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Ecología reproductora y uso espacio-temporal del hábitat de alimentación y reproducción por parte de la comunidad de garzas (Aves: Ciconiidae) de L'Albufera de València, España.

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Tesis titulada: *"Ecología reproductora y uso espacio-temporal del hábitat de alimentación y reproducción por parte de la comunidad de garzas (Aves: Ciconiidae) de L'Albufera de Valencia, España"* presentada por MARIELA FORTI TORRENS para optar al título de Doctora en Biodiversidad y Biología Evolutiva por la Universitat de València.

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A mis papis
A la Tuti, mi hermana
Al gordis, Marianito
Por todo el aguante

Índice

Resumen

Los humedales se encuentran entre los ecosistemas más amenazados del planeta, siendo, en parte, sustituidos por arrozales, los cuales son sitios importantes de alimentación para numerosas especies de aves acuáticas, especialmente en época de reproducción. Muchas de estas aves, incluidas las garzas, han establecido fuertes vínculos con este tipo de humedal, pudiendo verse afectadas negativamente por los cambios en las prácticas de cultivo, que reducen el tiempo y magnitud de la inundación de los campos. L´Albufera de València es uno de los humedales más extensos e importantes del Mediterráneo occidental, que alberga el 60% de las garzas nidificantes de la Comunidad Valenciana. El arrozal ocupa el 70% de la superficie de esta área protegida, cuyo manejo depende de la disponibilidad y demanda del recurso agua, y de las directrices que imponga el mercado. Ante esta situación, el éxito reproductivo de las garzas nidificantes en el área podría depender del manejo y gestión del arrozal. Por ello, es preciso conocer, en primer lugar, el comportamiento de las principales poblaciones reproductoras de garzas dentro de la Comunidad Valenciana y qué características del hábitat influyen en el establecimiento y desarrollo de sus colonias, así como también analizar los posibles efectos que el manejo del cultivo de arroz pueda tener sobre el éxito reproductivo de las colonias nidificantes de estas especies en L´Albufera, para luego proponer estrategias y acciones necesarias para la conservación y reproducción exitosa de dichas poblaciones.

El estudio se enfocó en cinco especies de garzas (Ardeidae): Garza real (*Ardea cinerea*), Garza imperial (*Ardea purpurea*), Garcilla cangrejera (*Ardeola ralloides*), Garcilla bueyera (*Bubulcus ibis*) y Garceta común (*Egretta garzetta*), y una especie de la familia Threskionithidae: Morito común (*Plegadis falcinellus*), que nidifican regularmente en L'Albufera y en otros humedales de la Comunidad Valenciana y del Mediterráneo occidental.

Los resultados obtenidos muestran que las poblaciones reproductoras de estas especies presentan una tendencia positiva en el periodo 1984-2015, dentro de la Comunidad Valenciana, pero que han detenido su crecimiento en las últimas décadas, con excepción de la Garcilla cangrejera y el Morito común, especies de más reciente colonización. Por otra parte, las poblaciones reproductoras de Garza real, Garza imperial, Garcilla cangrejera, Garcilla bueyera y Garceta común, mostraron estar asociadas a la presencia de arrozales, de otros cuerpos naturales de agua dulce y a grandes extensiones de superficie, mientras que las de Garza imperial y Morito común resultaron estar más asociadas a hábitats de marismas de agua dulce, dependientes de las precipitaciones, que cuentan con protección legal. Los arrozales y la amplia cobertura del área también caracterizan a L'Albufera, lo que explicaría que sea el humedal con mayor abundancia de parejas nidificantes dentro de la Comunidad.

Por otro lado, el régimen de las inundaciones y drenaje de los campos de arroz, influye sobre el éxito reproductivo de las especies estudiadas. Los días que transcurren entre la puesta de los huevos y el comienzo de las inundaciones, tienen un efecto negativo en el éxito reproductivo, siendo menor cuanto mayor es el tiempo transcurrido. Por otra parte, el éxito reproductivo fue mayor cuando la eclosión y el crecimiento de las crías coincide con la mayor superficie de los campos sembrados, con excepción de la Garza real, cuyo éxito reproductivo estuvo asociado a la disponibilidad de campos fangueados o semi-inundados. El periodo reproductivo de la Garza real se ha dividido en dos temporadas, producto del drenaje temprano de los campos en invierno y las inundaciones tardías para el inicio del cultivo en mayo, ocasionando la desaparición del hábitat de alimentación, dentro del arrozal por más de dos meses en las zonas más próximas a la laguna, alcanzando los seis meses en las zonas más alejadas. Estos resultados evidencian la importancia del manejo de las zonas inundadas de los humedales de la Comunidad Valenciana, y particularmente el manejo del régimen de inundaciones en el arrozal de L'Albufera de València (extensivo al manejo de los arrozales en general), para la reproducción exitosa de las poblaciones nidificantes de garzas.

CAPÍTULO 1

Introducción General

Replaza de Zacarés
Foto: Mariela Forti

Los humedales

Actualmente, los humedales son uno de los ecosistemas que se encuentran más amenazados en el planeta, por lo que muchas de las iniciativas de conservación están enfocadas en su preservación o restauración (Mediterranean Wetlands Observatory, 2012; MedWet, 2016; Wetland-Based Solutions, 2020; MITECO, 2022). La Convención de Ramsar sobre los Humedales (1971) define estos ecosistemas como “extensiones de marismas, pantanos y turberas, o superficies cubiertas de aguas, sean éstas de régimen natural o artificial, permanentes o temporales, estancadas o corrientes, dulces, salobres o saladas, incluidas las extensiones de agua marina cuya profundidad en marea baja no exceda de seis metros”. Esta definición tan amplia abarca una extensa variedad de ambientes, desde arrecifes de coral, ríos, planicies inundables hasta embalses. Sin embargo, todos ellos tienen en común tres características principales que se utilizan para definir un humedal: presencia de agua (estática o circulante), suelos hídricos con cualidades diferentes al de las zonas altas adyacentes, y vegetación adaptada a las condiciones húmedas (Cannicci y Contini, 2009; Reddy et al., 2010).

La importancia de estos ambientes radica en la variedad de servicios ecosistémicos que ofrecen a la población, que se traducen en millones de dólares al año, junto con el papel que desempeñan como reservas de biodiversidad y los altos niveles de productividad que presentan (Cannicci y Contini, 2009; Costanza et al., 2014; Convención de la Diversidad Biológica, 2015; Convención de Ramsar sobre los

Humedales, 2021). Los humedales, cubriendo sólo cerca del 6% de la superficie terrestre, albergan más del 40% de las especies a nivel global y el 12% de especies animales (Cannicci y Contini, 2009). Por otro lado, proveen alimentos esenciales como arroz y peces, agua para uso doméstico y agrícola, fibras (vegetales), madera para la construcción y como combustible (leña), aves y otros animales de interés cinegético, y tierras fértiles para el cultivo (MedWet, 2016; Convención de Ramsar sobre los Humedales, 2018). Además, participan en el control de inundaciones, protección contra las tormentas y estabilización de la costa, así como también contribuyen a la purificación del agua, participan en la regulación de los ciclos hidrológicos y en el ciclo de nutrientes (Cannicci y Contini, 2009; Reddy et al., 2010; Ten Brink et al., 2013; Convención de Ramsar sobre los Humedales, 2018). Por último, también aportan, de manera sustancial, a la regulación del clima mundial y a la mitigación del cambio climático (Cannicci y Contini, 2009; Convención de Ramsar sobre los Humedales, 2018), debido a que constituyen el principal reservorio de carbono a nivel global (Burkett y Kusler, 2000; Cannicci y Contini, 2009; Convención de Ramsar sobre los Humedales, 2018).

Se estima que, aproximadamente, la superficie ocupada por los humedales en el planeta es de 12,1millones de km^2 (el 6% de la superficie terrestre), de los cuales 570 millones de hectáreas son de humedales de agua dulce (MedWet, 2016; Convención de Ramsar sobre los Humedales, 2018). El mayor porcentaje de humedales se encuentra en el continente asiático (32%), mientras que Europa, con el 13%, se encuentra en cuarto lugar después de Norte América (27%) y Latinoamérica y el Caribe (16%) (Convención de Ramsar sobre los Humedales, 2018). Sin embargo, la superficie de los humedales ha disminuido en las últimas décadas principalmente por su transformación en tierras de cultivo o áreas urbanizadas. La tasa de reducción en superficie de los humedales naturales entre 1970 y 2015 fue del 35%, tres veces más alta que la tasa de pérdida de los bosques (Convención de Ramsar sobre los Humedales, 2018). En el Mediterráneo se estima que se ha perdido cerca del 48% del área de los humedales entre 1970 y 2013, un porcentaje mayor que en los tres continentes adyacentes (Gardner et al., 2015; MedWet, 2016; Convención de Ramsar sobre los Humedales, 2021). La pérdida de estos ecosistemas ha afectado a la biodiversidad de la región, estimándose que se ha perdido el 52% de la biodiversidad marina y el 28% de la de agua dulce desde 1992, mientras que el 36% de sus especies dependientes de los humedales se encuentra amenazada a nivel mundial (Convención de Ramsar sobre los Humedales, 2021). Particularmente, en España, el 60% de la superficie de humedales naturales se ha perdido en las últimas cuatro décadas (MedWet, 2016) y para el 2013, se estimó que el 45% de los servicios ecosistémicos de estos ambientes habían sido degradados o estaban siendo usados de manera insostenible (Gardner et al., 2015).

