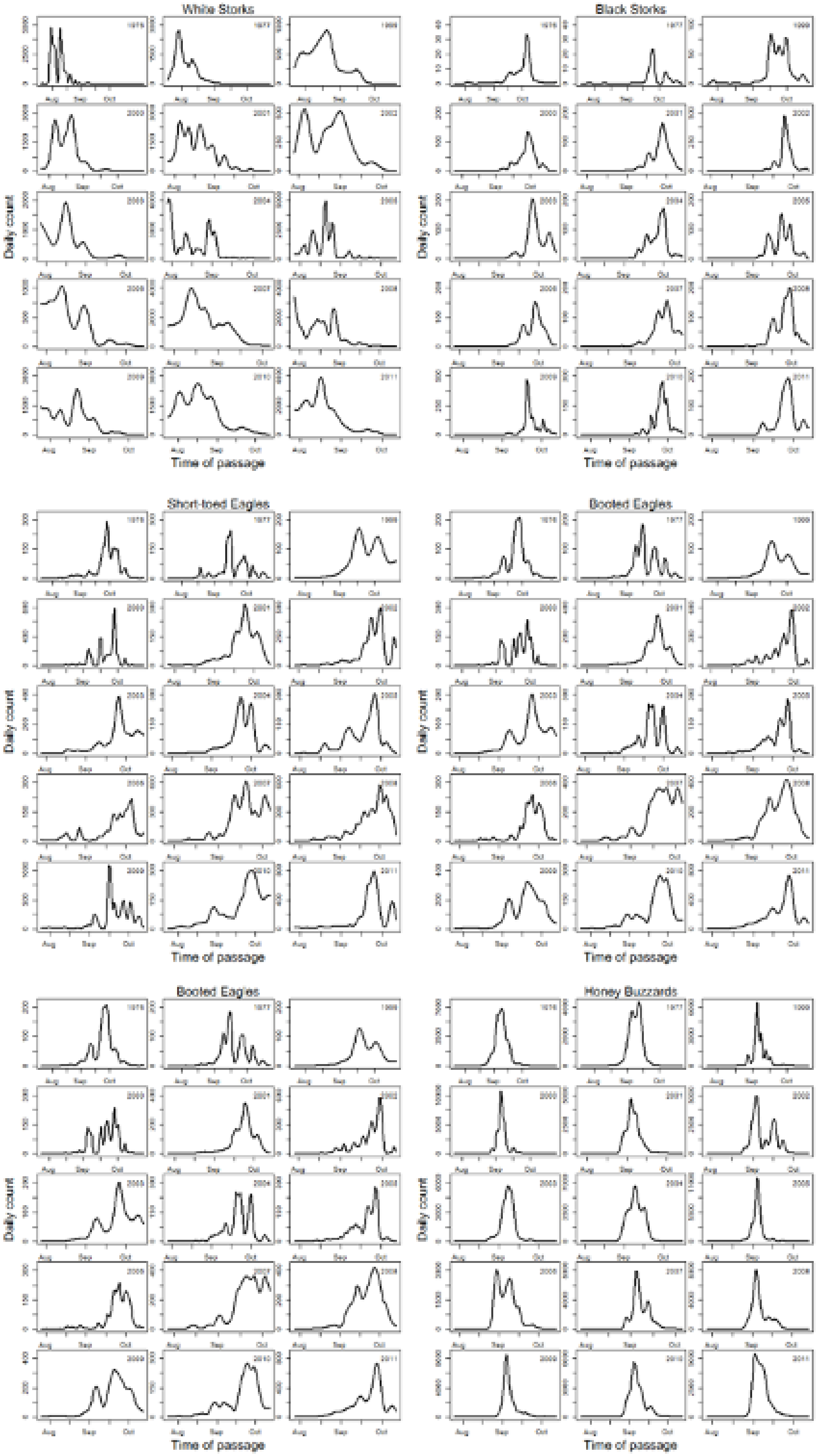
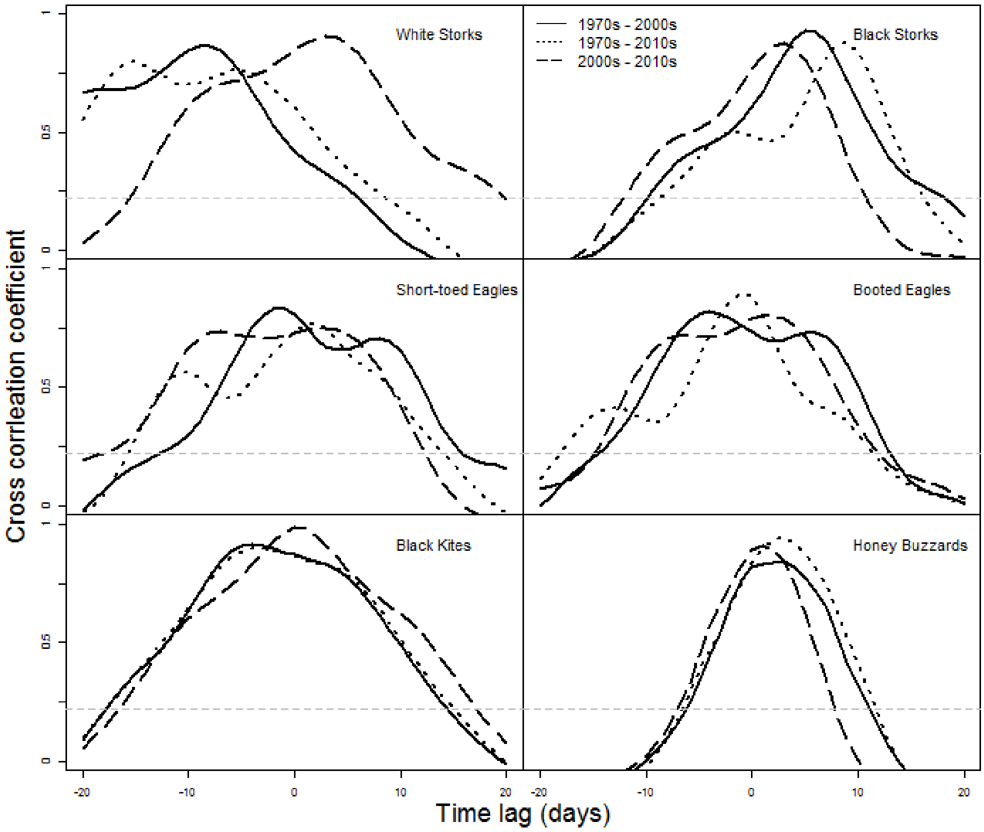


Figure 4. *Temporal cross-correlation functions relative to shifts in autumn migration phenology for Black Storks, White Storks, Honey Buzzards, Black Kites, Short-toed Eagles, and Booted Eagles at the Strait of Gibraltar, Spain. Positive values indicate an advancement in migration timing relative to 1976 while negative values indicate a delay.*



Shifts in migration phenology: comparisons between 1970s, 2000s and 2010s

Our results indicated that White Storks exhibited the greatest shift in phenology, delaying their passage up to 15 days from 1976-2011 (Fig 4). Although time series comparisons between 1970s-2000s and 1970s-2010s showed a gradual shift in the distribution peak towards later passage, a significant positive cross-correlation at lag +3 from 2000s-2010s suggests that this trend has slowed in the past decade. Similar to White Storks, Black Kites appear to have migrated later in autumn and these shifts were more pronounced before the 2000s. The cross-correlograms for Black Kites indicated peaks at lag -4 and -5 for both 1970s-2000s and 1970s-2010s comparisons and a lag at 0 between the 2000s and 2010s. Thus, while passage of Black Kites occurred later in the 2000s than in the 1970s, their migration timing appears to have changed little from the 2000s-2010s.

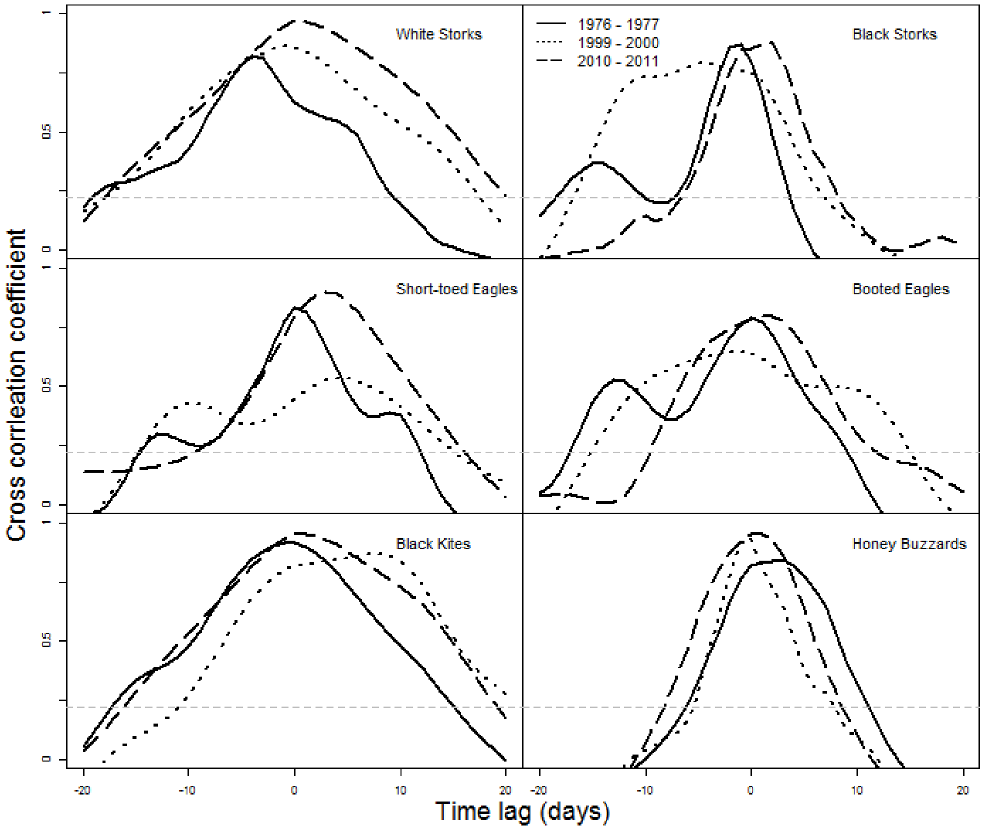
Time series of Black Storks also showed a clear, gradual shift in the distribution peak. In contrast to White Storks, a significant positive cross-correlation at lag +6 between 1970s-2000s and lag +9 for the 1970s-2010s suggests that Black Storks migrated earlier, and that the majority of this change occurred before the 2000s. Similarly, Honey Buzzards advanced their passage by three days between the 1970s-2010s; two of which occurred before the 2000s. This species displayed the most concentrated migration of the soaring birds we studied with 80-89% of the total birds counted each year passing within a two-week period across all years. Short-toed Eagles also appeared to have advanced their passage through the Strait, but their migration timing varied highly between years. Passage advanced by two days from the 1970s-2010s and a significant positive lag at +3 days between the 2000s-2010s indicates that this advancement likely occurred during the last decade.

We found no clear phenological shifts for Booted Eagles and comparisons between all three time periods were generally centered on zero. Cross-correlograms indicated peak lags at -4 and +1 between 1970s-2000s and 2000s-2010s, respectively. No overall change in migration timing occurred between the 1970s-2010s.

Inter-annual variation

All species showed between-year variation (Figure 3) and observed lags between adjacent years tended to be smaller than those identified by comparisons over larger time periods (Table 1, Figure 4 & 5). From 2010-2011 and 1976-1977, Black Kites showed no discernible shift in timing, but comparisons of 1999-2000 indicated a significant lag +7. For White Storks and Honey Buzzards, comparisons of 1999-2000 and 2010-2011 indicated significant correlations at lag 0, but between1976-1977 lags were detected at +3 for Honey Buzzards and lag -4 for White Storks. In contrast, Short-toed Eagles and Booted Eagles had distributions centered around zero for 1976-1977 time period while the form and strength of the cross-correlograms between 1999-2000 and 2010-2011 were more variable. Lags were greatest for Black Storks for comparisons of 1999-2000 and 2010-2011, and the direction of the shift differed from a lag of -4 days during the 2000s to a lag +3 days during the 2010s.

Figure 5. *Temporal cross-correlation functions relative to inter-annual variation for six species of soaring birds detected in the Strait of Gibraltar, Spain, during postnuptial migration.*



Discussion

Identifying shifts in migration phenology is crucial for our understanding of how birds with varying life histories will persist under a scenario of continued climate change. Previous studies have focused on first and last appearance dates, mean or median dates and different percentiles to characterize migration phenology (Knudsen *et al*. 2009). However, these techniques fail to consider the temporal distribution of the migration counts, an issue of particular importance in the case of birds that migrate in large flocks. Analyzing time series of passage dates accounts for the number of birds migrating when calculating phenological shifts, and, to the best of our knowledge, our study represents one of the first to use time series and cross-correlation analysis to explicitly model bird phenology for autumn migration. This approach also allows for a “snap shot” analysis of non-continuous series of data, such as the ones we utilized for soaring birds crossing the Strait.

Over the 36 year time period we considered, phenology advanced for three species whereas two species showed delayed passages and one species displayed no change. During this same time, surface air temperatures for our study area increased by 0.62°C and the majority of this warming occurred in the years between the mid-1970s and the late 1990s (Table 1). As in previous studies, these data provide no direct evidence that migratory shifts occurred as a result of climate warming. However, findings from the current study are broadly comparable to numerous works that have noted correlations between shifting migration phenology and climate change (Gordo 2007). The variable responses we observed in autumn passage timing supports previous heterogeneous findings on migratory shifts in postnuptial movements for other species (Jenni & Kéry 2003, Thorup *et al*. 2007, Filippi-Codacciuoni *et al*. 2010, Van Buskirk 2012). Other researchers have noted distinct increases in temperature for Western Europe during the later part of the 20th century, followed by a period of relative cooling (Jaffé *et al*. 2013) and these trends are in concordance with changes in temperature across the northern hemisphere (Lawrimore *et al*. 2011). Perhaps not surprisingly then, the shifts we detected generally occurred between 1970s-2010s or 1970s-2000s time series comparisons whereas no change or slight change were observed in the 2000s to 2010s (Figure 4). White Storks and Black Kites both showed annual rates of change in migratory timing for the 1970s-2000s that were more than twice as large as those detected for 2000s-2010s (Table 1). Honey Buzzards also showed a nearly two-fold increase in the rate of migratory change between 1970s-2000s compared to the 2000s-2010s. Many researchers have pointed to the importance of long term (i.e., > 10 years) studies in revealing phenological trends (Knudsen *et al*. 2007, Lehikoinen & Sparks 2010, Kerr & Dobroski 2013). Our results are in accordance with these statements and suggest that an analysis based on data from the last decade alone may not be a long enough time frame to detect shifts in phenology related to climate change in Europe.