La extracción del agua, la eutrofización, la contaminación, la sobreexplotación de sus recursos y la invasión de especies exóticas también son otros aspectos que han contribuido a la degradación de los humedales, así como también se han visto afectados por el cambio climático (Ten Brink et al., 2013; Gardner et al., 2015; MedWet, 2016; Convención de Ramsar sobre los Humedales, 2021).

La Unión Europea ha enfocado la conservación de los humedales, principalmente, en la conservación de las especies de aves que dependen de ellos, y si bien es cierto que varias de ellas han respondido positivamente a las medidas de conservación (Galewski et al., 2011; EEA, 2020), no es menos cierto que, la mayoría, se tratan de especies generalistas, que se adaptan bien al aumento de los humedales artificiales, a la intensificación de la agricultura y la pesca o a la eutrofización de estos ambientes (Mediterranean Wetlands Observatory, 2012; MedWet, 2016). Sin embargo, algunas especies propias de los humedales estacionales mediterráneos siguen disminuyendo (MedWet, 2016; Fraixedas et al., 2019; Convención de Ramsar sobre los Humedales, 2021). Por otra parte, aunque los humedales artificiales no pueden sustituir los ecosistemas naturales ni sus funciones, la creación y restauración de humedales se está convirtiendo en una prioridad cada vez mayor en los países industrializados, en los que la integridad de los humedales se ha degradado gravemente durante décadas (Convención de la Diversidad Biológica, 2015).

Los arrozales como humedales artificiales

Los cultivos de arroz pueden ser considerados como humedales artificiales y han sustituido a los humedales naturales en gran parte del mundo (Shine y Klemm, 1999; Elphick, 2000; Czech y Parsons, 2002). Se estima que los humedales naturales se han reducido en un 35% entre 1970 y 2015, mientras que los humedales artificiales, incluyendo los arrozales, han aumentado un 233%, según el índice WET (Wetlands Extent Trend) (Convención de Ramsar sobre los Humedales, 2021), constituyendo el 12% de los humedales hoy en dia (Convención de Ramsar sobre los Humedales, 2018; Davidson y Finlayson, 2018; Davidson et al., 2018). En general, 167 millones de hectáreas de la superficie terrestre fueron utilizadas para el cultivo de arroz durante el 2018, de las cuales 635.000 ha fueron en Europa (FAOSTAT, 2020). En el Mediterráneo, la situación sigue el mismo patrón, con un incremento en las áreas de arrozales de más del 30% desde 1960, en detrimento de los humedales naturales (Longoni, 2010; MedWet, 2016; Convención de Ramsar sobre los Humedales, 2018).

Aunque la conversión de los humedales naturales en el entorno de arrozales constituye una amenaza para la biodiversidad asociada a este tipo de ecosistema, algunas especies de aves acuáticas se han visto beneficiadas en tales cultivos (Fasola y Ruiz, 1996; Elphick, 2000; Czech y Parsons, 2002; Elphick, 2010; Giosa et al., 2018). Los arrozales se han convertido en sitios importantes de alimentación de numerosas especies de anátidas, zancudas y limícolas, especialmente durante el periodo reproductivo (Hafner et al., 1987; Fasola y Ruiz, 1996; Fasola et al., 1996; Elphick et al., 2010). En Japón, se sabe que 49 especies de aves dependen, de moderada a fuertemente, de los arrozales para reproducirse o alimentarse (Katayama et al., 2015). Las inundaciones post-cosecha en el invierno, parecen ser beneficiosas para varias especies de patos invernantesen el oeste de Europa, que utilizan los arrozales como sitios de forrajeo nocturno (Pernollet et al., 2015). Además, durante el otoño e invierno, estos campos inundados proveen sitios importantes de parada, descanso y alimentación de especies migratorias (Sánchez-Guzmán et al., 2007; Laurenço y Piersma, 2008; Santiago-Quesada et al., 2014). Asimismo, los arrozales presentan una alta riqueza de macroinvertebrados, pudiendo incluso ser mayor que en los humedales naturales (Lupi et al., 2013; Marques et al., 2015), al igual que de anfibios, cuya presencia en los canales de irrigación pueden ser un aporte importante a la biodiversidad de ciertas regiones (Maltchik et al., 2011). Tanto los macroinvertebrados como los anfibios constituyen parte elemental de la dieta de numerosas especies de aves acuáticas en estos ecosistemas.

Las garzas (Ardeidae) es uno de los grupos de aves que han establecido una fuerte relación con este tipo de humedales artificiales (Hafner et al., 1987; Fasola et al., 1996; Tourenq et al., 2004; Mugica et al., 2006; Kazantzidis y Goutner, 2008; Fasola y Brangi, 2010; Fasola et al., 2010; Fujioka et al., 2010; Cardarelli et al., 2017). Por un lado, las tendencias de las poblaciones reproductoras están positivamente relacionadas con la presencia de arrozales (Fasola y Brangi, 2010; Fasola et al., 2010; Ramo et al., 2013), así como también el tamaño de las colonias de reproducción (Hafner et al., 1987; Tourenq et al., 2004). El éxito reproductivo también se ha asociado positivamente con los campos de arroz (Cardarelli et al., 2017), ya que estos ambientes ofrecen una buena fuente de alimento en una etapa de alta demanda energética (Mugica et al., 2005). La presencia y disponibilidad de las presas potenciales de las garzas varían estacionalmente, dependiendo de la fase del cultivo y el régimen de inundación, coincidiendo los máximos de diversidad y biomasa con el periodo reproductivo, en la mayoría de los casos (Fasola y Ruiz, 1996; Marques y Vicente, 1999; Mugica et al., 2005).

Sin embargo, los cambios en las prácticas de cultivo del arroz pueden afectar negativamente a la diversidad de aves acuáticas asociadas a estos ambientes (Petrie et al., 2014; Xie et al., 2018; Fasola et al., 2022). En las últimas décadas, el cultivo industrializado del arroz ha ido sustituyendo al cultivo tradicional, trayendo como consecuencia la reducción del área inundada y del nivel de inundación, coincidiendo con una disminución en el número de especies y de individuos que hacen uso de estos ambientes (Lane y Fujioka, 1998; Wood et al., 2010; Sesser et al., 2016; Xie et al., 2018; Fasola et al., 2022). Este efecto negativo en las poblaciones de aves acuáticas muestra la relación de la disponibilidad de hábitats de alimentación asociada a la presencia de arrozales, que se reducen con la implementación de nuevas prácticas de cultivo (Fasola et al., 2022).

L'Albufera

L'Albufera es un humedal costero que se encuentra ubicado en la Comunidad Valenciana, y es uno de los principales humedales de la Península Ibérica, así como también uno de los más importantes del Mediterráneo occidental (Generalitat Valenciana, 2002; WetNet, 2017). Su alto valor dentro de la región viene dado, tanto por su extensión (21.120 ha), como por la alta biodiversidad que alberga. Por esto mismo, L'Albufera fue declarada "Parc Natural"de acuerdo con la legislación regional en 1986, y ha sido posteriormente incluida dentro de los "Humedales de Importancia Internacional" (sitio RAMSAR) en 1989, además es reconocida como "Zona Especial para la Protección de Aves" (ZEPA) desde 1991 y "Lugar de Interés Comunitario" (LIC), desde 1992.

L'Albufera se encuentra a 12 Km al sur de la ciudad de Valencia, al este de la Península Ibérica, en la vertiente mediterránea (39°20'N, 00°20'W). Es el humedal más grande de la Comunidad Valenciana y contiene la laguna natural más extensa de España. Sin embargo, el paisaje que se observa actualmente es producto de extensas modificaciones del ambiente que se han realizado desde hace siglos. Antiguamente, el marjal dominaba el área, pero con la transformación agrícola, mayormente entre los años 1650 y la década de 1920, se convirtió en un monocultivo de arroz (Generalitat Valenciana, 2002; Segarra y Dies, 2014). De esta manera, las 14.000 ha que ocupaban originalmente los ambientes del marjal quedaron reducidas a las 2.837 ha representadas por la laguna y su orla de vegetación palustre, que conformanvarias islas o formaciones vegetales, llamadas localmente "matas", que ocupan unas 300 ha. (Generalitat Valenciana, 2002). El desarrollo del arrozal ha comprendido la construcción de sistemas de drenaje (acequias y canales de irrigación), compuertas que comunican la laguna con el mar ("goles") y un régimen de inundación que permiten que los campos permanezcan inundados la mayor parte del año. De esta forma, la actividad del cultivo del arroz ha permitido el mantenimiento del espacio como zona húmeda (Segarra y Dies, 2014).