While most of the soaring bird species we studied appeared to have experienced shifts in their migration phenology, the direction of those shifts was species-specific. Black Storks, Short-toed Eagles, and Honey Buzzards all advanced their passage date. Filippi-Codacciuoni *et al*. (2010) reported an advance in migration of 0.79 days for Short-toed Eagles and 3.39 days for Honey Buzzards. Our estimates of an advance in passage timing of 2 and 3 days for these two species, respectively, are in agreement with these observations and support other works which report advancing passage dates in European short-distance soaring birds (Jaffré *et al*. 2013). The most common explanation for earlier passage timing is that it results from an earlier arrival to breeding areas in spring without a change in the length of stay and, consequently, an advance in the timing of all events from arrival to breeding to departure (Lehikoinen *et al*. 2004, Gordo 2007). It has also been proposed that a shortening of the distance between wintering and breeding areas could lead to a strong advancement in passage timing (Visser *et al*. 2009).

Contrary to our prediction, White Storks and Black Kites delayed their passage. Late autumn passage could suggest that White Storks and Black Kites are benefiting from an increased amount of time spent at or near the breeding area, perhaps as a result of an increased number of reproductive attempts or at least an increased opportunity to re-nest after early season nest failures. Jaffré *et al*. (2013) found support for an overall lengthening of the breeding area residence-time (BART) in soaring birds and this lengthening was correlated to increasing spring temperatures in Western Europe (Lawrimore *et al*. 2011). Soaring birds that advance their spring migration timing while also delaying autumn departure could experience a reduction in migratory behavior that eventually leads to residency (Pulido & Bethold 2010, Jaffré *et al*. 2013). There is evidence of advances in the spring migration of long-distance migratory raptors (Van Buskirk 2012). In the case of White Storks, advances in spring migration have also been found (Ptaszky *et al*. 2003, Vaitkuviene *et al*. 2015) and the number of overwintering birds in southern Europe increased during the past three decades (Molina & Del Moral 2005). It therefore seems reasonable to suggest that the observed delay in passage for White Storks and Black Kites may be a result of an increased BART for these species throughout their range.

For data collected during the 2000s, the distribution of migration counts for White Storks and Black Kites appears incomplete for the earliest phase of the migration (Figure 3). For example, 1646 and 4348 White Storks were observed crossing the Strait during the first day of migration counts for 2003 and 2004, respectively. Thus, these species may also have advanced their migration and the apparent delay in passage is simply an artifact of counts beginning too late from 1999-2011. Results of these shifts should therefore be interpreted with caution. Regardless of the causal mechanism, this scenario underlines the need for bird observatories charged with monitoring migration to review the time frame in which counts for migratory birds are conducted. In the case of White Storks and Black Kites, our data indicated that autumn migration counts should start at least two weeks earlier than in 1976 to capture the complete migration period for these species. Therefore, White Storks and Black Kites not only delayed their migration but they also appear to have lengthened the total migration period although we cannot detect an earlier arrival because of the lack of data. One explanation is that lengthening of the migration period may be related to population increases for these species. European populations of White Storks declined between 1976 to 1999 (Birdlife International 2004) but a strong recovery took place from 2000 to 2011. In particular, northern populations of White Storks, which migrate later than southern populations, have increased substantially over the last decade and may be responsible for the observed delay in migration (B. Martin unpubl. data). Similarly, populations of Black Kites declined across much of Europe by nearly 30% between 1970 and 2000, but have since stabilized and may have begun to increase (Birdlife International 2004).

Regional weather conditions have a strong influence on the flight speed and performance of soaring birds (Vansteelant *et al*. 2014, Vaitkuviene *et al*. 2015). The unique weather conditions of the Strait are no exception, and greatly affect the migration phenology for all species, especially during periods of sustained high winds when birds are prevented from crossing to Africa. Moreover, meterological events related to deteriorating living and flight conditions at the breeding area likely influence departure timing of soaring birds while weather conditions encountered en route to bottleneck sites can modulate the timing of their passage at such locations (Shamoun-Baranes *et al*. 2006). Thus, while our phenological trends from consecutive years seem to support that lags are due to a changing trend in migration patterns for some species, results for species where inter-annual variation was high are less certain. In particular, Short-toed Eagles, Booted Eagles, and to a lesser extent, Black Storks, all showed variation in the strength and direction of inter-annual shifts. This might indicate a greater influence of proximate weather conditions in determining the migration timing for these species. Whatever the cause, results from these species should be interpreted with caution.

Current theory predicts that long-distance migrants should have more difficulty shifting their migratory behavior because migratory cues are more likely to be determined by endogenous factors when breeding and wintering areas are far apart (Lehikoinen *et al*. 2004). Under such a scenario, long-distance migrants should be constrained in their ability to adapt to climate change compared to short-distance migrants.

Little work has been conducted on long-lived species such as storks and raptors which may live to greater than 20 years of age in the wild (Mebs & Schmidt 2006). As all soaring birds are generally long-lived, their ability to learn and therefore adjust their behavior may be greater than smaller birds with shorter life expectancies. Hence, their handicap in being able to detect climatic cues may be offset by their capacity for phenotypic adjustment based on accumulated learned experiences during migration. Indeed, in a study of Black Kites, Sergio *et al*. (2014) demonstrate that migration behavior changes throughout the life of a migrant and is promoted by gradual individual improvements to migration routes and flight technique. Our findings on long-term trends in the phenology of soaring migrants add to the growing body of literature indicating that migrants with varied life history characteristics are shifting their migration patterns. Other migration count-sites or bird observatories lacking continuous times series of count data may consider adopting a similar approach to explore changes in phenological trends.

Acknowledgments

Our thanks and gratitude goes out to the many people who took part in conducting the migration surveys throughout the Strait of Gibraltar. This study was funded by grants of the Regional Ministry for Environment of Andalusia and

Fundación Migres. We are grateful to Dr. Mark Rudin for making possible an international collaboration between the Intermountain Bird Observatory and Fundación Migres. Comments from R. Klaassen, W. Vansteelant, and an anonymous reviewer greatly improved the quality of this manuscript.

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CAPITULO 10. Influencia de las condiciones meteorológicas locales y regionales sobre los conteos de migración postnupcial de aves planeadoras en el estrecho de Gibraltar, España

Local and regional weather patterns influencing post-breeding migration counts of soaring birds at the Strait of Gibraltar, Spain

Este capítulo reproduce el texto del siguiente artículo:

Miller R.A., Onrubia A., Martín B., Kaltenecker G.S., Carlisle J.D., Bechard M.J. & Ferrer M. *en prensa*. Local and regional weather patterns influencing post-breeding migration counts of soaring birds at the Strait of Gibraltar. *Ibis*.

Local and regional weather patterns influencing post-breeding migration counts of soaring birds at the Strait of Gibraltar, Spain

Resumen

La migración es un evento importante en el ciclo anual de muchas especies de aves. Durante la migración deben enfrentarse a multitud de desafíos, como la búsqueda de lugares de alimentación y refugio en lugares poco familiares, lo que se traduce en tasas más elevadas de mortalidad en esta época respecto a otros momentos del año. La meteorología puede afectar de manera decisiva tanto al inicio de la migración, como al desarrollo y la supervivencia a lo largo de la misma, y puede repercutir en los censos de aves migratorias en los lugares de concentración. Cuantificar el efecto a corto plazo de las condiciones meteorológicas sobre estos censos es fundamental para interpretar adecuadamente los datos obtenidos en otros análisis. Con este fin, en este trabajo analizamos el efecto de las condiciones meteorológicas locales y regionals sobre los censos otoñales de aves planeadoras en el estrecho de Gibraltar. Para ello utilizamos aproximaciones teóricas para analizar la influencia de las condiciones locales y en el norte de España sobre los conteos de cinco especies de aves planeadoras en dos observatorios del estrecho de Gibraltar. Encontramos que los censos son más elevados en días con vientos locales de norte y poniente, a menudo después de días de vientos de levante, así como en días con altas presiones locales a menudo posteriores a una jornada de bajas presiones. Además se ha encontrado que las condiciones meteorológicas en el norte de España influyen en los conteos en el estrecho de Gibraltar en días posteriores, aunque el efecto es mucho más débil que las condiciones locales. Se confirma que las condiciones meteorológicas a corto plazo, a escala local y regional, pueden influir en los conteos de migración y esto debería tenerse en cuenta cuando estos datos se usan en otros análisis.

Abstract

Migration is a significant event in the annual cycle of many avian species. During migration birds face many challenges, including unfamiliar foraging and refuge habitats, resulting in a much higher rate of mortality during migration than during other seasons of the year. Weather may significantly affect a bird's decision to initiate migration, the course and pace of migration, and its survival during migration. Each of these influences may impact the counts of migrating birds at geographic convergence zones or bottlenecks. It is important to quantify the effect of short-term weather on these counts to appropriately interpret and use such counts in other analyses. To this end, we set forth to analyze the effects of local and regional weather conditions on the migration counts of soaring birds at the Strait of Gibraltar during post-breeding migration. We used information theoretic approaches to analyze the influence of local weather and weather in northern Spain on the migration counts of five soaring bird species from two count sites near the Strait of Gibraltar. We found that migration counts were higher on days with local north and westerly winds, often following a day of easterly winds, on days with local high pressure systems, and often following a day of lower pressure. We found that weather conditions in northern Spain influenced migration counts at the Strait of Gibraltar, but the effects were much weaker than local weather conditions. We confirm that short-term weather conditions, locally and regionally, can influence migration counts and should thus be considered when these counts are used in other analyses.

Introduction

Migration is a significant event in the annual cycle of many avian species and is thus important to study if we expect to conserve these species (Kirby *et al*. 2008). Some of the challenges faced by migrating species include adapting to unfamiliar habitats, gathering food to support a 10-25× increase in the basal metabolic rate (Gill 2007), and a significant increase in the risk of predation. Each of these factors can increase mortality during migration. To this point, Sillett and Holmes (2002) found that 85% of apparent annual mortality occurred during migration for a migrating songbird and Klaassen *et al*. (2014) found mortality among European breeding raptors that over-winter in Africa to be six times higher during migration than in other seasons.

Weather has a large impact on the life of a migrating bird. Weather plays a role in initiating migration (Shamoun-Baranes *et al*. 2006a, Gill 2007), directly or indirectly influences the course and pace of migration (Gauthreaux Jr. 1971, Gordo 2007, Bohrer *et al*. 2012, Limiñana *et al*. 2013), and can directly impact survival during migration (Newton 2007, Oppel *et al*. 2015). The strength of each of these impacts may vary by the size of the bird, speed of the bird, migration strategy, and style of flight (Hedenstrom 2008, Shamoun-Baranes *et al*. 2010, Vansteelant *et al*. 2014b). Soaring birds are generally dependent upon thermals created by the differential warming of the earth's surface and updrafts created by differing topography for lift. The use and advantage of these landscape-influenced features varies with the size of the bird and the loading of the wings (Shamoun-Baranes *et al*. 2003) and can be a major factor in the speed of migration (Chevallier *et al*. 2010, Klaassen *et al*. 2011).

In this study we set forth to analyze the effects of local and regional weather conditions on the migration counts of soaring birds at the Strait of Gibraltar during post-breeding migration. A better understanding of the effects of weather conditions on migration counts will enable better interpretation of these counts and the precision of studies dependent upon this data. We expected that migration counts at the Strait of Gibraltar would be affected by local wind conditions and weather conditions across the Pyrenees Mountains in northern Spain. We specifically expected that the number of birds observed migrating, as counted at the Strait of Gibraltar, would be larger during local westerly winds, local high pressure systems, and after fair weather conditions in northern Spain some days prior (Shamoun-Baranes *et al*. 2006b, Chevallier *et al*. 2010). We also expect that poor weather in northern Spain, another bottleneck for migratory birds, could delay migration and affect the volume of birds observed at the Strait of Gibraltar a few days later. Lastly, we expected that cloud cover and visibility could affect both the detection of birds and the number of birds migrating as birds appear more willing to cross the Strait of Gibraltar when Africa is easily viewed from Europe (Evans and Lathbury 1973).

Methods

Study area

We conducted our study in the area of the Strait of Gibraltar (hereafter the Strait) located in the southern extreme of Spain (Fig. 1). This area represents the shortest distance between continental Europe and North Africa (approximately 14 km) and acts as an obligatory crossing point for the majority of soaring birds migrating from Western Europe to Africa (Bernis 1980, Finlayson 1992). The migration routes of different species vary (Bernis 1980), making the Atlantic side of the Strait optimal for viewing some species while others concentrate further east along the Mediterranean Sea. We therefore collected count data for migratory soaring birds at two different observatories positioned near the coast of the Strait: Algarrobo (36.0903° N, 5.4840° W), which is situated near the city of Algeciras, Spain along the Mediterranean Sea at the east end of the Strait, and Cazalla (36.0330° N, 5.5774° W), located closer to the Atlantic coast at the west end of the Strait (Fig. 1). The species that migrate in abundance past the Algarrobo count site tend to migrate later in the year, thus our counts begin later at this site resulting in fewer days of monitoring.