Además de las 14.500 ha del arrozal y la laguna central, el Parc Natural L'Albufera incluye la restinga o barra litoral, un cordón dunar de 30 km de longitud y 1 km de ancho, aproximadamente, que separa la laguna del mar.

Estas condiciones particulares favorecen el establecimiento de una numerosa comunidad de aves acuáticas a lo largo de todo el año, tanto en la época de reproducción, como en la migración y la invernada (WetNet, 2017). Por un lado, los cultivos de arroz proporcionan alimento durante todo el año para gran número de especies que forrajean en los cultivos y canales de riego, mientras que, por otro lado, las asociaciones vegetales existentes suministran el sustrato necesario para la instalación de las colonias reproductoras de aves, como son los carrizales, masegares y arboledas (Segarra y Dies, 2014). En este sentido, L'Albufera juega un papel relevante como sitio para la conservación de la avifauna, especialmente de las aves acuáticas, incluyendo algunas especies que se encuentran amenazadas. En general, esta área alberga cerca de 240 especies de aves durante el año, de las cuales 90 son reproductoras habituales y 75 de ellas son aves acuáticas, entre las que se destacan el grupo de las garzas. L'Abufera es el tercer lugar más importante de nidificación de garzas dentro de España (Garrido et al., 2012) y alberga el 60% de estas especies que nidifican en la Comunidad Valenciana (Generalitat Valenciana, 2018).

Por otro lado, L'Albufera cuenta con valores patrimoniales únicos, resultado de los usos y tradiciones milenarias de los pobladores del humedal (Segarra y Dies, 2014; WetNet, 2017). Las prácticas tradicionales de aprovechamiento y explotación de los recursos que ofrece el humedal, como la pesca, la caza y la navegación a vela latina, así como las construcciones y herramientas relacionadas con el cultivo del arroz forman parte de este valioso patrimonio cultural (Generalitat Valenciana, 2002; Segarra y Dies, 2014; WetNet, 2017).

La conservación del ambiente natural, en este contexto, está directamente conectada con los usos tradicionales del humedal, como el cultivo del arroz y la caza, así como con usos más recientes como el turismo (WetNet, 2017).

Los arrozales de l'Albufera desde una perspectiva agronómica

El cultivo del arroz en l'Albufera se viene realizando desde hace siglos, siendo las primeras referencias que se tienen de 1339 (Roselló, 1995), aunque el desarrollo y expansión del mismo ocurrió entre los años 1650 y la segunda década del siglo XX (Generalitat Valenciana, 2002; Segarra y Dies, 2014). Actualmente, el arrozal ocupa el 70% de la superficie del parque natural y, además de constituir el pilar básico de la economía local, tiene papel primordial en el mantenimiento de las superficies inundadas y de un paisaje agrario de gran tradición, así como en la conservación de aves acuáticas (Generalitat Valenciana, 2002).

El mantenimiento del arrozal depende del manejo del agua proveniente de los ríos Júcar y Turia, que se utiliza para la inundación de los campos mediante canales y acequias, para desembocar finalmente en la laguna. El régimen hidrológico de los cultivos consiste en inundar los campos dos veces al año: una estival para el cultivo propiamente dicho y otra en invierno como medida agroambiental aprovechada con fines cinegéticos. El cronograma de inundaciones puede sufrir ligeras variaciones en cuanto a la fecha de inicio, pero generalmente sigue el siguiente patrón:

- A finales del mes de octubre y durante el mes de noviembre, posterior a la cosecha, comienza la inundación invernal ("perellonà"), con el fin de suministrar un ambiente adecuado para las especies migratorias, invernantes y especialmente las de interés cinegético (se abre la temporada de caza). Durante esta etapa los arrozales situados a menor cota ("tancats") permanecen completamente inundados, formando una extensa lámina de agua que rodea la laguna, mientras que los situados en zonas altas permanecen secos prácticamente todo el invierno.
- A mediados de enero comienza el drenaje de los campos, que suele finalizar a mediados de marzo. En el proceso, van quedando campos encharcados con

bajos niveles de agua, momento en que se remueve el terreno con maquinarias ("fangueig") para prepararlo para la siembra posterior.

- A finales de marzo y durante todo el mes de abril, toda el agua restante de los campos se ha evaporado y se encuentran completamente secos. En esta etapa se procede con el arado y nivelado del terreno.
- A mediados de mayo comienza la inundación de los campos para dar inicio a la siembra. Dependiendo del productor y del tamaño del campo, la siembra se realiza esparciendo la semilla, siendo muy escasa la tradicional siembra manual de plantones, utilizada en la actualidad para reforzar sectores de campos con menor desarrollo de plantas.
- Para principios de junio ya han comenzado a germinar las plantas de arroz, que continúan su crecimiento durante todo el mes de junio y agosto, cuando alcanzan su máximo desarrollo. Durante este período se producen diversas prácticas de abonado y cambios en el nivel de inundación de los campos ("eixugons"). A mediados de agosto comienza la retirada del agua para realizar posteriormente la cosecha.
- A finales de septiembre se inicia la cosecha del arroz que se extiende hasta el mes de octubre, cuando se inicia nuevamente el ciclo.

Este régimen de inundaciones ha sufrido algunas variaciones en el tiempo, como el hecho que en décadas anteriores (80's y 90's) la inundación de los campos para el cultivo comenzaba en las últimas semanas de abril, mientras que a principio de siglo los campos comienzan a inundarse en las primeras semanas de mayo (Prósper, 2000; Oltra et al., 2001; Gómez de Barreda, 2009) y en la actualidad se llega a producir a finales de mayo e incluso junio. Por otra parte, el área inundada durante el invierno ha disminuido en épocas recientes, así como también el volumen de agua en un 6% aproximadamente (Soria et al., 2015).Paralelamente, se ha observado que entre 2008 y 2018 existe una tendencia significativa al aumento de los valores mínimos de la conductividad en la laguna, lo cual indicaría una disminución de la cantidad de agua dulce que llega a ésta (Soria et al., 2021a). Asimismo, este efecto se ha agravado al combinarse con un aumento del tiempo de residencia del agua de la laguna entre 1988 y 2018, siendo precisamente mayor el tiempo de residencia en el entorno de las matas que mayor regresión han experimentado (Soria et al., 2021b).

Hasta la entrada en vigor del plan de cuenca del Júcar aprobado en 2022, el ciclo de las inundaciones en l'Albufera ha estado sujeto a la disponibilidad y distribución del recurso hídrico. El desarrollo y crecimiento de las áreas urbanizadas e industriales y de otros tipos de cultivos en los alrededores de L'Albufera, incrementa la demanda por el recurso, el cual se ha vuelto más escaso debido las menores precipitaciones causadas, probablemente, por el cambio climático (Palop, 2015). Por otro lado, el cultivo del arroz se enfrenta a presiones de mercado, cada vez más competitivo, y a una disminución de la rentabilidad (Girona, 1998; Picazo-Tadeo et al., 2009; Martínez, 2018). Esta situación, junto con los costes del bombeo del agua para drenar e inundar los campos, condiciona el cuándo y cómo se realiza la inundacióndel arrozal.

Las garzas de L'Albufera

Las garzas son algunas de las especies que se encuentran más asociadas a los arrozales y que se han visto favorecidas por este tipo de humedal. Estas pertenecen a la familia Ardeidae del orden Pelecaniformes, conformada por 64 especies distribuidas a nivel mundial (Clements et al., 2022), aunque son más abundantes y diversas en los trópicos. Un grupo afín a las ardeidas son los ibis de la familia Threskiornithidae, cuyos integrantes se observan generalmente asociados a las garzas. Esta familia incluye 34 especies (Clements et al., 2022), distribuidas igualmente a nivel mundial y con hábitos semejantes a las ardeidas.

En L'Albufera nidifican regularmente siete especies de garzas: Garza real (*Ardea cinerea*), Garza imperial (*Ardea purpurea*), Garcilla bueyera (*Bubulcus ibis*), Garceta común (*Egretta garzetta*), Garcilla cangrejera (*Ardeola ralloides*), Martinete común (*Nycticorax nycticorax*) y Avetorillo común (*Ixobrychus minutus*). Recientemente se ha registrado la nidificación ocasional de Garceta grande (*Ardea alba*) (Generalitat Valenciana, 2021). Además, también es nidificante regular el Morito común (*Plegadis falcinellus*) perteneciente a la familia Threskiornisthidae (Generalitat Valenciana, 2021). Todas estas especies fueron incluidas en el presente estudio, a excepción del Martinete común, el Avetorillo común y la Garceta grande.