Study species and count data collection

Data collected from standardized monitoring efforts are unequivocally the best data available for characterizing bird migration and, importantly, allow for analysis of complete seasonal distributions (Knudsen *et al*. 2007). We used count data for soaring birds collected at each of the two count sites during post-breeding migration from 2009–12. For each year, counts were conducted by a minimum of two trained observers at each location during the post-breeding migration beginning in mid-July and ending in mid-October. Under suboptimal weather conditions in the Strait (e.g. high winds, rain, or low visibility between Spain and Africa) soaring birds will often delay their crossing until conditions improve. Therefore, all birds detected were assigned cardinal values for their direction of origin and destination (Scholer *et al*. 2015). We only considered individuals for analysis if they were assigned a southern trajectory (southwest, south, or southeast; i.e. indicating they were likely to attempt to cross the Strait) to minimize the possibility of over-estimating the number of birds migrating. This approach minimizes, but does not eliminate, the issue of duplicate counting of individual birds that do not cross to Africa. Counts were not conducted on days with persistent precipitation or when wind speeds exceeded a Beaufort scale value of six.

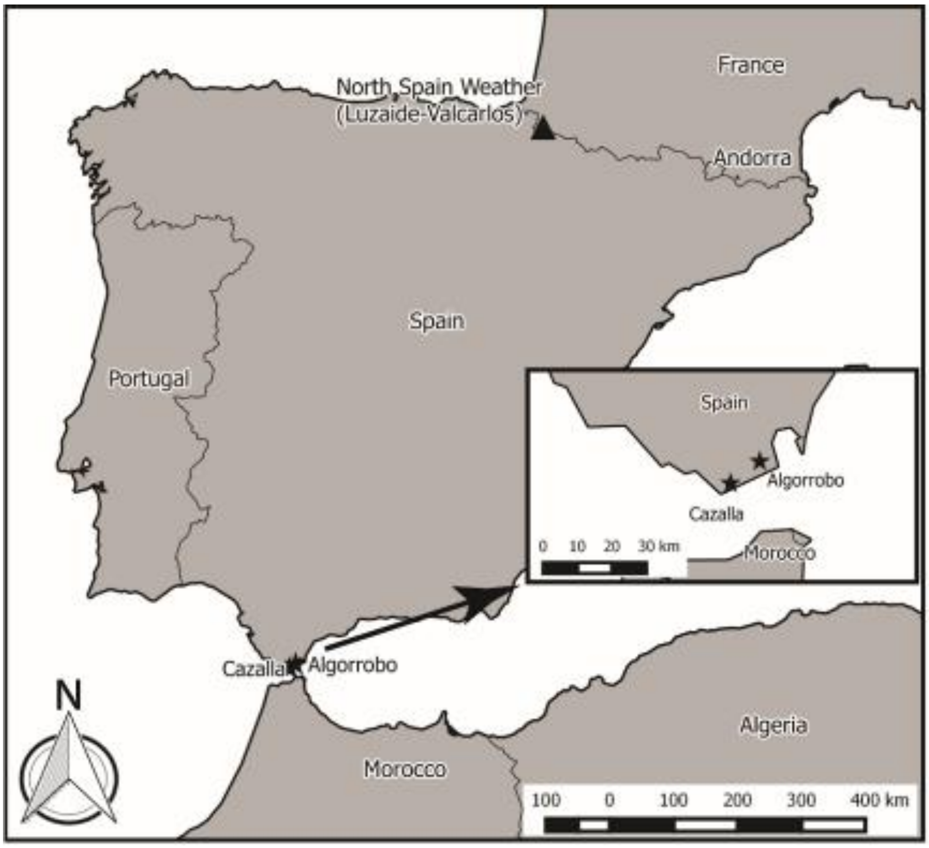
Up to 30 species of soaring birds can be counted at the Strait each year. For our analysis, we considered species that could easily and accurately be identified by observers and were most abundant during the post-breeding migration. We included White Stork *Ciconia ciconia*, Honey Buzzard *Pernis apivorus*, Short-toed Eagle *Circaetus gallicus*, Booted Eagle *Hieraaetus pennatus*, and Black Kite *Milvus migrans*. These five species represent a suite of long-lived European breeding species which annually migrate to non-breeding areas south of the Sahara desert (Cramp and Simmons 1980).

Weather data

We gathered local viewing condition data in the field hourly at each respective count site including cloud cover percentage (0, 20, 40, 60, 80, 100) and visibility (0 [low], 1, 2, 3 [high]). Hourly data was averaged together to generate a daily average value for cloud cover and visibility at each count site. We acquired historical precipitation data for Estación de Luzaide-Valcarlos (43.093° N, 1.302° W) in northern Spain within the Pyrenees Mountains from Unidad de Información Meteorológica de España (Fig. 1). We gathered local and regional wind and pressure data from the U.S. National Oceanic and Atmospheric Administration's (NOAA) National Center for Environmental Prediction (NCEP) Reanalysis Project (Kalnay *et al*. 1996). We extracted wind data at a pressure level of 925 hPa which represents an average altitude of approximately 750 m above sea level to represent winds above the ground surface and within an elevational range expected to be experienced by migrating birds (Thorup *et al*. 2003, Klaassen *et al*. 2011). We used linear spatial and temporal interpolation to derive daily values for wind at each location. We did not use local precipitation data in the analysis as local rainfall often resulted in cancellation of counting for the given day.

We retrieved weather data for the western slope of the Pyrenees Mountains in northern Spain centered on Luzaide-Valcarlos (43.093° N, 1.302° W; Fig. 1) as this area offered the more consistent correlation with migratory counts at the Strait for most species than locations further east (Andorra or Pic du Midi du Bigorre; R.A. Miller unpubl. data). We extracted data for this location with time lags between two and nine days to represent the possible migration timing from northern Spain to the Strait of Gibraltar. Based on documented migration speeds, two to three days should be the minimum length of time to complete the journey from north Spain to the Strait (Vansteelant *et al*. 2014a). We retrieved weather data for the Strait (36.033° N, 5.577° W) for the day of migration and for the previous day to represent any delays in migration caused by local weather.

Figure 1. *Map of Spain and the Strait of Gibraltar, count site locations, and northern Spain weather sampling location. Inset: Map of southern Spain and the Strait of Gibraltar, with two count site locations illustrated.*



For each time and location, we retrieved three variables representing the flight conditions for the respective area. These variables included the zonal winds (east-west wind component; m/s), the meridional winds (north-south wind component; m/s), and the geopotential height (m) which we consider a proxy for local air pressure.

Statistical methods

We analyzed the data using generalized linear mixed models with various weather variables as fixed effects and with species and count site as random effects. To compensate for expected temporal auto-correlation, we included day-of-year, day-of-year^2, year, and the previous day's count as fixed effects in all models, including the null model. We used a negative binomial distribution as our response variable consisted of count data that was over-dispersed (Lindén and Mäntyniemi 2011). We ranked all models using Akaike Information Criterion, adjusted for small sample size (AIC$_c$; Burnham and Anderson 2002).

We first evaluated the northern Spain weather data lag by comparing models containing the four weather predictor variables (east/west wind, north/south wind, air pressure and precipitation) for each time lag between two and nine days inclusive with each other and with the null model. Thus, each model used in model selection represented a different time lag (i.e. our ecological question). We chose to not analyze each variable independently so as to avoid data dredging (Burnham and Anderson 2002). We chose the top model to represent the most influential time lag for influencing migration and propagated this time lag into all further analyses. We then evaluated local viewing conditions (local cloud cover and local visibility), local weather variables (east/west wind, north/south wind, and air pressure), the previous day's weather variables (east/west wind, north/south wind, and air pressure), and the northern Spain weather variables (east/west wind, north/south wind, air pressure and precipitation) as predictors for migration counts. We used model selection to evaluate all subsets of these four groups of variables, but not each individual variable, so as to avoid data dredging.

We consider a variable as having an effect on migration counts if the 95% confidence interval for the model coefficient failed to overlap zero in the top model. We created model predictions for each of these variables from the top model by varying a given value over its observed range while holding all other variables constant at their mean value. We present graphs of these model predictions to help visualize the influence of the various predictors on migration counts.

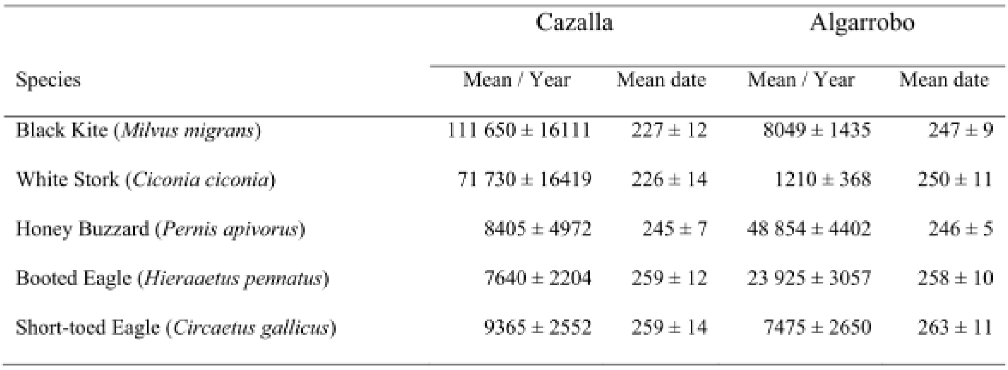
Lastly, we applied the general structure (i.e. same fixed effects and the random effect for site) of the top global model to each of the five species (without the random effect for species) to generate model coefficients for comparison among species. We should note that the correlation matrices vary between the global model and species models making direct comparison of coefficient magnitudes inappropriate for full inference. However, among species comparisons are valid as are the direction of influence between global and species models.

We conducted all statistical analyses in Program R (R Development Core Team 2013). We retrieved and interpolated the NCEP data to location and daily values by using the R package RNCEP (Kemp *et al*. 2012). We fit negative-binomial models using R package glmmADMB (Skaug *et al*. 2013). We ranked models using R package MuMIn (Barton 2013).

Results

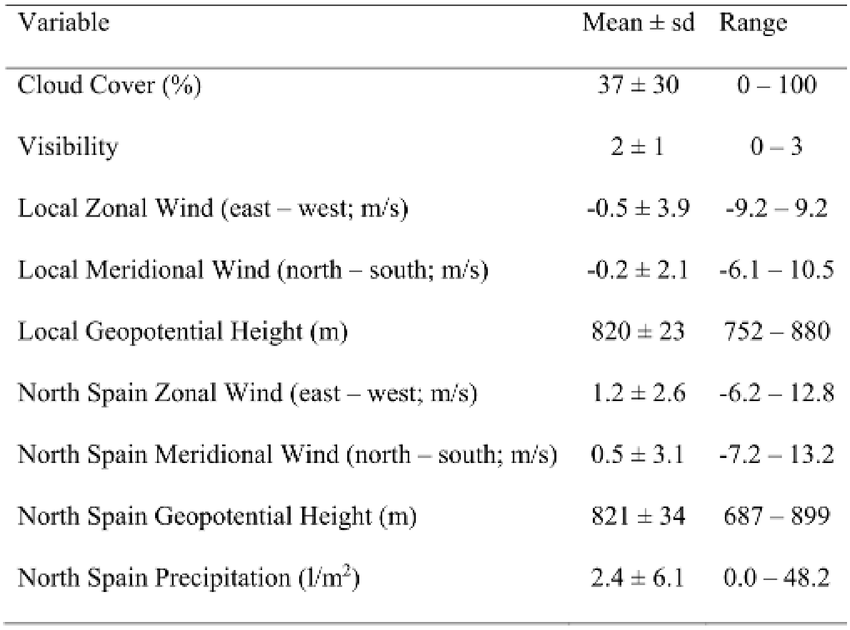
Between 2009 and 2012 we counted post-breeding migration on 273 days at the Cazalla count site, an average of 68.3 ± 3.6 sd d/yr, and on 172 days at the Algarrobo count site, an average of 43 ± 1.4 sd d/yr. We counted a total of 1 355 993 raptors and storks of which 1 230 749 were believed to be actively migrating. This included 478 580 Black Kites, 290 512 White Storks, 228 985 Honey Buzzards, 126 242 Booted Eagles, and 67 360 Short-toed Eagles (Table 1). Each of the five species evaluated were counted annually at each count site, but the relative proportion of each species differs between sites based upon the tendency for a given species to utilize different routes and local topography (Table 1; Bernis 1980). During the counts the local and regional weather conditions presented a wide range of values (Table 2).

Table 1. *Mean soaring-bird counts ± sd and mean passage dates ± sd from 2009–12 at two separate count sites neat the Strait of Gibraltar, Spain. Data illustrate the relative volumes among species and the differential use of survey sites by different species.*



Species	Cazalla		Algarrobo	
	Mean / Year	Mean date	Mean / Year	Mean date
Black Kite (*Milvus migrans*)	111 650 ± 16111	227 ± 12	8049 ± 1435	247 ± 9
White Stork (*Ciconia ciconia*)	71 730 ± 16419	226 ± 14	1210 ± 368	250 ± 11
Honey Buzzard (*Pernis apivorus*)	8405 ± 4972	245 ± 7	48 854 ± 4402	246 ± 5
Booted Eagle (*Hieraaetus pennatus*)	7640 ± 2204	259 ± 12	23 925 ± 3057	258 ± 10
Short-toed Eagle (*Circaetus gallicus*)	9365 ± 2552	259 ± 14	7475 ± 2650	263 ± 11

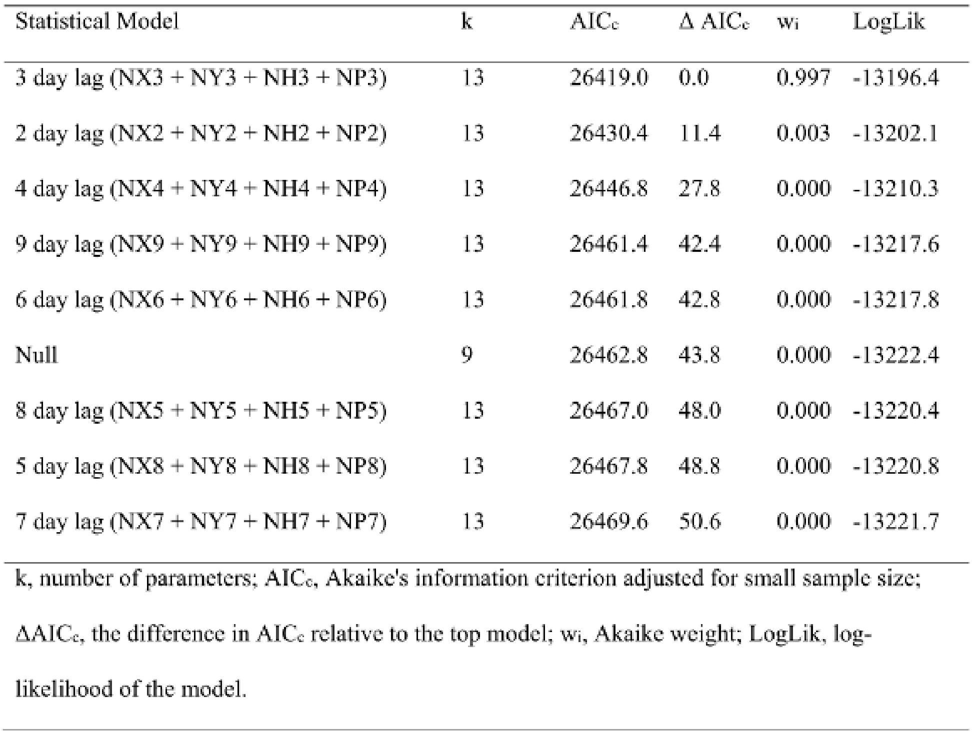
Table 2. *Summary statistics of observational and weather related variables predicted to effect observed migratory counts at the Strait of Gibraltar during post-breeding migration 2009–12. Cloud cover and visibility recorded during counts at Algarrobo (36.0903° N, 5.4840° W) and Cazalla (36.0330° N, 5.5774° W) count sites. Local weather data collected for Cazalla count site (36.033° N, 5.577° W). North Spain weather collected from Estación de Luzaide-Valcarlos (43.093° N, 1.302° W).*



Variable	Mean ± sd	Range
Cloud Cover (%)	37 ± 30	0 – 100
Visibility	2 ± 1	0 – 3
Local Zonal Wind (east – west; m/s)	-0.5 ± 3.9	-9.2 – 9.2
Local Meridional Wind (north – south; m/s)	-0.2 ± 2.1	-6.1 – 10.5
Local Geopotential Height (m)	820 ± 23	752 – 880
North Spain Zonal Wind (east – west; m/s)	1.2 ± 2.6	-6.2 – 12.8
North Spain Meridional Wind (north – south; m/s)	0.5 ± 3.1	-7.2 – 13.2
North Spain Geopotential Height (m)	821 ± 34	687 – 899
North Spain Precipitation (l/m^2)	2.4 ± 6.1	0.0 – 48.2

In evaluating the time lag for northern Spain weather on the migration counts at the Strait of Gibraltar, we found the top model represented a time lag of three days, and was superior to models representing other lags (> 2 ΔAIC c ; Table 3). In evaluating the effects of local viewing conditions (cloud cover and visibility), local weather, the previous day's local weather, and north Spain weather three days prior, the top model included all components except viewing conditions, and a second model was similar but with the local viewing conditions (Table 4). We chose not to use model averaging as the top model was > 2 ΔAIC c from the second ranked model (Table 4).

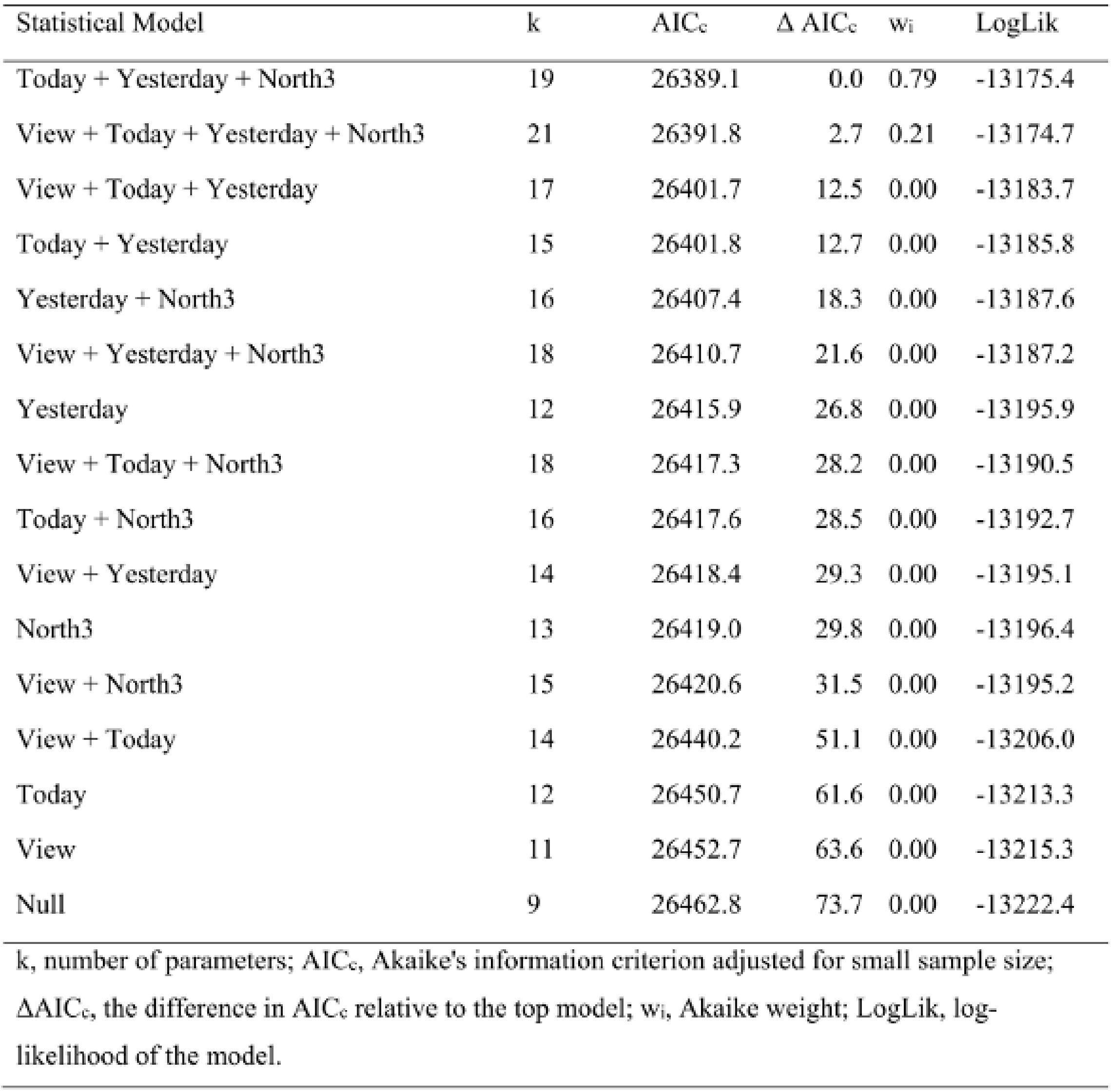
Table 3. *Model selection table evaluating the effects of north Spain weather conditions on migration counts of five species at two count sites at the Strait of Gibraltar, 2009–12. All models, including the null, include day-of-year, day-of-year 2 , year, and previous day's count to offset the effects of auto-correlation, and include species and count site as random effects. NXx = northern Spain east-west wind component, x days prior; NYx = northern Spain north-south wind component, x days prior; NHx = northern Spain air pressure, x days prior; and NPx = north Spain precipitation, x days prior.*



Statistical Model	k	AIC_c	ΔAIC_c	w_i	LogLik
3 day lag (NX3 + NY3 + NH3 + NP3)	13	26419.0	0.0	0.997	-13196.4
2 day lag (NX2 + NY2 + NH2 + NP2)	13	26430.4	11.4	0.003	-13202.1
4 day lag (NX4 + NY4 + NH4 + NP4)	13	26446.8	27.8	0.000	-13210.3
9 day lag (NX9 + NY9 + NH9 + NP9)	13	26461.4	42.4	0.000	-13217.6
6 day lag (NX6 + NY6 + NH6 + NP6)	13	26461.8	42.8	0.000	-13217.8
Null	9	26462.8	43.8	0.000	-13222.4
8 day lag (NX5 + NY5 + NH5 + NP5)	13	26467.0	48.0	0.000	-13220.4
5 day lag (NX8 + NY8 + NH8 + NP8)	13	26467.8	48.8	0.000	-13220.8
7 day lag (NX7 + NY7 + NH7 + NP7)	13	26469.6	50.6	0.000	-13221.7

k, number of parameters; AIC_c, Akaike's information criterion adjusted for small sample size; ΔAIC_c, the difference in AIC_c relative to the top model; w_i, Akaike weight; LogLik, log-likelihood of the model.

Table 4. *Model selection table evaluating the effects of viewing conditions, local weather at the Strait, and weather in northern Spain on migration counts of five species at two count sites near the Strait of Gibraltar, Spain, 2009–12. All models, including the null, include day-of-year, day-of-year 2 , year, and previous day's count to offset the effects of auto-correlation, and include species and count site as random effects. 'View', local visibility and cloud cover; 'Today', local east-west wind, local north-south wind, and local air pressure; 'Yesterday', previous day's wind and air pressure; and 'North3', weather in northern Spain (wind, pressure, and precipitation) three days prior.*

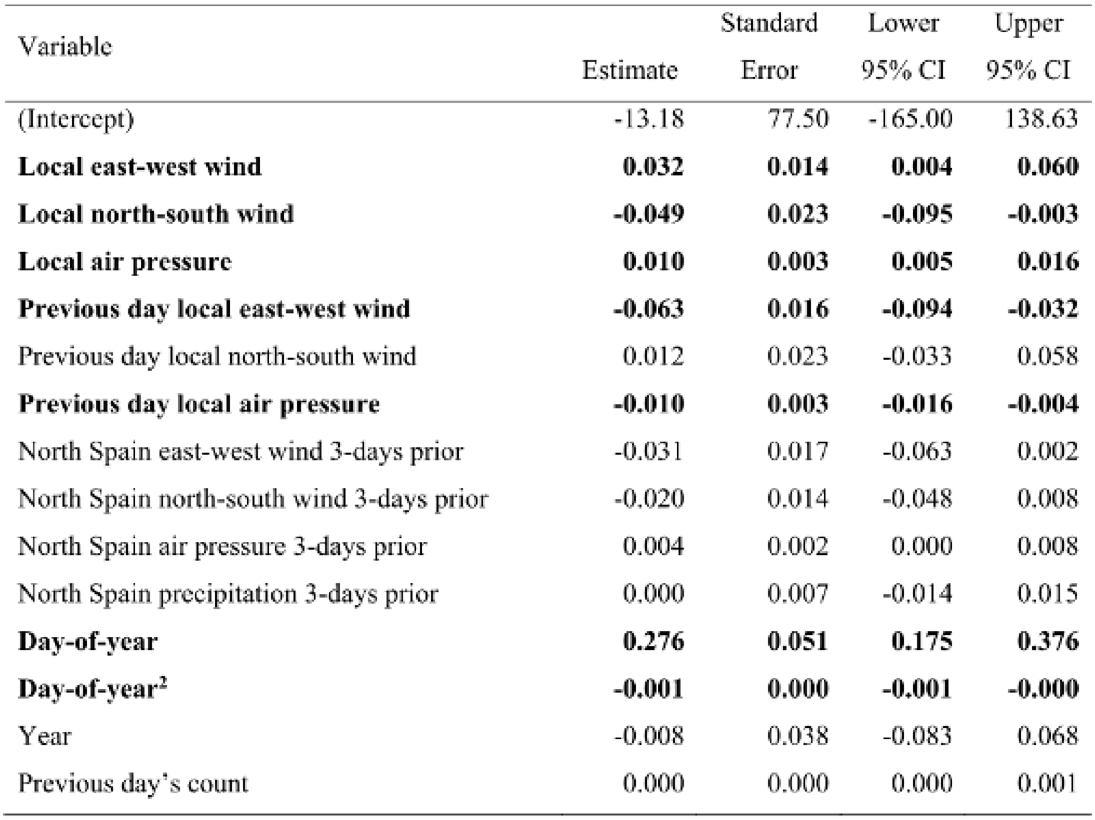


Statistical Model	k	AIC_c	Δ AIC_c	w_i	LogLik
Today + Yesterday + North3	19	26389.1	0.0	0.79	-13175.4
View + Today + Yesterday + North3	21	26391.8	2.7	0.21	-13174.7
View + Today + Yesterday	17	26401.7	12.5	0.00	-13183.7
Today + Yesterday	15	26401.8	12.7	0.00	-13185.8
Yesterday + North3	16	26407.4	18.3	0.00	-13187.6
View + Yesterday + North3	18	26410.7	21.6	0.00	-13187.2
Yesterday	12	26415.9	26.8	0.00	-13195.9
View + Today + North3	18	26417.3	28.2	0.00	-13190.5
Today + North3	16	26417.6	28.5	0.00	-13192.7
View + Yesterday	14	26418.4	29.3	0.00	-13195.1
North3	13	26419.0	29.8	0.00	-13196.4
View + North3	15	26420.6	31.5	0.00	-13195.2
View + Today	14	26440.2	51.1	0.00	-13206.0
Today	12	26450.7	61.6	0.00	-13213.3
View	11	26452.7	63.6	0.00	-13215.3
Null	9	26462.8	73.7	0.00	-13222.4

k, number of parameters; AIC_c, Akaike's information criterion adjusted for small sample size; ΔAIC_c, the difference in AIC_c relative to the top model; w_i, Akaike weight; LogLik, log-likelihood of the model.