En cuanto a su estado de conservación, todas las especies están catalogadas como de Preocupación menor en la Lista Roja de la IUCN, así como en el Libro Rojo de las Aves de España (SEO/BirdLife, 2021), a excepción de la Garza imperial, que está catalogada como Casi amenazada en este último, al igual que la población reproductora del Morito común, aunque se hace la aclaratoria de los altos números de parejas reproductoras que se han contabilizado en los últimos años. Por su parte, cuatro especies están listadas en el Anexo I de la Directiva de Aves (Directiva 2009/147/EC), que incluye las especies que requieren de medidas de protección especiales, a saber: la Garcilla cangrejera, Garceta común, Garza imperial y Morito común. Igualmente, todas las especies están incluidas en el Apéndice III del Convenio de Berna, relativo a la conservación de vida silvestre y medio natural de Europa (BOE núm. 235 del 01/10/86), mientras que la Garza imperial y el Morito común se incluyen en el Apéndice II del Convenio de Bonn, relativo a la conservación de especies migratorias de animales silvestres (Decisión 82/461/EEC). A nivel nacional, la Garcilla cangrejera aparece como Vulnerable en el Catálogo Español de Especies Amenazadas (Real Decreto 139/2011) y en el Catálogo Valenciano de Especies de Fauna Amenazadas (Decreto 32/2004), acompañada en este último por la Garza imperial.

A continuación, se describen brevemente las especies que se han considerado en este estudio.

a) Garza real (*Ardea cinerea*)

Se encuentra distribuida por Europa, África y Asia (Del Hoyo et al., 1992), mientras que en España se encuentra en todas las Comunidades Autónomas menos Canarias y Ceuta (Garrido-López, 2022a). Dentro de la Comunidad Valenciana, se encuentra el 20% de la población invernante del país y el 13% de la población reproductora (Garrido et al., 2012) y se la considera nidificante e invernante común (Gómez-López et al., 2006).

Los primeros registros de nidificación en L'Albufera son de 1984 (Gómez-López et al., 1985) y hasta el 2004, esta población concentraba el 98% de las parejas reproductoras de la Comunidad Valenciana (Gómez-López et al., 2006). Sin embargo, en los últimos censos dicha población representa el 61% de los nidificantes de la región (Generalitat Valenciana, 2021). Se ha registrado que la cantidad de parejas está disminuyendo en sus principales núcleos de cría, lo que en la Comunidad Valenciana ha representado una disminución del 30% (Garrido-López, 2022a).

El hábitat natural son las aguas poco profundas y remansos, incluyendo cultivos de arroz, pero puede explorar diversos ambientes urbanos, como puertos y basureros (Gómez-López et al., 2006; Garrido-López y Del Moral, 2012). Principalmente piscívora, pero también consume pequeños mamíferos y crías de patos (Marquiss y Leitch, 1990; González-Martín y González-Solís, 1990). El sustrato de nidificación es variable, puede establecer los nidos en vegetación palustre, aunque también lo hace sobre árboles próximos a medios acuáticos (Belamendia et al., 2003; Garrido et al., 2012). El periodo reproductor comienza aproximadamente en enero, con el cortejo y la construcción de nidos, y culmina en julio con el abandono de los nidos por parte de los pollos (Belamendia et al., 2003). En L'Albufera de València presenta dos picos de puestas, uno a finales de enero y el otro a principios de marzo (Prósper y Hafner, 1996). Está presente en los arrozales durante todo el año, incluso cuando los campos están secos, asociándose en este periodo a las acequias y canales de irrigación.

b) Garza imperial (*Ardea purpurea*)

Esta especie se encuentra distribuida en el Paleártico occidental y en el África subsahariana (Del Hoyo et al., 1992). En España está presente en todas las comunidades autónomas excepto Canarias, Asturias, Murcia, Ceuta y Melilla (Garrido-López, 2022b) y en época de reproducción se concentra principalmente en las comunidades autónomas de Andalucía, Cataluña y Comunidad Valenciana (Garrido et al., 2012). En invierno, la población europea migra al África tropical, aunque algunos ejemplares pueden permanecer en los límites sur del área de cría, por lo que se le considera como invernante raro (Gómez-López et al., 2006; Garrido-López, 2022b).

L'Albufera de València alberga el 45% de la población nidificante de la Comunidad Valenciana (Gómez-López et al., 2006; Generalitat Valenciana, 2016). Es una especie que ha venido en aumento dentro de la región en los últimos años, alcanzando un máximo histórico en el 2016 de 175 parejas reproductoras en la región, de las cuales 76 nidificaron en L'Albufera de València (Generalitat Valenciana, 2016), aunque en el 2021 el número de parejas bajó a 49 (Generalitat Valenciana, 2021). A pesar de esta disminución, se considera que la población se mantiene estable dentro de la región, luego de un periodo de incremento moderado si se considera el periodo de los últimos 15 años (Garrido-López, 2022b; Generalitat Valenciana, 2022).

Su hábitat principal son las grandes masas de aguas someras con carrizales (Navedo et al., 2004). Se alimenta principalmente de peces y en menor grado de larvas de insectos (Amat y Herrera, 1977; Campos y Lekuona, 1997). Cría en colonias laxas, en zonas de alta densidad de carrizo, en aguas someras o pantanos (Sánchez et al., 1999; Belamendia et al., 2003). Las puestas tienen lugar generalmente desde mediados de abril hasta finales de mayo, mientras que las eclosiones tienen lugar sobre todo a finales de mayo y principios de junio con la emancipación de los pollos a finales de julio y principios de agosto (Sánchez et al., 1999; Prósper, 2000). Se la comienza a observar en los arrozales a comienzo del periodo reproductivo, a finales de abril, y hace uso de los mismos durante toda la temporada.

c) Garcilla bueyera (*Bubulcus ibis*)

Es una especie que ha alcanzado distribución mundial debido a su gran capacidad de expansión (Del Hoyo et al., 1992). En España se distribuye ampliamente, estando ausente solo en La Rioja, Galicia y Ceuta (Garrido-López, 2022c). Las poblaciones más abundantes se encuentran en la zona occidental del país, principalmente en las comunidades de Andalucía y Extremadura, junto con Castilla-La Mancha, Castilla y León y Madrid (Garrido, 2003; Garrido et al., 2012; Garrido-López, 2022c). En la Comunidad Valenciana es la garza más abundante, tanto en época de reproducción como en invierno (Gómez-López et al., 2006; Generalitat Valenciana, 2015; 2018).

En la Comunidad Valenciana se ha llegado a obtener un promedio de 2.398 parejas reproductoras, siendo L'Albufera de València el sitio más importante que albergaba el 84% del contingente nidificante (Gómez-López et al., 2006). Sin embargo, en los últimos censos este porcentaje ha disminuido,en el 2018, a un 62% (692 parejas) de un total de 1.120 parejas nidificantes en toda la región y a un 43% (1165 parejas) de un total de 2.700 parejas, en el 2021 (Generalitat Valenciana, 2018; 2021). A pesar de esta disminución a nivel general, L'Albufera de València sigue siendo el sitio con mayor número de parejas dentro de la Comunidad Valenciana, junto con el Parque Natural El Hondo (Generalitat Valenciana, 2021).

Es una especie oportunista que consume principalmente insectos (Kopij, 1999; Si Bachir et al., 2001), pero que puede variar su alimentación dependiendo de la disponibilidad, por lo que utilizan distintos tipos de hábitats, tales como campos agrícolas, arrozales, humedales naturales, basureros, entre otros (Garrido, 2003; Garrido et al., 2012). Esta especie nidifica en zonas arboladas cercanas a cuerpos de agua o en vegetación palustre y de ribera, mayormente en carrizo (*Phragmites australis*), formando colonias con otras garzas (Belamendia et al., 2003; Gómez-López et al., 2006; Garrido-López, 2012). En L'Albufera de Vàlencia las primeras puestas ocurren a finales de abril y la cría se prolonga hasta julio (Prósper, 2000), presentando dos máximos de puesta en abril-mayo y en junio-julio (Prósper y Hafner, 1996). Se la observa haciendo uso de los arrozales durante todas las etapas del cultivo, incluyendo la postcosecha, en los restos de paja del arroz, concentrándose mayor número durante las labores del fangueo.

d) Garceta común (*Egretta garzetta*)

Su distribución a nivel mundial abarca Europa, sur y este de Asia, África y Australia (Del Hoyo et al., 1992). En España se encuentra ampliamente distribuida, con excepción de La Rioja y Ceuta, siendo Andalucía, Comunidad Valenciana y Cataluña las regiones que albergan la mayor parte de la población (Garrido-López, 2022d). Ocupa el segundo lugar en abundancia dentro de la Comunidad Valenciana, después de la Garcilla bueyera (Generalitat Valenciana, 2016; 2018), siendo considerada como nidificante abundante e invernante común en el área de estudio (Gómez-López et al., 2006).

Las colonias más importantes, dentro de la Comunidad, se encuentran en L'Albufera de València, llegando a albergar el 15% de la población reproductora de España (Dies et al., 2001) y el 90% de la Comunidad Valenciana (Gómez-López et al., 2006), aunque actualmente ese porcentaje ha disminuido al 70% (Generalitat Valenciana, 2018). Las parejas reproductoras han tenido un descenso moderado en los últimos años, pasando del orden de miles de nidificantes entre 2010 y 2015, a 658 parejas en el 2018, aunque el número se ha recuperado en el último censo llegando a alcanzar las 1290 parejas en el 2021 (Generalitat Valenciana, 2018; 2021). A pesar de estas fluctuaciones, su población se considera estable dentro de la región (Garrido-López, 2022d).