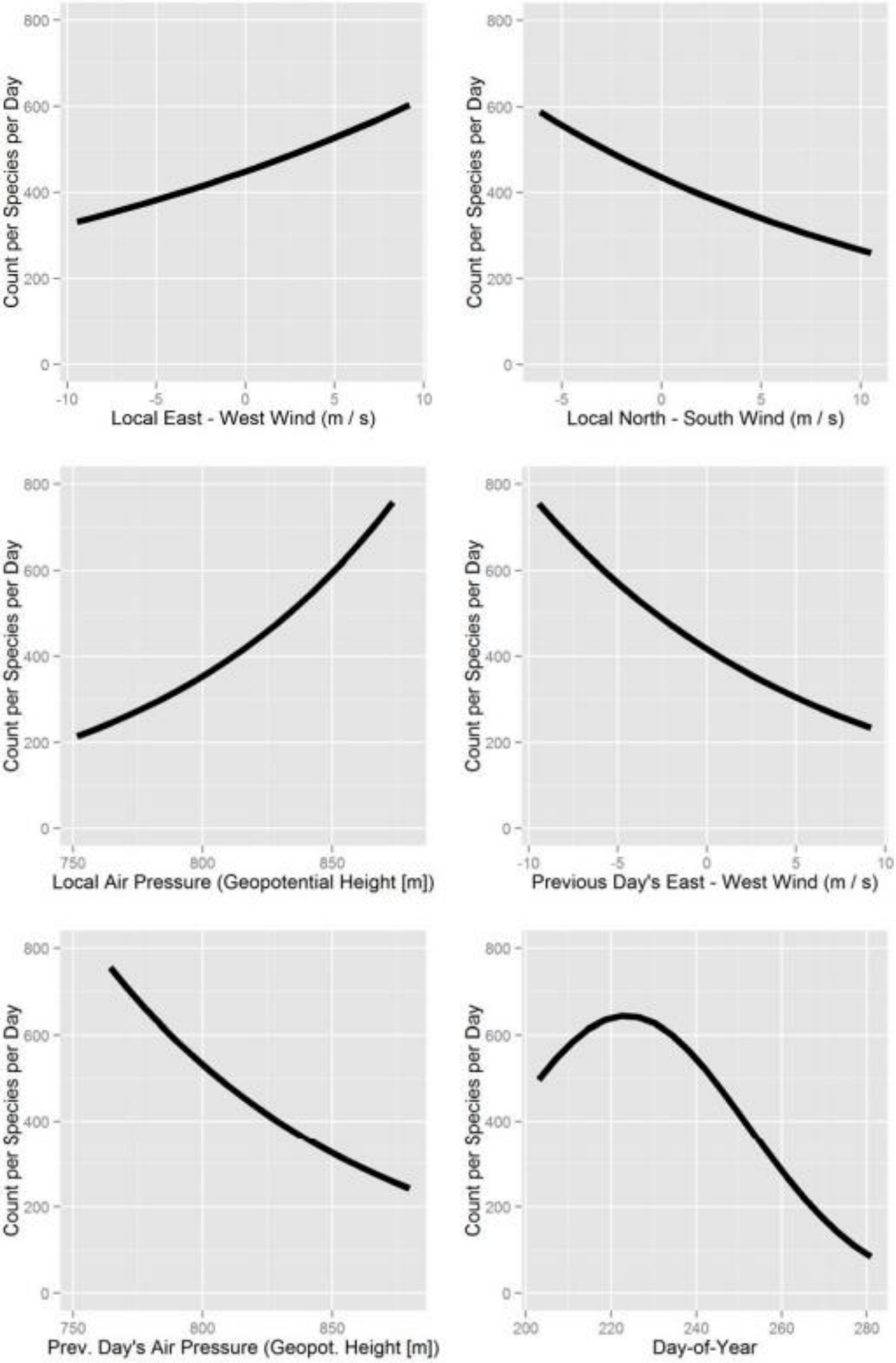
We found effects of seven model coefficients from the top model, including local east-west wind, local north-south wind, local air pressure, previous day's local east-west wind, previous day's air pressure, day-of-year, and day-of-year 2 (Table 5). Specifically, counts were expected to be highest on days with locally north and west winds with high pressure, following days with local east winds and lower pressure, and generally earlier in the count season (Fig. 2).

Table 5. *Coefficients, SE, and 95% confidence intervals generated from the top model predicting migration counts of five species at two count sites near the Strait of Gibraltar, Spain, 2009–12. Bold values indicate variables whose confidence interval does not overlap zero.*



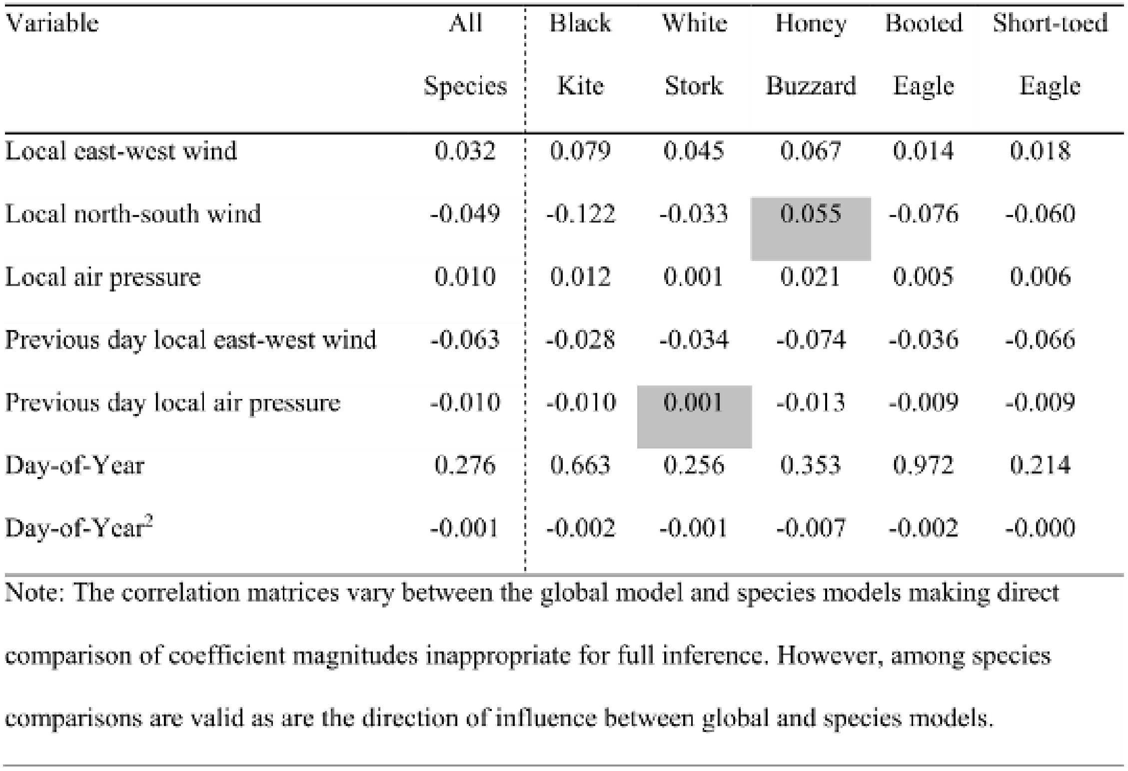
Variable	Estimate	Standard Error	Lower 95% CI	Upper 95% CI
(Intercept)	-13.18	77.50	-165.00	138.63
Local east-west wind	**0.032**	**0.014**	**0.004**	**0.060**
Local north-south wind	**-0.049**	**0.023**	**-0.095**	**-0.003**
Local air pressure	**0.010**	**0.003**	**0.005**	**0.016**
Previous day local east-west wind	**-0.063**	**0.016**	**-0.094**	**-0.032**
Previous day local north-south wind	0.012	0.023	-0.033	0.058
Previous day local air pressure	**-0.010**	**0.003**	**-0.016**	**-0.004**
North Spain east-west wind 3-days prior	-0.031	0.017	-0.063	0.002
North Spain north-south wind 3-days prior	-0.020	0.014	-0.048	0.008
North Spain air pressure 3-days prior	0.004	0.002	0.000	0.008
North Spain precipitation 3-days prior	0.000	0.007	-0.014	0.015
Day-of-year	**0.276**	**0.051**	**0.175**	**0.376**
Day-of-year^2	**-0.001**	**0.000**	**-0.001**	**-0.000**
Year	-0.008	0.038	-0.083	0.068
Previous day's count	0.000	0.000	0.000	0.001

Figure 2. *Migration counts at the Strait of Gibraltar per sampled species per day as predicted by variables within the top model whose coefficient confidence interval failed to overlap zero. In each instance, all other variables within the top model were held at their mean values as the variables of interest were spanned over their sampled range.*



The species models for the five species of interest generally agreed with the global model (Table 6). The two exceptions were for Honey Buzzards and the local north-south wind component and for White Storks and the previous day's air pressure component (Table 6). In the latter case, the magnitude of the coefficient was near zero suggesting it may have been an anomaly for that species.

Table 6. *Top coefficients (confidence interval failed to overlap zero in global model) generated from the top model with data for all species together (species and site as random effects), and for each of the five species independently (with only site as a random effect), each predicting migration counts at two count sites near the Strait of Gibraltar, Spain, 2009–12. Shaded values indicate coefficients for species whose sign is opposite the global model for that value.*



Variable	All Species	Black Kite	White Stork	Honey Buzzard	Booted Eagle	Short-toed Eagle
Local east-west wind	0.032	0.079	0.045	0.067	0.014	0.018
Local north-south wind	-0.049	-0.122	-0.033	0.055	-0.076	-0.060
Local air pressure	0.010	0.012	0.001	0.021	0.005	0.006
Previous day local east-west wind	-0.063	-0.028	-0.034	-0.074	-0.036	-0.066
Previous day local air pressure	-0.010	-0.010	0.001	-0.013	-0.009	-0.009
Day-of-Year	0.276	0.663	0.256	0.353	0.972	0.214
Day-of-Year^2	-0.001	-0.002	-0.001	-0.007	-0.002	-0.000

Note: The correlation matrices vary between the global model and species models making direct comparison of coefficient magnitudes inappropriate for full inference. However, among species comparisons are valid as are the direction of influence between global and species models.

Discussion

This study measured the effects of local and regional weather on the counts of migratory raptors and storks at two major count sites near the Strait of Gibraltar during the post-breeding migratory season. We found that local same-day and previous-day weather conditions and day-of-year were correlated with the daily counts of migrating raptors and storks.

The results clearly show that north and west winds with higher pressure, the day after east winds and lower pressure, result in the highest counts. Birds arriving in the area of the Strait during adverse crossing conditions (east winds) tend to wait for favorable conditions (west winds) to cross to Africa. This is readily visible with the daily accumulation of Black Kites in the fields around Tarifa or White Storks in the area of Laguna de la Janda during east wind conditions (R.A. Miller, A. Onrubia pers. obs.). Similarly, higher counts were observed on days with high pressure systems, often following days of lower pressure. These results are consistent with observation across Europe and eastern North America where counts of birds have been shown to respond to rising air pressure (Richardson 1990, Allen *et al*. 1996, van Belle *et al*. 2007).

Our analysis approach selected influences of weather conditions in northern Spain with short time lags (three days). This preliminary model selection highlights that northern Spain weather helps predict counts at the Strait. However, counter to our expectations, the confidence intervals for the four coefficients in the final model all failed to overlap zero, suggesting the effects are much less influential than local weather conditions. The failure to find a strong influence of northern Spain weather in our final model could be the result of many factors including differential responses by the various species modeled, differential migration speeds through Spain by the various species modeled, the fact that northern Spain presents less of a bottleneck for migratory species offering alternative routes to accommodate different weather conditions, use of stop-over sites by some individuals during migration that could dilute responses, or a true lack of influence.

Also counter to our expectations, local viewing conditions (cloud cover and visibility) were not selected in the top model. The failure to measure an effect from these variables may stem from their subjective nature, the low resolution of values, or mixed impacts such as cloud cover masking high flying species and lowering the flight of other species (Evans and Lathbury 1973). We suspect the lack of a measured influence of local viewing conditions on counts is the result of mixed impacts as our observations support a lower flight on cloudy days, yet birds are also often observed through gaps between clouds.

The species models provide some great insight into the differences among species. The Honey Buzzard was the only species which migrated in higher numbers with southerly winds. Their greater use of powered flight during migration enables them to overcome the increased force of the wind during these conditions. Their willingness to fly into a headwind may influence or be influenced by the fact that they have the shortest migratory window of the species we evaluated. The apparent use by the Honey Buzzard of days with high pressure at the Strait supports the observed high altitude flight of this species. The Honey Buzzard is one of only two of the evaluated species that migrate in larger numbers at the Algarrobo count site at the eastern end of the Strait. This site provides different topography, possibly resulting in different impacts from the various weather conditions. This may confound the direct comparison with species that are counted in greater numbers the Cazalla count site near the western end of the Strait.

As expected, the Black Kite was most sensitive to local wind conditions at the Strait. The lower response of Black Kites to the previous day's weather suggest that they may not be the first to migrate after a shift in the winds from easterly to westerly. The White Storks were the second most sensitive to local wind conditions, particularly the east-west component. The two eagle species were generally similar in their use of conditions and appear to favor more neutral wind conditions, with the Short-toed Eagle migrating soon after a change in the winds. The Booted Eagle is counted in higher numbers at the Algarrobo count site near the east end of the Strait, but there was no measured response in our results that suggests the results were confounded by this factor.

The results from this study provide evidence that local and northern Spain weather each influence the timing of storks and raptors migrating across the Strait, but the northern Spain influences are weak in comparison to local weather conditions. We suspect that weather influences are amplified by the bottleneck nature that these two areas present to migrating birds, but are stronger in the south due to a more restricted bottleneck and the temporal proximity to the counts. We therefore conclude that weather is an important consideration in any analyses using migration counts, especially at these natural bottlenecks. Global climate models predict that the variables included in our analysis will change over time as the result of climate change (de Castro *et al*. 2005). Specifically, de Castro *et al*. (2005) report that winds are expected to decrease on average in autumn in northern Spain, but increase on average at the Strait over the next century. These changes could cause a slowing of the migration through Spain resulting in a perceived delay in migration when considered from the perspective of the Strait, even if species do not delay the departure from their breeding grounds. This could create the situation where this delay could be misinterpreted if weather conditions are not central to the analysis.

Conclusion

In conclusion, we found that counts were expected to be highest on days with locally north and west winds and high pressure following days with local east winds and lower pressure, and before the middle of the count season. This aggregate picture demonstrates the complex interactions of differing weather systems across large geographic areas influencing migration across the varied landscape that migrating birds must face. The results also suggest that careful consideration of weather events may be required or may provide higher resolution when analyzing migration count data.