Su hábitat son las aguas someras, arrozales y otros tipos de zonas húmedas que juegan un papel importante en la alimentación (Garrido-López, 2012) por lo que son sensibles a las variaciones del régimen hídrico y la calidad del agua (Hafner et al., 1987; Bartolomé et al., 1997). La dieta consiste mayormente en peces junto con insectos y anfibios (González-Martín y González-Solís, 1990; Kazantzidis y Gounter, 2005). En general nidifica sobre árboles, carrizos, eneas e incluso matorrales cerca de cuerpos de agua particularmentede humedales costeros (Garrido, 2003; Garrido et al., 2012). En la Comunidad Valenciana nidifica en carrizales, pudiendo formar grandes colonias mixtas junto con otras garzas (Gómez-López et al., 2006). En L'Albufera de València las puestas comienzan en abril y finalizan en julio, con un máximo a mediados de mayo (Prósper y Hafner, 1996). Al igual de la Garcilla bueyera, puede observársela a lo largo de todo el año, aunque más asociada a las áreas inundadas del arrozal y en mayor cantidad en la época reproductiva y junto a las labores de fangueo.

e) Garcilla cangrejera (*Ardeola ralloides*)

Esta especie se encuentra, durante el periodo reproductor, en los países mediterráneos de Europa y en el norte y este de África, mientras que en el invierno migra al África subsahariana (Del Hoyo et al., 1992). En España las colonias reproductoras están presentes en Cataluña, Comunidad Valenciana y Andalucía, concentrándose en el Delta del Ebro, L'ALbufera y Doñana (Pérez-Aranda et al., 2003; Garrido et al., 2012; Vera, 2022). Aunque mayormente estival, se la considera un invernante raro y escaso, pero regular (Garrido et al., 2012).

L'Albufera de València es la localidad más importante de cría dentro de la Comunidad Valenciana (Pérez-Aranda et al., 2003), donde en el 2011 nidificaba el 25% de la población reproductora de España (Garrido et al., 2012). Actualmente, esta localidad alberga alrededor del 50% de los efectivos reproductores de la Comunidad (Generalitat Valenciana, 2016; 2018; 2021). La población de parejas nidificantes dentro de la Comunidad Valenciana, ha presentado un aumento significativo en los últimos 30 años (Generalitat Valenciana, 2013) llegando a alcanzar un máximo histórico de más de 700 parejas en el 2016 (Generalitat Valenciana, 2016). En general, dentro de España se considera que sus poblaciones reproductoras tienen una tendencia positiva (Vera, 2022) y dentro de la Comunidad Valenciana han presentado un incremento moderado desde 1995 (Generalitat Valenciana, 2022).

Nidifica en arboledas y vegetación palustre (Pérez-Aranda et al., 2003; Garrido et al., 2012). Es una especie muy ligada a las grandes masas de agua someras y los humedales que cuentan con grandes extensiones de arrozal se han convertido en sus principales localidades de reproducción (Ibáñez et al., 2004; Gómez-López et al., 2006). La dieta consiste, en orden de importancia, de insectos, anfibios y peces (Petrescu, 1999; Delord et al., 2004; Kazantzidis y Goutner, 2005). La cría ocurre generalmente entre abril y agosto (Ibáñez et al., 2004). En L'Albufera de València la postura comienza en abril y se extiende hasta julio, con un pico de puesta en abril-mayo y otro en junio-julio (Prósper y Hafner, 1996). Comienza a llegar a los arrozales a finales de abril y se la puede observar mayormente en las orillas de los campos sembrados.

f) Morito común (*Plegadis falcinellus*)

Presenta una distribución mndial amplia, aunque muy fragmentada. Cría en el sur y este de Europa, África, sur de Asia y Australia, así como también en la costa este de los Estados Unidos, Canadá y países del Caribe (Del Hoyo et al., 1992). En España su presencia es relativamente reciente, encontrándose en Cataluña, Andalucía y la Comunidad Valenciana (Figuerola et al., 2003; Garrido et al., 2012). Doñana, el Delta del Ebro y los humedales de laComunidad Valenciana son los lugares importantes de reproducción (Santoro et al., 2022). Esta especie ha experimentado una expansión geográfica notable en las últimas dos décadas (Santoro et al., 2022).

La población reproductora en España está experimentando un fuerte crecimiento poblacional en los últimos años (Garrido et al., 2012; Máñez et al., 2012), desde que volvió a reproducirse en el país a partir de 1993 (Figuerola et al., 2004). En la Comunidad Valenciana, el incremento también es significativo, pasando de las 700 parejas reproductoras en 2016 (Generalitat Valenciana, 2016), a 2686 parejas en el 2021, que representa el 73% de la población reproductora de la Comunidad Valenciana (Generalitat Valenciana, 2021). La población invernante también se ha incrementado, posiblemente como consecuencia del aumento de su población reproductora (Máñez et al., 2012) y de la ampliación de hábitat idóneo para la especie (Garrido et al., 2012).

Utiliza una amplia variedad de tipos de humedales interiores y lagunas costeras y estuarios, en menor grado (Davis y Kricher, 2000). Su alimentación consiste en su mayoría de insectos acuáticos, larvas y crustáceos, pero puede incluir pequeños peces y salamandras (Macías et al., 2004). En algunas localidades se ha encontrado que consume arroz en época no reproductiva (Acosta et al., 1996), así como también se ha reportado el consumo del caracol manzana (*Pomacea maculata*) en el delta del Ebro (Bertolero y Navarro, 2018). Nidifica en masas de vegetación palustre, principalmente enea y carrizo, pero también puede hacerlo sobre árboles y otra diversidad de sustratos (Davis y Kricher, 2000; Figuerola et al., 2003). El periodo de puesta pude abarcar desde principios de abril hasta mediados de julio (Boucheker et al., 2009), aunque el periodo de nidificación puede extenderse hasta agosto (Figuerola et al., 2004). En L'Albufera se pueden observar grupos de cientos de individuos durante el invierno, cuando los campos aún se encuentran anegados, así como en la época reproductiva, aunque no alcanza números tan altos.

Objetivos

El objetivo general de este trabajo fue el de actualizar la información y aportar nuevos datos sobre la ecología reproductiva y tendencias poblacionales de la comunidad de garzas de L'Albufera (y de otros humedales de la Comunidad Valenciana) y evaluar el uso espacio-temporal del arrozal como principal hábitat de alimentación en la época reproductiva, analizando los posibles efectos de la gestión y manejo del mismo en la composición y comportamiento de dicha comunidad, y aportando información de interés para mejorar las capacidades de gestión de las especies y del propio arrozal como hábitat de alimentación de éstas.

Para ello se plantearon los siguientes objetivos específicos:

- Evaluar las tendencias poblacionales de las especies consideradas en los humedales de la Comunidad Valenciana en los últimos 30 años y dilucidar qué características del hábitat, junto con algunas condiciones ambientales (precipitaciones y temperatura), determinan los tamaños de sus colonias reproductoras.
- Identificar las colonias reproductoras en L'Albufera y realizar el seguimiento de los nidos identificados durante el periodo de reproducción con el fin de estimar los parámetros reproductivos de las especies objeto de estudio.
- Caracterizar el estado de los campos de cultivo de arroz en L'Albufera y describir los cambios estructurales en los mismos a lo largo del año, como consecuencia del manejo agrícola.

- Establecer la riqueza y abundancia de las especies de garzas en los arrozales durante el periodo reproductor y determinar las variaciones temporales en relación con el estado o fase de cultivo en el que se encuentra.
- Analizar los efectos del estado de los campos de arroz (fase del cultivo) en los parámetros reproductivos de las garzas.

Estructura de la tesis

La tesis se presenta en forma de capítulos, comenzando por esta Introducción que corresponde al Capítulo 1. El resto de los capítulos contienen artículos ya publicados, junto con los métodos, la discusión y conclusiones generales. Los capítulos siguientes están organizados de la siguiente forma:

Capítulo 2: Métodos generales

Capítulo 3:Forti M., Monrós J.S., Vera P. 2021. Habitat and weather conditions effects on long-term breeding population dynamics of five species of herons (Ardeidae) and Glossy ibis (Threskiornithidae) in the Valencian Community, Spain. Limnetica 40: 417-433.

Capítulo 4: Forti M., Monrós J.S., Vera P. 2021. Effects of rice field phenology on breeding parameters of heron colonies in the east of the Iberian Peninsula. Ardea 109: 149–165.

Capítulo 5: Forti M., Flórez-Montero G.L., Monrós J.S., Vera P. 2022. Effects of rice field water cycles on the breeding biology of Grey heron (*Ardea cinerea*) and conservation implications. Waterbirds 46(3): 328-344(en prensa).

Capítulo 6: Discusión general y consideraciones finales

Capítulo 7: Conclusiones.