Acknowledgements

This study was funded by grants from the Regional Ministry for Environment of Andalusia and from Fundación Migres. We would like to thank the board of Fundación Migres for their continued support. We are grateful to Boise State University’s Office of Research and specifically Dr. Mark Rudin for making the international collaboration between the Intermountain Bird Observatory and Fundación Migres possible. We would like to thank Boise State University’s Raptor Research Center for additional financial support to continue the collaborative development of this work. Our special thanks and gratitude goes out to employees of Fundación Migres and the many volunteers who worked tirelessly in the field collecting the data used in this analysis. We thank Laura Bond of Boise State University's Biomolecular Research Center for providing consultation on the statistical analysis. Lastly, we would like to thank José A. Alves, Jeff Kelly, and an anonymous reviewer for their careful review of, and detailed feedback on previous versions of this manuscript.

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RESUMEN

RESUMEN

Las aves juegan un papel importante como centinelas ambientales: se trata de organismos bien conocidos y relativamente fáciles de estudiar, se encuentran distribuidos por prácticamente todos los ambientes de la Tierra, ocupan los niveles superiores de las pirámides tróficas, y sus poblaciones responden cumplidamente a los cambios en los ecosistemas. En especial resultan valiosas las respuestas de aves de presa, por sus elevadas exigencias ecológicas, y de las aves migratorias, que precisan de un buen estado de conservación de los distintos hábitat que utilizan durante sus periplos migratorios. El seguimiento a largo plazo de la migración a través de programas estandarizados puede aportar una valiosa información sobre estos grupos bioindicadores, útil para evaluar el efecto real de la actividad humana en los ecosistemas.

El estrecho de Gibraltar es uno de los lugares de concentración de aves migratorias más importantes del mundo, especialmente para las aves planeadoras, cigüeñas y rapaces. Su posición estratégica en la ruta occidental del sistema migratorio Paleártico-Africano y su conformación en forma de embudo natural de apenas 14 kilómetros entre los continentes europeo y africano que suponen el tránsito de menor distancia sobre el mar, explican las extraordinarias cifras de aves en paso, circunstancia esta que ha ejercido un notable atractivo sobre los estudiosos de las aves.

Los trabajos más exhaustivos de la migración de aves planeadoras por el estrecho se desarrollan en la década de 1970 a cargo de equipos de ornitólogos liderados por los profesores Francisco Bernis y Manuel Fernández-Cruz, que desarrollan varias campañas de censo, las más completas en los otoños de 1976 y 1977. Desde entonces se han desarrollado otras campañas de ámbito más local, hasta que en 1997 se inicia un programa de seguimiento anual que incluye tanto el paso postnupcial como el prenupcial.

Este programa de seguimiento, denominado programa Migres, se basa en censos diarios de la migración diurna de aves planeadoras desarrollados en observatorios fijos que operan con protocolos de esfuerzo constante siguiendo los estándares recomendados para este tipo de estudios. Los conteos son

realizados por observadores expertos ayudados por voluntarios y tratan de cubrir la ventana temporal del 95% del paso estacional y diario de los efectivos. Así, desde 1999 hasta 2015 se han realizado censos diarios de la migración otoñal desde dos observatorios estratégicamente situados, Cazalla y Algarrobo, entre el 20 de julio y el 10 de octubre, desde las 7:00 hasta las 16:00 (hora solar). Por su parte, entre 2008 y 2012 se han realizado censos diarios de la migración primaveral desde dos observatorios fijos, Cazalla y Punta Carnero, entre el 1 de febrero y el 10 de junio, desde las 10:00 hasta las 16:00 (hora solar). Estos programas se completan con algunas campañas específicas para estudiar la migración de cigüeñas blancas y buitres leonados, cuyo paso por el estrecho queda parcialmente fuera de los periodos estándar de censo.

La información recogida en este programa de seguimiento ha permitido abordar aspectos inéditos de la migración de las aves planeadoras en el estrecho de Gibraltar como por ejemplo, la magnitud y fenología del paso prenupcial y postnupcial (capítulos 1 y 2 de la presente tesis), o los cambios en la composición y entidad de la migración en distintos horizontes temporales: 1970-1990-2010 (capítulos 3 y 4). Dichos cambios pueden reflejar respuestas poblacionales (capítulo 4) o modificaciones en los patrones migratorios, los cuales pueden suponer cambios en las distancias de migración (capítulos 5), cambios de la ruta migratoria (capítulos 6 y 7) o aparición de nuevas rutas (capítulo 8). Asimismo se han podido estudiar los cambios en la fenología del paso en distintos horizontes temporales 1970-1990-2010 (capítulo 9) y la influencia de las condiciones meteorológicas locales y regionales en el paso (capítulo 10). Todo esto permite revalorizar la importancia del Estrecho para la migración de las aves planeadoras en el contexto de las poblaciones nidificantes europeas (capítulos 1 y 2) y el interés de los programas de seguimiento para valorar tendencias poblacionales (capítulo 4) o estudiar cambios en los patrones migratorios en un escenario de cambio global (capítulo 5 y 9).

Magnitud y fenología del paso de aves planeadoras por el Estrecho.

A pesar de ser un lugar de notable tradición ornitológica y de relevancia mundial para la migración de las aves, la información actualmente disponible de la entidad y calendarios de paso de aves planeadoras por el Estrecho resulta incompleta y muy sesgada hacia el paso postnupcial. Por ejemplo, se dispone de información más o menos completa de la migración de ambas especies de cigüeñas, pero hasta la fecha no existían estimas fiables de la entidad del paso de aves rapaces por el estrecho, salvo para algunas especies. El principal problema es que los censos de paso se han realizado durante el periodo otoñal y el efecto de los vientos en los circuitajes locales de las aves producía cifras de difícil interpretación. En este trabajo se realiza el primer intento de estimar la magnitud real y definir los calendarios de la migración de aves planeadoras durante ambos pasos migratorios a través del estrecho de Gibraltar (*capítulos 1 y 2*).

Se analizó la migración visible de las aves planeadoras a través de los conteos diarios recogidos en dos observatorios principales en cada estación entre los años 2009 y 2012. Durante la migración prenupcial, los censos se realizaron entre el 1 de febrero y el 10 de junio en los observatorios de Cazalla y Punta Carnero, con dos campañas específicas para el censo de cigüeñas blancas entre el 10 de octubre y el 10 de junio. En el caso de la migración postnupcial, los censos se realizaron entre el 20 de julio y el 10 de octubre en los observatorios de Cazalla y Algarrobo, con una campaña específica para el censo de buitres leonados entre el 10 de octubre y el 5 de diciembre.

Las estimas del número de aves en migración se basaron en los resultados de los conteos diarios a los que se aplicaron sendas correcciones temporales y espaciales para las aves no observadas. Para la corrección temporal se tuvo en cuenta el patrón de paso diario de cada especie obtenido con prospecciones específicas durante todas las horas de luz, determinando la proporción detectada en el horario estándar de censo. Para la corrección espacial se tuvo en cuenta el patrón espacial de paso de cada especie obtenido con prospecciones específicas con una red de observatorios distribuidas por el frente del estrecho y con comunicación entre ellos, de manera que se pudo estimar la proporción de aves detectadas en los dos observatorios fijos respecto al total en tránsito.

La migración primaveral o prenupcial se extiende desde finales de enero hasta mediados de junio, con dos momentos álgidos: uno que se extiende desde mediados de febrero hasta finales de marzo, protagonizado por la entrada masiva de milanos negros, águilas culebreras, calzadas y aguiluchos; un segundo pico se produce a finales de abril o principios de mayo, con la arribada masiva y concentrada de los halcones abejeros. El paso de primavera termina con la llegada escalonada de los buitres leonados que tienen sus máximos en abril y mayo. Un caso particular lo constituye la cigüeña blanca que extiende su migración entre octubre y mayo.

El paso otoñal o postnupcial se extiende entre principios de julio y mediados de noviembre y en él se van sucediendo diferentes oleadas de migrantes. Julio y agosto está dominado por el paso de millares de cigüeñas blancas y milanos negros- poca variedad pero espectacular por los números implicados. A finales de agosto y principios de septiembre se produce el paso masivo de los halcones abejeros con varias decenas de miles de individuos en unos pocos días. Septiembre es un mes de enorme variedad de especies con el paso de alimoches, gavilanes, cigüeñas negras, aguiluchos, águilas calzadas, culebreras y pescadoras. Octubre y noviembre tienen los últimos coletazos de cigüeñas negras, calzadas y culebreras, el paso de los presaharianos (ratoneros, milanos reales …) y el cruce de los buitres leonados.

En total, entre 425.000 y 500.000 aves planeadoras cruzan el estrecho de Gibraltar cada temporada. Alrededor de 135.000-150.000 cigüeñas (dos especies diferentes con presencia regular durante el periodo migratorio) y 290.000-350.000 rapaces (28 especies observadas con regularidad durante el periodo de migración) pueden observarse en migración a través del estrecho de Gibraltar. Las especies más abundantes fueron: milano negro (> 160.000 aves), cigüeña blanca (> 130.000), abejero europeo (> 59.000), aguililla calzada (> 21.000), águila culebrera (> 19.000), buitre leonado (> 8.000), cigüeña negra (> 3.000), gavilán (> 3.000), alimoche (> 1.300), aguilucho cenizo (> 1.300), aguilucho lagunero (> 700) y cernícalo primilla (> 300).

Tanto la composición de las especies como sus abundancias fueron muy similares en primavera y otoño. Sin embargo, la migración otoñal tiene lugar en un marco temporal mucho más reducido en comparación con la migración primaveral.

Cuando se comparan los números de paso por el Estrecho con las cifras de las poblaciones reproductoras de Europa occidental, las estimas de aves en migración sobrepasan notablemente las estimas disponibles de población reproductora en el caso de varias de las especies de aves planeadoras estudiadas (cigüeña blanca, abejero, milano negro, aguililla calzada y águila culebrera).

La entidad del paso a través del estrecho de Gibraltar le erige como uno de los cuellos de botella más importantes a lo largo del sistema migratorio europeo-africano y el cuello de botella más importante para las aves migratorias de toda Europa occidental.

Cambios en el paso de aves planeadoras por el Estrecho.

En el periodo 1970-2010 han tenido lugar cambios ambientales importantes reflejo de los profundos cambios socioeconómicos y culturales de la actividad humana. En este periodo se ha registrado un notable incremento de aquellos convenios y normas relativos a la conservación de la naturaleza que tienen su consiguiente reflejo en el aumento de la superficie de áreas protegidas y la puesta en marcha de numerosos programa de protección de especies amenazadas, a la vez que la actividad humana está produciendo cambios profundos de los usos del suelo que van desde la intensificación agrícola, el aumento de la superficie forestal, el incremento de las áreas urbanas y las infraestructuras de transporte o vinculadas a la producción y distribución de energía, alteración de zonas húmedas, o proliferación de especies invasoras, entre otros procesos. Estos patrones se producen en un contexto de cambio climático que se ha acelerado en los últimos 30 años. En estas circunstancias es previsible que las poblaciones de cigüeñas y rapaces migratorias estén respondiendo entre los márgenes impuestos por un medio sujeto a intensos y profundos cambios del hábitat y el incremento de programas y medidas de conservación enfocadas a paliar estos impactos.

La información recogida en distintas campañas de censo realizadas en el estrecho de Gibraltar permite estudiar los cambios en el paso en distintos horizontes temporales (*capítulos 3 y 4*). Así, desde los 1970s hasta la actualidad se han desarrollado diversas campañas de censo y desde 1999 cuenta con un programa de seguimiento anual operando con protocolos estandarizados.

La comparación de las cifras de paso de las campañas de 1976-1977 con las realizadas en 1999-2000 y 2011-2012 permiten evaluar los cambios en el paso migratorio en un periodo largo de tiempo (35 años), mientras que los censos anuales realizados entre 1999 y 2013 permiten evaluar en detalle las tendencias en el paso en los últimos 15 años.

Los resultados obtenidos muestran un incremento generalizado en el número de aves planeadoras en paso, aunque este aumento parece haberse producido mayoritariamente en la última década. Las especies más abundantes en los años 70 también lo son en la actualidad, aunque la contribución de cada una de ellas al paso total ha cambiado ligeramente entre ambos periodos. En general, hay un aumento significativo de migrantes transaharianos (cigüeña blanca, milano negro, águila calzada, águila culebrera, cigüeña negra, alimoche), algunos presaharianos (gavilán), residentes en dispersión (grandes águilas y buitre leonado), y se producen algunas nuevas incorporaciones, como especies de filiación africana (buitre moteado, busardo moro, halcón borní) y algunos migrantes orientales (águila pomerana, aguilucho papialbo, cernícalo patirrojo). Este patrón contrasta con la estabilidad o disminución de los migrantes presaharianos (cernícalo vulgar, busardo ratonero, aguilucho pálido, esmerejón, azor, milano real) y algunos transaharianos (abejero, aguilucho cenizo, cernícalo primilla, alcotán).

Estas tendencias son consistentes con las obtenidas en otros lugares de concentración de migrantes como por ejemplo, en los observatorios de Falsterbo (Suecia) o en los Pirineos occidentales, pero sin embargo contrastan en algunos casos con las estimadas para las poblaciones nidificantes del centro y norte de Europa.

En general estos cambios detectados están relacionados con las tendencias de las poblaciones de origen pero en algunos casos son debidos a cambios en los patrones migratorios por acortamiento de la migración o cambios de ruta o distribución.

Hemos estudiado en detalle el caso del busardo ratonero (*Buteo buteo*), una rapaz migradora presahariana que muestra tendencias poblacionales en Europa estables o de incremento, que contrastan con la disminución de los ratoneros en paso por el Estrecho y otros observatorios europeos (*capítulo 5*).

El análisis de las recuperaciones de ratoneros anillados en Europa entre 1959 y 2009 muestra un aumento estadísticamente significativo en la proporción de ejemplares sedentarios durante los últimos 40 años y una tendencia a reducir las distancias de migración, especialmente en las poblaciones del norte de Europa. Este acortamiento de la migración se ha relacionado además con las anomalías de las temperaturas del Hemisferio Norte, lo que evidencia la relación entre el calentamiento global y los cambios en la migración de esta especie (*capítulo 5*).