Justificación de la Tesis

Los humedales naturales están entre los ecosistemas más productivos del planeta y de los que ofrecen mayor cantidad de servicios ecosistémicos a la población, los cuales han sido valorados en millones de dólares (Cannicci y Contini, 2009; Costanza et al., 2014; Convención de la Diversidad Biológica, 2015; Convención de Ramsar sobre los Humedales, 2021). Sin embargo, la tasa de desaparición y degradación de estos ambientes es preocupante, estando por encima, incluso, de la tasa de desforestación de los bosques (Gardner et al., 2015; MedWet, 2016; Convención de Ramsar sobre los Humedales, 2021), poniendo en peligro toda la biodiversidad asociados a ellos y los procesos ecológicos que albergan (Gardner et al., 2015; Convención de Ramsar sobre los Humedales, 2021). Una de las principales amenazas de los humedales naturales es su sustitución por tierras agrícolas y, en la mayoría de los casos, por arrozales (Shine y Klemm, 1999; Elphick, 2000; Czech y Parsons, 2002; Davidson y Finlayson, 2018; Davidson et al., 2018; Convención de Ramsar sobre los Humedales, 2018). No obstante, los arrozales se han constituido como humedales artificiales que sustentan una alta diversidad, especialmente de aves acuáticas, algunas de las cuales se han asociado estrechamente con este tipo de ambiente (Hafner et al., 1987; Fasola y Ruiz, 1996; Fasola et al., 1996; Elphick, 2000; Czech y Parsons, 2002; Elphick, 2010; Katayama et al., 2015; Giosa et al., 2018). La relación que se ha desarrollado entre las poblaciones de numerosas especies de aves acuáticas y el cultivo del arroz es tan intensa, que cambios en la práctica del cultivo, tales como reducción del tiempo de inundación, disminución del nivel de agua, siembra en seco, o la industrialización del proceso, ha causado impactos negativos en la abundancia de dichas especies (Lane y Fujioka, 1998; Wood et al., 2010; Petrie et al., 2014; Sesser et al., 2016; Xie et al., 2018; Fasola et al., 2022).

El Parc Natural de L'Albufera, además de albergar las colonias reproductoras de garzas más importantes de la región e incluso a nivel nacional (Generalitat Valenciana, 2002; Garrido et al., 2012; WetNet, 2017), tiene la particularidad de estar conformado, casi en su totalidad, por campos de arroz. El arrozal es la principal fuente de alimento, tanto de las especies que nidifican en L'Albufera, como de las especies invernantes y migratorias, por lo que adquiere una importancia relevante en el mantenimiento de estas poblaciones (Generalitat Valenciana, 2002; WetNet, 2017). Sin embargo, el cultivo del arroz en L'Albufera no escapa a la realidad del contexto europeo y del mercado internacional, por lo que se enfrenta al reto de modernizar o cambiar ciertas prácticas para ser competitivos en el mercado, por un lado, y cumplir con las condiciones establecidas por la Unión Europea en materia ambiental, por el otro (Girona, 1998; Picazo-Tadeo et al., 2009; Palop, 2015; Martínez, 2018). Considerando las consecuencias que los cambios en las prácticas de cultivo han ocasionado en otras regiones en las poblaciones de aves acuáticas, cobra especial importancia establecer cuál es la verdadera relación o dependencia de las poblaciones reproductoras, en nuestro caso de garzas, con la dinámica del arrozal, y de qué manera se verían afectadas en el caso que se modifique la forma tradicional que se ha venido realizando el cultivo. Por otro lado, las poblaciones de Garza real, Garcilla bueyera y Garceta común, han registrado descensos en sus poblaciones en los últimos años (Generalitat Valenciana, 2018; Garrido-López, 2022a), lo que se ha asociado al posible detrimento en la calidad del agua del arrozal, o a cambios en la dinámica de las inundaciones del mismo, por lo cual se hace necesario estudiar si dichas modificaciones están afectando de alguna manera a estas poblaciones.

En este contexto, se planteó, en primer lugar, determinar el estado y tendencias de las poblaciones reproductoras de garzas en los principales humedales de la Comunidad Valenciana y caracterizar estos ambientes en base a un grupo de variables ambientales, con el fin de establecer una relación entre las tendencias poblacionales y dichas variables. Es decir, qué características del humedal están favoreciendo el establecimiento y la dinámica de las poblaciones reproductoras de una determinada especie. De esta manera, al identificar estas variables, se contribuye con información que debe tomarse en cuenta a la hora de realizar manejo de hábitat o de autorizar cualquier intervención en estos humedales. Además, se actualiza el estado de las poblaciones reproductoras de las seis principales especies de garzas de la región.

Por otro lado, para evaluar si los cambios en la forma de cultivar el arroz en L'Albufera afectan la reproducción de las garzas nidificantes en el área, se determinó, en primera instancia, los parámetros reproductivos de las seis especies más relevantes, al mismo tiempo que se registró la condición de los campos a lo largo de todo el año. De esta manera se pudo relacionar, en líneas generales, el éxito reproductivo con las condiciones de los campos y con la fenología del cultivo, es decir, con la fecha de inicio y duración de la inundación y de la siembra. Así mismo, se realizó el mismo análisis considerando el período reproductor invernal y primaveral de la Garza real, proporcionando información adicional sobre el efecto de la inundación invernal y posterior drenaje de los campos. Con esta información se pueden tomar decisiones en el manejo y gestión del agua del arrozal, de manera que sean cónsonas con los requerimientos biológicos de las especies de garzas nidificantes en L'Albufera y asegurar su reproducción exitosay un estado de conservación favorable de sus poblaciones reproductoras. Por último, este estudio también actualiza la información sobre la reproducción de las garzas en L'Albufera, ya que el último trabajo sobre parámetros reproductivos se realizó hace casi 30 años (Prósper y Hafner, 1996; Prósper, 2000).

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CAPÍTULO 2

Métodos Generales

Anillado de pollos en Mata del Fang,
L'Albufera
Foto: Mariela Forti

Área de estudio

El trabajo se realizó en dos niveles, el primero a escala de la Comunidad Valenciana (capítulo 3) y el segundo en el Parc Natural L'Albufera (capítulo 4 y 5). La Comunidad Valenciana se encuentra ubicada al este de la Península Ibérica (Fig. 1), para la cual se encuentran listados 48 humedales, donde la mayoría (77%) corresponden a albuferas, marjales, litorales y ambientes asociados (Generalitat Valenciana, 2002a). L'Albufera es un humedal costero, ubicado en la vertiente mediterránea de la Comunidad Valenciana, a 12 Km de la ciudad de Valencia (39°20'N, 00°20'W) (Fig. 1).

Primeramente, para evaluar las tendencias poblacionales de las colonias reproductoras objeto de estudio, así como su relación con las características del hábitat que influyen en su establecimiento y desarrollo (capítulo 3), se seleccionaron 11 humedales de los 48 registrados en el Catálogo de Zonas Húmedas de la Comunidad Valenciana (Generalitat Valenciana, 2002a). La selección se realizó en base a la actividad reproductiva, resultando seleccionados aquellos sitios que presentaron actividad, por lo menos, en tres años consecutivos (en el periodo 1984-2015) y con un mínimo de 10 parejas reproductoras. Con estos criterios, los humedales seleccionados fueron: el Parc Natural L'Albufera, Parque Natural Salinas de Santa Pola, Parque Natural El Hondo, Parque Natural Pego-Oliva, Marjal de Almenara, Marjal dels Moros, Marjal de Xeresa-Xeraco, Marjal Hondo de Amorós, Embalse Beniarrés, Embalse La Pedrera y Embalse Embarcaderos. Sus ubicaciones se muestran en la figura 1.

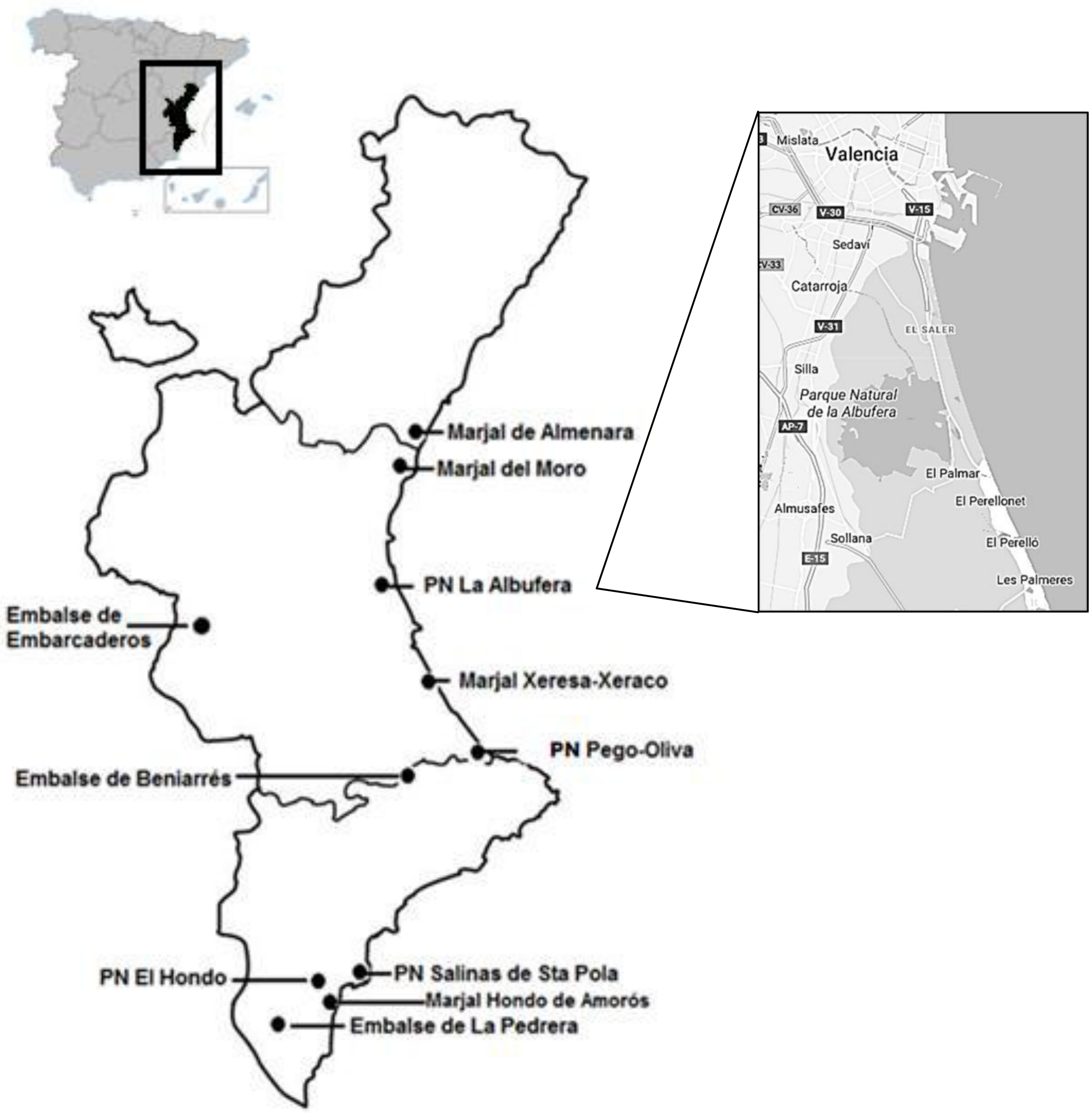

Fig. 1: Ubicación de los humedales dentro de la Comunidad Valenciana y del P.N. L'Albufera.

La segunda parte de este estudio, donde se analizaron los posibles efectos que el manejo en el cultivo del arroz pueda tener sobre el éxito reproductivo de las diferentes especies de garzas consideradas (capítulo 4 y 5), se realizó en el Parc Natural L'Albufera. Este sitio es uno de los humedales más importantes del Mediterráneo occidental y de la Península Ibérica (Generalitat Valenciana, 2002b; WetNet, 2017), por lo que también se ha incluido dentro de los "Humedales de Importancia Internacional" (sitio RAMSAR) desde 1989 y declarado como "Zona Especial para la Protección de Aves" (ZEPA) desde 1991 y "Lugar de Interés Comunitario" (LIC) desde 1992.

El área protegida abarca una superficie total de 21.120 ha, de las cuales 2.837 ha corresponden a la laguna y 14.500 ha a cultivos de arroz alrededor de la misma.La laguna presenta varias islas o formaciones vegetales, llamadas localmente "matas", que ocupan unas 290 ha, las cuales son utilizadas por las garzas y otras aves para establecer sus colonias de nidificación.La vegetación predominante en estas matas es el carrizo común (*Phragmites australis*), la enea (*Thypha domingensis*), la malva de agua (*Kosteletzkia pentacarpos*) y masiega (*Cladium mariscus*), sobre la cual las garzas establecen sus colonias heterospecíficas. Las colonias estudiadas se encontraron en Mata del Fang, la cual es una zona de reserva situada en la vertiente este del lago que presenta una superficie de aproximadamente 30 ha, y en la Replaza de Zacarés, ubicada en la orilla sur del lago y con alrededor de 11 ha de superficie (Fig. 2).

Métodos

Tendencias poblacionales

Utilizando los datos de los censos anuales coordinados por la Sociedad Española de Ornitología (SEO/BirdLife) y la administración regional (Generalitat Valenciana), que abarcan un periodo desde 1984 hasta el 2015, se estimó la tendencia poblacional de las poblaciones reproductoras de las seis especies consideradas, en los 11 humedales seleccionados de la Comunidad Valenciana. Se utilizó el número de parejas nidificantes para calcular la tendencia lineal (r^2) en cada humedal y también considerando toda la Comunidad Valenciana, en el periodo de 32 años (largo plazo), de 16 años (mediano plazo) y en los últimos 8 años (corto plazo).

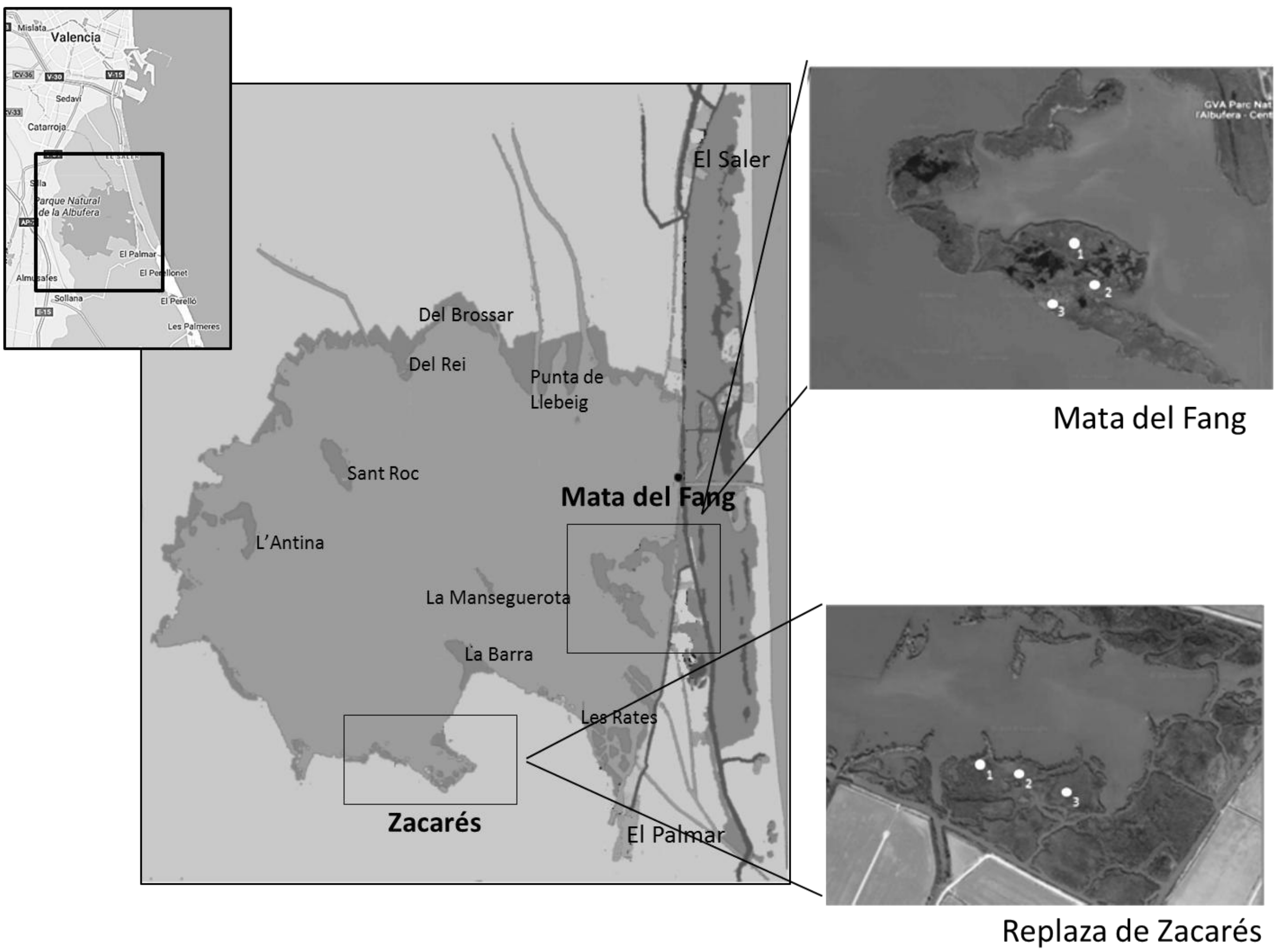

Fig. 2: Ubicación de las colonias de reproducción en Mata del Fang y Replaza de Zacarés, en la laguna de L'Albufera.