Otros cambios en el paso de planeadoras por el estrecho incluyen la incorporación de rapaces de migración típicamente oriental, como el águila pomerana *Aquila pomarina* o el aguilucho papialbo *Circus macrourus* (*capítulos 6 y 7*), o de especies de filiación africana, como el busardo moro *Buteo rufinus* o el buitre moteado *Gyps rueppellii* (*capítulo 8*). Estas especies, consideradas rarezas en España, muestran un paso regular aunque minoritario por el Estrecho que no se había registrado hasta fechas recientes. La nueva aparición de estas especies parece estar vinculada a los procesos de expansión de sus áreas de distribución hacia el norte y oeste de Europa (caso del águila pomerana o del aguilucho papialbo) o de nueva colonización del continente europeo desde sus áreas de distribución originales del norte de Africa (caso del busardo moro) o del Sahel (buitre moteado). Para la configuración de estas nuevas rutas a través del Estrecho podrían jugar un importante papel los procesos de dispersión de estas especies junto a otras variables como las condiciones meteorológicas encontradas en el camino o en las zonas de invernada o procesos de atracción heteroespecífica o de aprendizaje.

Cambios en la fenología de paso de las aves planeadoras por el Estrecho.

A pesar de que los cambios en los patrones migratorios de las aves son uno de los efectos ecológicos más evidentes del cambio climático, existen pocos estudios relativos a los cambios en la fenología migratoria de especies longevas transaharianas. En este trabajo utilizamos los censos de migración otoñal en el estrecho de Gibraltar para analizar la magnitud y dirección de los cambios fenológicos de seis especies comunes de aves planeadoras en un periodo de 35 años, entre 1976 y 2011 (*capítulo 9*). Para ello se ha utilizado un análisis de correlación cruzada para comparar los datos recientes de paso desde 1999 a 2011 con datos de censos realizados en 1976-1977. En ese periodo las temperaturas medias de España han subido 0.63ºC aunque el mayor incremento se ha producido entre 1976 y 1997.

En ese periodo los cambios encontrados en los calendarios de paso son específicos de cada especie. Así por ejemplo, las cigüeñas blancas *Ciconia ciconia* y los milanos negros *Milvus migrans* han retrasado el paso entre 1.1 y 4.2 días por década. Sin embargo, las cigüeñas negras *Ciconia nigra*, águilas culebreras *Circaetus gallicus* y abejeros europeos *Pernis apivorus* han adelantado el paso entre 1 y 2.5 días por década, mientras aguilillas calzadas *Hieraeetus pennatus* no muestran cambios aparentes. En todos los casos, las variaciones en la fenología de paso son más marcadas entre 1970 y 2000 que en la década posterior con temperaturas más estables.

El retraso en el paso y el alargamiento de la duración del mismo en cigüeñas blancas y milanos podría estar relacionado con la tendencia creciente a permanecer durante el invierno cerca de las zonas de cría y vinculado con procesos de aprendizaje característicos de aves longevas, así como con la expansión distributiva que muestran estas especies en Europa. Por otro lado, el adelanto en el paso del resto de especies podría estar relacionado con la presión por alcanzar pronto las zonas de invernada en el Sahel y poder establecerse en los mejores territorios.

No obstante, estos datos hay que tomarlos con cierta cautela, especialmente en el caso de las especies de migración temprana como cigüeñas blancas y milanos negros, debido a la concurrencia de ciertos problemas metodológicos y al efecto de las condiciones meteorológicas locales. Así, las ventanas temporales de censo han permanecido invariables durante los últimos quince años y es posible que no estén cubriendo adecuadamente el calendario de paso si esté se está adelantando, como parece ser el caso. Por otro lado, los datos fenológicos presentan una fuerte variabilidad interanual que parece estar relacionada con las condiciones meteorológicas locales. Así, cuantificar el efecto a corto plazo de las condiciones meteorológicas sobre los censos es fundamental para interpretar adecuadamente los datos derivados en otros análisis.

Este último aspecto se ha abordado específicamente también en esta tesis (*capítulo 10*). Con este fin, en este trabajo analizamos el efecto de las condiciones meteorológicas locales y regionales sobre los censos otoñales de aves planeadoras en el estrecho de Gibraltar. Para ello se ha analizado mediante modelos lineales generalizados mixtos la influencia de las condiciones locales y en el norte de España sobre los conteos de cinco especies de aves planeadoras en el estrecho de Gibraltar. Hemos encontrado que los censos son más elevados en días con vientos locales de norte y poniente, a menudo después de días de vientos de levante, así como en días con altas presiones locales a menudo posteriores a una jornada de bajas presiones. Además se ha encontrado que las condiciones meteorológicas en el norte de España influyen en los conteos en el estrecho de Gibraltar en los tres días posteriores, aunque el efecto es mucho más débil que las condiciones locales. Asimismo, estos efectos son específicos de cada especie, dependiendo de su comportamiento y sus capacidades de vuelo. Se confirma que las condiciones meteorológicas a corto plazo, a escala local y regional, pueden influir en los conteos de migración y esto debería tenerse en cuenta cuando estos datos se usan en otros análisis, más teniendo en cuenta que estas condiciones locales están modificándose debido al cambio climático.

Importancia del Estrecho para las aves planeadoras.

Cada año, más de 400.000 aves planeadoras de una treintena de especies diferentes cruzan el estrecho en cada paso migratorio. Las especies más numerosas en tránsito corresponden a cigüeñas y rapaces de migración transahariana. Aquí se canaliza el paso de una parte significativa de las poblaciones de aves planeadoras del sistema migratorio paleártico-africano y concentra la práctica totalidad de los efectivos migradores de cigüeñas blancas y negras, milanos negros, halcones abejeros, alimoches, aguilillas calzadas y águilas culebreras nidificantes en Europa occidental. Además recoge una porción variable de aguiluchos, águilas pescadoras, gavilanes y halcones. La entidad numérica y específica de cigüeñas y rapaces en tránsito erige al estrecho de Gibraltar como uno de los lugares más importantes del mundo para la migración de aves planeadoras. De hecho, las cifras de paso de milano negro, alimoche, aguililla calzada y águila culebrera son las más altas del mundo.

Esta elevada concentración de rapaces en paso ofrece la mejor posibilidad de estudiar las tendencias en sus poblaciones y patrones migratorios, teniendo en cuenta la dificultad de trabajo en las áreas de cría –densidades bajas, comportamientos discretos o elusivos…–. Además constituye un lugar idóneo para el estudio de la migración de las aves planeadoras (cantidad, condicionantes de vuelo, estrategias migratorias…) que puede aportar una información complementaria a otros sistemas y métodos de estudio. Finalmente tampoco se puede olvidar la importancia del Estrecho de Gibraltar para otros intereses: lugar de formación de nuevos ornitólogos o estudiosos de las aves de presa, enclave para enmarcar programas de sensibilización o educación ambiental, zona para desarrollar proyectos de ecoturismo y de desarrollo socioeconómico con la migración como gancho, … amén de otros intereses de tipo estético, artístico o cultural.

ABSTRACT

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Birds play an essential role as environmental sentinels: they are well-known living organisms and relatively easy to study; they can be found in almost all environments of the planet; they are at the top of the food chains, and their populations respond fully to changes in the ecosystems. Especially valuable is the response of birds of prey because of their very demanding ecological needs, as well as the response of migratory birds, due to the fact that the habitats they use during their different migration periods all need to be in a very good state of conservation. Long-term monitoring of migration patterns through standardized programs can provide very valuable information about these bioindicator groups and help assess the real impact of human activity on ecosystems.

The strait of Gibraltar is one of the most important migratory bird concentration points in the world, particularly for soaring birds, storks, and birds of prey. Strategically situated in the western route of the Palaearctic-African migratory path, this 14 km-funnel-shaped strait acts as a natural bridge between two continents, Europe and Africa. 14 km is a short distance across the sea, and this is surely the explanation for the extraordinary number of passing birds, a circumstance that has deeply attracted the attention of ornithologists from all over the world.

Some of the most comprehensive studies on soaring bird migration across the Strait were carried out in the 1790s by teams of ornithologists led by professors Francisco Bernis and Manuel Fernández-Cruz, who conducted several censuses, the most detailed in the autumns of 1976 and 1977. Other local campaigns have been developed since then, until 1997, when an annual monitoring programme was implemented to cover both the post-nuptial and the pre-nuptial migration.

This monitoring programme, called Migres, is based on a daily census of diurnal migrant soaring birds, which are carried out at established observatories with constant effort work protocols following standard recommendations for these type of studies. The counts are done by expert observers helped by volunteers,

and they try to cover the time span of 95 % of the seasonal and daily stream of birds passing.

Between 1999 and 2015 daily census of autumn migration have been performed from two strategically situated observatories, Cazalla and Algarrobo, between July 20th and October 10th, from 7 am till 4 pm (solar time). Daily counts have also been made between 2008 and 2012 of the number of spring migrants from two established observatories, Cazalla and Punta Carnero, between February 1st and June 10th, from 10 am till 4 pm (solar time). These programs are further complemented by some specific campaigns designed to study migration patterns of white storks and griffon vultures, as their passing numbers across the Strait are partially excluded from the census standard periods.

The information gathered for this programme has allowed us to highlight unknown aspects of soaring bird migration across the Strait of Gibraltar, such as the population size and phenology of pre- and post-nuptial migrants (chapters 1 and 2 of the present dissertation), or the changes in composition and identity of migrants in different time frameworks: 1970-1990-2010 (chapters 3 and 4). Such changes could reflect population responses (chapter 4) or changes in migratory patterns, which could account for variations in the migration distances (chapters 5), changes in migration routes (chapters 6 and 7) and the emergence of new routes (chapter 8). Other aspects that have been studied are the shifts in the phenology of migration in different timeframes 1970-1990-2010 (chapter 9), and the impact of local and regional weather conditions during migration (chapter 10). The results of this research has allowed us to reassess the significance of the Strait in the migration of soaring birds within the context of European nesting populations (chapters 1 and 2), to weigh up the benefits of monitoring programs in the assessment of population trends (chapter 4), and to identify changes in migratory patterns within a global climate change scenario (chapters 5 and 9).

Population size and phenology of pre- and post-nuptial soaring birds at the Strait.

Despite being a place of outstanding ornithological tradition and special significance in terms of bird migration in the world, the information currently available at the entity and the migration schedules of soaring birds crossing the Strait appears to be incomplete and very biased with regard to post-nuptial migration. For instance, we have more or less complete information about the migration of the two species of storks, but to date we lacked reliable figures of birds of prey migration across the Strait, except for some specific species. The main issue is that the migration censuses carried out in autumn periods together with the effects of winds in local bird movements yielded numbers which were difficult to interpret.

The present research is a first attempt to estimate the real magnitude and to define migration schedules of soaring birds during both migratory periods across the Strait of Gibraltar (chapters 1 and 2). We analyzed visible migration of soaring birds using the daily counts collected each season between 2009 and 2012 at the two main observatories. During the pre-nuptial migration period, the censuses were performed between February 1st and June 10th at the observatories of Cazalla and Punta Carnero, with two specific campaigns for the census of white storks between October 10th and June 10th. As for post-nuptial migration, the censuses took place between July 20th and October 10th at the observatories of Cazalla and Algarrobo, with a specific campaign for the census of griffon vultures between October 10th and December 5th.

The estimation of the number of passing birds was based on the results of daily counts, and included temporal and spatial corrections to account for unobserved individuals. For temporal correction, we took into account the daily migration pattern of each species obtained with specific explorations during all the hours of daylight, in order to calculate the percentage detected during the standard hours of the census. For spatial correction we analyzed the spatial migration pattern of each species, obtained by carrying out specific surveys in a network of observatories communicated with each other and scattered along the frontal area of the Strait. This allowed us to estimate the percentage of birds counted at both established observatories with regard to the total number of individuals in transit.

Spring or prenuptial migration lasts from the end of January to mid-June, with two seasonal peaks: one ranging from mid-February to the end of March, marked by the massive entrance of black kites, short-toed eagles, booted eagles, and harriers; and a second one at the end of April or the beginning of May, with the massive and concentrated arrival of honey buzzards. The spring migration flight ends with the staggered arrival of griffon vultures, which are most numerous in April and May. A particular case is that of white storks, that lengthen their migration times between October and May.

Autumn or postnuptial migration spans from the beginning of July to mid-November, with various subsequent migration waves. July and August are marked by the flight of thousands of white storks and black kites. The variety is poor but impressive from a numbers perspective. At the end of August and the beginning of September the Strait witnesses the massive migration of honey buzzards, with several tens of thousands of individuals in just a few days. September is a month of a huge variety of species, with the crossing of Egyptian vultures, sparrowhawks, black storks, harriers, booted eagles, short-toed eagles, and ospreys. October and November see the last stage of the migration of black storks, short-toed eagles, and booted eagles, the flight of pre-Saharan species (buzzards, red kites, etc.), and the crossing of griffon vultures.

In total, between 425,000 and 500,000 soaring birds travel across the Strait of Gibraltar every season. Around 135,000-150,000 storks (two different species with a regular presence during the migratory period), and 290,000-350,000 birds of prey (28 species regularly observed during the migration period) can be seen in migration across the Strait of Gibraltar. The most abundant species were: black kite (> 160,000 birds), white stork (> 130.000), European honey-buzzard (> 59,000), booted eagle (> 21,000), short-toed eagle (> 19.000), griffon vulture (> 8,000), black stork (> 3,000), sparrowhawk (> 3,000), Egyptian vulture (> 1,300), montagu´s harrier (> 1,300), marsh harrier (> 700), and lesser kestrel (> 300).

Both the composition of the species and the number of individuals were very similar in spring and autumn. However, autumn migration takes place in a much narrower timeframe than spring migration.

When we compare the number of individual birds crossing the Strait with the number of breeding birds in Western Europe, the estimation of migrants appreciably exceed the available estimations of breeding populations of several of the soaring bird species studied (white stork, honey buzzard, black kite, booted eagle, and short-toed eagle).

The significance of the migration pattern across the Strait of Gibraltar makes this location one of the most relevant bottlenecks of the African-European migratory system, and the most important one for migrants from all over Western Europe.

Changes in the migration of soaring birds across the Strait

Between 1970 and 2010 several important environmental changes have taken place which reflect the deep transformation of socio-economic and cultural aspects of human activity. This period has seen a considerable increase in agreements and regulations related to the conservation of nature, which have had an obvious impact on the expansion of protected areas and the implementation of numerous endangered species protection programs. At the same time, human activity is causing dramatic changes in land use, from agricultural intensification, to the increment of forested areas, the growth of urban areas, the expansion of transport infrastructures and other types of construction linked to energy production and distribution, the alteration of wetlands, and the proliferation of invasive species, amongst other processes. These patterns have arisen in the context of a climatic change which has (been) sped up within the last 30 years. In the light of these circumstances, it was foreseeable that the population of storks and birds of prey would respond in accordance to the restrictions imposed by an environment strongly affected by profound habitat alterations, as well as to the increased number of nature conservation programs and measures aimed at alleviating these effects.

All of the data collected in the different censuses held in the Strait of Gibraltar allows us to study changes in migration patterns at different timeframes (chapters 3 and 4). In this sense, several censuses have been carried out since the 1970s until today, and since 1999 there is an annual monitoring programme in place that uses standardized protocols.

After comparing migrant figures of 1976-1977 censuses with those from 1999-2000 and 2011-2012, we have gathered enough data to assess the changes in the migration patterns throughout a long period of time (35 years). Likewise, annual censuses carried out between 1999 and 2013 allow us to analyze in detail the migration trends in the last 15 years.

The results obtained have showed a generalized increase in the number of passing soaring birds, although this rise seems to have taken place mainly in the last decade. The species which were most abundant in the 1970s are also the most abundant today, although the contribution of each of them to the total number of migrants has slightly changed in both periods. In general, there is a significant increase of trans-Saharan migrants (white stork, black kite, booted eagle, short-toed eagle, black stork, Egyptian vulture), some pre-Saharan (sparrowhawk), dispersal residents (big eagles and griffon vulture), together with new additions, like some species with African origin (Ruppell´s vulture, Long-legged buzzard, Lanner *Falco*n), and some Eastern migrants (lesser spotted eagle, pallid harrier, red-footed *Falco*n). This pattern is in contrast with the steadiness or reduction of pre-Saharan migrants (common kestrel, common buzzard, hen harrier, merlin, goshawk, red kite), and some trans-Saharan passing birds (honey buzzard, montagu´s harrier, lesser kestrel, hobby).

These trends are consistent with the data collected at other migrant concentration places, such as at the observatories of Falsterbo (Sweden) or the Western Pyrenees. But in some cases they are in clear contrast with the estimations of breeding populations from Central and North Europe.

In general, the changes identified are related to the trends observed in the populations of origin, but in some cases they are linked to variations in migration patterns due to shortened migration, or to changes in routes or distribution.

We have thoroughly studied the case of the common buzzard (*Buteo buteo*), a pre-Saharan migrant bird of prey showing stable or increasing population trends in Europe, which are in clear contrast with the reduction of the number of common buzzards flying across the Strait and counted at other European observatories (chapters 5). The recovery analysis of common buzzards ringed in Europe between 1959 and 2009 show a significant statistical increase in the percentage of sedentary individuals in the last 40 years, together with a trend to shorten migration distances, especially in the populations of Northern Europe. This migration reduction has also been linked to the temperature anomalies experienced in the Northern hemisphere, proving the existence of a connection between global warming and the changes in this species' migration (chapter 5).

Other alterations observed in the migration of soaring birds across the Strait include the incorporation of birds of prey that used to follow eastern migratory paths, such as the lesser spotted eagle *Aquila pomarina* or the pallid harrier *Circus macrourus* (chapters 6 and 7), or of species of African origin, such as the long-legged buzzard *Buteo rufinus* or the Rüppell's vulture *Gyps rueppellii* (chapter 8). These species, considered as rarities in Spain, exhibit a regular but limited passing across the Strait that had never been recorded until a short time ago. The recent appearance of these species seems to be linked to the expansion processes of the birds' distribution areas towards the North and the West of Europe (case of the lesser spotted eagle or the pallid harrier) or to the new colonization of the European continent from their original distribution areas in the North of Africa (case of the long-legged buzzard) or the Sahel region (Rüppell's vulture). In the configuration of these new routes across the Strait an aspect that could play a truly important role is the dispersion patterns of these species, together with other variables, like the weather conditions birds encounter along their way or at their over-wintering sites, the interspecific attraction among individuals or the learning patterns.

Shifts in the phenology of the soaring bird passage across the Strait.

Despite the changes in bird migration patterns being one of the most obvious ecological effects of climatic change, there are very few studies about the changes of migration phenology of these long-lived trans-Saharan species. In the present dissertation we have used autumn migration censuses taken in the Strait of Gibraltar to analyze the magnitude and direction of phenological changes of six common species of soaring birds along a period of 35 years, between 1976 and 2011 (chapter 9). For that we have used a cross-correlation analysis to compare recent migration data collected between 1999 and 2011 with data included in the censuses performed between 1976 and 1977. In that period average temperatures in Spain have climbed by 0,63 ºC, although the greatest increase has taken place between 1976 and 1997.

In that period the changes identified in the migration schedules are specific for each species. It is the case, for instance, of white storks *Ciconia ciconia* and black kites *Milvus migrans*, species that have delayed their flight 1,1 to 4,2 days per decade. Nevertheless, black storks *Ciconia nigra*, short-toed eagles *Circaetus gallicus* and European honey buzzards *Pernis apivorus* have anticipated their passing 1-2,5 days per decade, while booted eagles *Hieraetus pennatus* do not seem to show noticeable changes. In all the cases, the variations in migration phenology were more relevant between 1970 and 2000 than in the decade after that, when the temperatures remained more stable.

The delay of migration and the lengthening of its duration in the case of white storks and black kites could be related to the growing tendency to remain close to breeding areas in the winter, to the typical learning processes of long-lived birds, and to the geographical distribution expansion of these species in Europe. On the other hand, the migration anticipation of the rest of the species could be connected to the pressure to reach over-wintering areas in the Sahel region as soon as possible in order to settle in the best territories.

Nevertheless, these data should be handled with certain care, especially in the case of early migration species such as white storks and black kites, due to the concurrence of several methodological problems and the impact of local weather conditions. In this sense, census timeframes have remained unchanged in the last fifteen years so it is possible that they are not properly reflecting migration temporal patterns if birds are anticipating or delaying their flights, as seems to be the case. On the other hand, phenological data show a marked inter-annual variability that seems to be connected to local weather conditions. In this sense, to quantify the short-term impact of weather conditions on censuses is essential to properly interpret data derived from other analyses.

This last aspect has also been specifically dealt with in this dissertation paper (chapter 10). With this aim, in the present work we have measured the effect of local and regional meteorological conditions on the autumn censuses of soaring birds flying across the Strait of Gibraltar. For that purpose, we have used generalized mixed linear models (GLMM) to study the influence of local conditions and in the north of Spain on the numbers of five species of soaring birds counted in the Strait of Gibraltar. We have discovered that numbers are higher on windy days with local northern and westerly winds, often after several days of Levante (east wind), as well as on days with local high pressure, often after a day of low pressure. Besides, we have discovered that the weather conditions in the north of Spain also affect count numbers in the Strait of Gibraltar on the three days after, although the effect is weaker than that of local conditions. In the same way, these effects are specific of each species, depending on their behavior and their particular flight abilities. We can confirm that short-term weather conditions, both at local and regional levels, can have an impact on migrations counts, and this should be born in mind when extrapolating these data to other analyses, most especially considering that these local conditions are currently suffering the effect of global climatic changes.

Importance of the Strait for soaring birds

Every year more than 400,000 soaring birds of around thirty different species fly across the Strait of Gibraltar at each migratory event. The most abundant species are storks and birds of prey following trans-Saharan migration routes. The Strait funnels the migration of a significant part of the soaring bird population of the Palaearctic-African migration system, and concentrates almost all migrant white and black storks, black kites, honey buzzards, Egyptian vultures, booted eagles, and short-toed eagles breeding in Western Europe. It also includes a variable number of harriers, ospreys, sparrowhawks, and *Falcons*. The significant total number of migrants and the specific high number of passing storks and birds of prey across the Strait of Gibraltar make this location one of the most relevant places in the world for the migration of soaring birds. In fact, the number of passing black kites, Egyptian vultures, booted eagles, and short-toed eagles are the highest in the world.

This high concentration of birds of prey offers the best opportunity to study population trends and migratory patterns, considering the complexity of working in breeding areas (low densities, shy or elusive behaviours, etc.). The Strait is also an ideal place to carry out studies on soaring birds migration (quantity, flight conditioning factors, migrating strategies, etc.), which yield a rich set of complementary information that is useful for other research systems and methods. Finally we cannot forget the importance of the Strait of Gibraltar for other purposes: as a perfect training place for new ornithologists and birds of prey students, as an ideal location to carry out programs of environmental awareness and education, as a good area to develop eco-tourism and socio-economic development projects using migration as a point of attraction, … and further interests of aesthetic, artistic or cultural nature.

CONCLUSIONES

CONCLUSIONES

- Cada año, entre 425.000 y 500.000 aves planeadoras de una treintena de especies cruzan el estrecho de Gibraltar en cada paso migratorio. Las especies más numerosas en tránsito corresponden a cigüeñas y rapaces de migración transahariana. Alrededor de 135.000-150.000 cigüeñas (dos especies) y 290.000-350.000 rapaces (28 especies) pueden observarse en paso regular a través del estrecho de Gibraltar.

- Las especies más abundantes fueron: milano negro (> 160.000 aves), cigüeña blanca (> 130.000), abejero europeo (> 59.000), aguililla calzada (> 21.000), águila culebrera (> 19.000), buitre leonado (> 8.000), cigüeña negra (> 3.000), gavilán (> 3.000), alimoche (> 1.300), aguilucho cenizo (> 1.300), aguilucho lagunero (> 700) y cernícalo primilla (> 300).

- Los datos confirman la notable importancia del Estrecho para las aves planeadoras, concentrando la práctica totalidad de los efectivos migradores de cigüeñas blancas y negras, milanos negros, halcones abejeros, alimoches, aguilillas calzadas y águilas culebreras nidificantes en Europa occidental. Además recoge una porción variable de aguiluchos, águilas pescadoras, gavilanes y diversas especies de falcónidos.

- La entidad numérica y específica de cigüeñas y rapaces en tránsito erige al estrecho de Gibraltar como uno de los lugares más importantes del mundo para la migración de aves planeadoras. Las cifras de paso de milano negro, alimoche, aguililla calzada y águila culebrera son las más altas del mundo.

- El seguimiento a medio y largo plazo de planeadoras en el Estrecho refleja cambios significativos en el paso, especialmente en la última década, que reflejan recuperaciones poblacionales de muchas especies de cigüeñas y rapaces, descensos en unas pocas, pero también cambios en los patrones migratorios que incluyen acortamientos en las distancias de migración, aparición de nuevas rutas migratorias y la colonización de elementos de filiación africana.

- Los censos a medio y largo plazo de aves planeadoras en el estrecho reflejan cambios significativos en los calendarios de paso, especialmente entre 1976 y 1999, con adelantos en el paso de algunas especies y retrasos en otras. Estos rápidos cambios en la fenología de paso aconsejan revisar periódicamente los protocolos y fechas de censo para ajustarlos a las tendencias detectadas.

- Las condiciones meteorológicas locales y a escala regional afectan sensiblemente a los números de aves planeadoras en tránsito por el estrecho de Gibraltar. Estas circunstancias deberían tenerse en cuenta cuando se hacen análisis de la fenología migratoria en base a los datos de observatorios de migración.

- Los conteos en puntos de concentración de migrantes, como el Estrecho de Gibraltar, constituyen una excelente alternativa a los censos mediante otros métodos, consiguiendo una gran cobertura con un esfuerzo relativamente reducido. La combinación de los datos recogidos en diferentes observatorios de migración situados en el sistema migratorio Europeo-Africano pueden constituir una poderosa herramienta para medir los rápidos cambios en las tendencias poblacionales y los patrones migratorios de las aves migratorias europeas

CONCLUSIONS

- Every year between 425,000 and 500,000 soaring birds of around thirty species fly across the Strait of Gibraltar at each migratory event. The most abundant in transit species are storks and birds of prey following trans-Saharan migration routes. Around 135,000-150,000 storks (two species), and 290,000-350,000 birds of prey (28 species) can be seen in regular migrations across the Strait of Gibraltar.

- The most abundant species were: black kite (> 160,000 birds), white stork (> 130,000), European honey buzzard (> 59,000), booted eagle (> 21,000), short-toed eagle (> 19,000), griffon vulture (> 8,000), black stork (> 3,000), sparrow-hawk (> 3,000), Egyptian vulture (> 1,300), montagu´s harrier (> 1,300), marsh harrier (> 700), and lesser kestrel (> 300).

- The whole of the data collected allows us to confirm the great importance of the Strait of Gibraltar within the context of soaring bird migration, as it concentrates almost all the migrant individuals of white and black storks, black kites, honey buzzards, Egyptian vultures, booted eagles, and short-toed eagles breeding in Western Europe. It also accounts for a variable number of harriers, ospreys, sparrowhawks, and several species of falcons.

- The significant number of birds and species of storks and birds of prey makes the Strait of Gibraltar one of the most relevant places in the world for soaring birds migration. The numbers of migrant black kites, Egyptian vultures, booted eagles, and short-toed eagles are the highest in the world.

- The medium- and long-term monitoring of soaring birds in the Strait confirms the existence of significant variations in migration behavior, especially within the last decade, which reflect a population recovery of many species of storks and birds of prey, and the decline of a few species. It also confirms changes in migration patterns, like the shortening of migration distances, the appearance of new migration routes, and the colonization of African species.

- Medium- and long-term censuses of soaring birds in the Strait show significant changes in migration schedules, most notable between 1976 and 1999, with some species anticipating the moment of their migration and others delaying it. These rapid changes in the phenology of migration advise us to regularly update protocols and census dates in order to adjust them to the trends detected.

- Local and regional weather conditions have a considerable impact on the number of soaring birds flying across the Strait of Gibraltar. These circumstances should be included and studied in migratory phenology analyses with regard to the data collected at migration observatories.

- Bird counts at migrant concentration sites like the Strait of Gibraltar are an excellent alternative to censuses with other methods, as they are able to cover wider areas with relatively less effort. The combination of data collected at all the migration observatories distributed along the African-European migratory network proves to be a powerful tool to assess rapid changes in population trends as well as migration patterns of European migratory birds.

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