Igualmente, se realizó un análisis no paramétrico de Kruskal-Wallis para evaluar si existían diferencias significativas entre las poblaciones de los distintos humedales. Para evaluar si las poblaciones reproductoras de una determinada especie, de los distintos humedales, se relacionaban entre sí, se realizó una correlación de Spearman con corrección de Bonferonni. Estos análisis estadísticos se realizaron utilizando el programa Past3 v3.14 (Hammer et al., 2001). Por otro lado, se determinó el orden de la colonización de los humedales más importantes y los cambios en la composición de las especies, tomando el número de parejas reproductoras de cada una de ellas en dichos humedales, en tres momentos diferentes: al inicio de los censos (1984 para L'Albufera, 1985 para el PN El Hondo y 1988 para el resto), medio periodo (2000) y al finalizar el periodo (2015).

Variables de hábitat

Se realizó una matriz con aquellas variables de hábitat que podrían estar relacionadas con las tendencias poblacionales en cada humedal, resultando una matriz con 42 variables ambientales (ver Tabla 1 en el capítulo 3).

Se incluyó la superficie del marjal o área inundada (con o sin vegetación), ya que este tipo de ambientes están relacionados positivamente con la presencia de colonias de reproducción de garzas (Hafner et al., 1987). Igualmente se consideró la superficie total del área protegida o embalse, así como la distancia del humedal en consideración a L'Albufera y al PN El Hondo, debido a que estas localidades albergan las colonias más numerosas dentro de la región y sus tendencias podrían influir en las poblaciones de los humedales cercanos. Estas variables se estimaron utilizando GoogleEarth® (images from 2016). Por otro lado, se consideró la temperatura promedio mensual previo y durante el periodo reproductivo (marzo-julio) y la precipitación total de los meses previos a dicho periodo (septiembre-abril), ya que estas variables pueden influir en el éxito reproductivo de las colonias (Hafner et al., 1994; Lekuona, 2002). Estos datos se obtuvieron de la Agencia Estatal de Meteorología (AEMET). Por otra parte, debido a que el tipo de hábitat cercano a las colonias de reproducción influye en su tamaño y tendencias poblacionales (Hafner et al., 1987, Fasola et al. 2010, Manikowska-Slepwronska et al., 2016), uso de la tierra en un radio de 5, 10 y 15 km alrededor de las colonias también se incluyó dentro del análisis. El porcentaje de cada categoría de uso de la tierra se calculó utilizando GVSig (versión 2.2.0.2313) a partir de datos obtenidos de CorineLandCover map (2012). Por último, se consideró la categoría de conservación y el tiempo de protección de cada localidad.

La relación de las variables de hábitat con el número de parejas reproductoras en cada humedal, por año, se evaluó utilizando un Análisis de Correspondencia, el cual se corrió en el programaPast3 v3.14 (Hammer et al., 2001).

Parámetros reproductivos

Durante el periodo reproductivo de los años 2015, 2016 y 2017, se visitaron las distintas colonias de nidificación cada 7-10 días, entre los meses de junio y julio en 2015 y 2017, y de mayo a principios de julio en 2016. En el caso del estudio con la Garza real (capítulo 5), las visitas se iniciaron en enero y continuaron hasta principios de abril (2016-2018), ya que su periodo reproductivo abarca también estos meses del año (Prósper, 2000). Los nidos encontrados se marcaron con una cinta numerada y se identificó la especie a la que pertenecía. Se anotó el contenido del mismo en cada visita.

Se definió el tamaño de la puesta como el número máximo de huevos observados en el nido, que no sufrió variaciones en visitas posteriores. Se estimó la fecha de la puesta contando regresivamente los días de incubación a partir de la eclosión de los pichones, considerando 25 días para Garza real (Hankock y Kushlan 1984), 26 días para Garza imperial (Tomlinson 1975), 23 días para Garcilla bueyera y Morito común (Blaker 1969, Del Hoyo et al. 1992) y 22 días para Garceta común y Garcilla cangrejera (Hafner 1980, Sterbetz 1962).

Como tamaño de la nidada se consideraron los pollos exitosos por nido. En el caso de Garza real se consideraron aquellos que superaban los 20 días (Jakubas 2005, Ashoori et al. 2009), mientras que para el resto de las especies se definieron como aquellos que superaban los 15 días (Hafner 1980, Bartolomé et al. 1997, Hafner et al. 2001, Nedjah et al. 2010, Nefla et al. 2014), ya que a partir de este tiempo son nidífugos y se desplazan por las ramas o saltan al suelo, haciendo difícil su observación y siendo imposible identificar el nido al que pertenecen. Si después de transcurrido ese tiempo se encontraba el pollo muerto se registraba como no exitoso.

Con los datos obtenidos se estableció las fechas de inicio de la puesta y los máximos de eclosión. Igualmente se estimó, por nido y para cada especie, el éxito de eclosión (número de huevos eclosionados/número total de huevos), el éxito de nidificación (número de pollos exitosos/número de pollos eclosionados) y éxito de reproducción (número de pollos exitosos/número total de huevos).

Los parámetros reproductivos para cada especie se compararon entre años y entre etapas (antes y después de la inundación, invierno y verano en el caso de la Garza real) utilizando el análisis no paramétrico de Kruskal-Wallis.

Estado del Arrozal

Los cultivos de arroz se recorrieron cada dos semanas, entre febrero de 2016 y junio del 2017. Los puntos de observación se establecieron sobre los caminos que recorren los arrozales, resultando en 26 puntos en 22 km de trayecto por la zona sur y 15 puntos en 9 km por la zona norte, cubriendo un área total de 1.839 ha de campos (Fig. 3). La selección de puntos y recorridos estuvieron condicionadas a las áreas accesibles durante la temporada de caza cuando varios caminos y campos son cerrados al público general. El estado del campo se clasificó en seco (campo totalmente seco, presencia de grietas, arado o no), fangueado/húmedo (campo con tierra húmeda, barro, con pequeños charcos de agua dispersos, trabajado con máquinas o no), semi-inundado (campo con algunas áreas cubiertas de agua, muy somera, pero no cubren la extensión total), inundado (campo con la totalidad de la superficie inundada, semejando una laguna, sin vegetación visible), sembrado (campo con cubierta de agua pero con plantas de arroz, en todos los estadíos) y cosechado (campo con restos de la cosecha, barbecho, quemado o no), con lo que se calculó la proporción de cada una de estas categorías para cada mes. Por otro lado, se registró el número de individuos de cada especie presentes en cada punto de muestreo.

La relación entre la condición del campo y el éxito reproductivo de las distintas especies integrantes de la colonia de L'Albufera, se analizó mediante un Modelo Mixto Lineal Generalizado (GLMM por sus siglas en inglés).

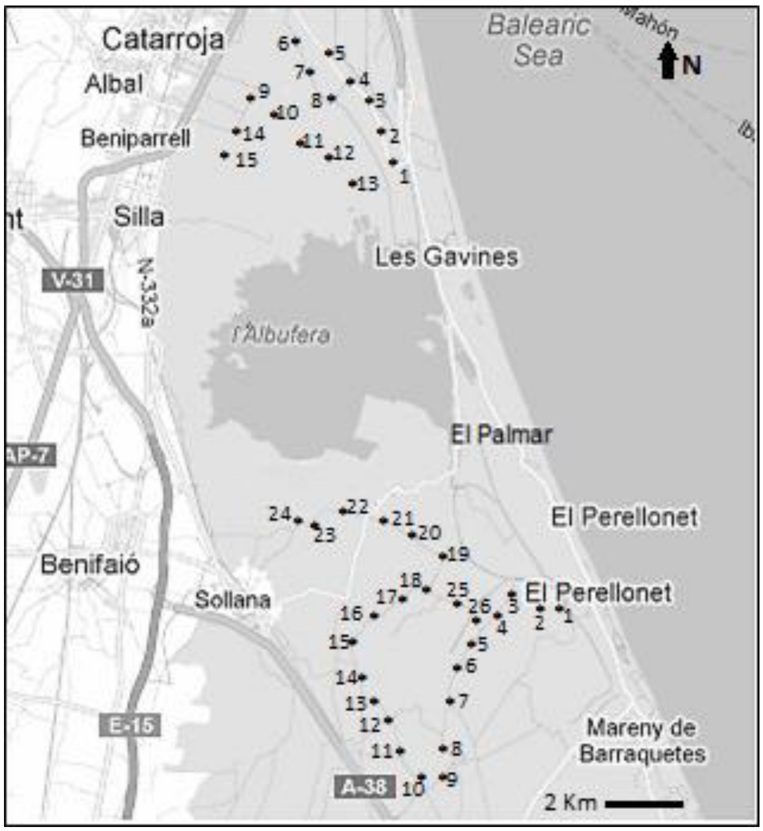

Fig. 3: Ubicación de los puntos de conteo en los cultivos de arroz de L'Albufera.

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CAPÍTULO 3

Habitat and Weather Conditions Effects on Long-Term Breeding Population Dynamics of Five Species of Herons (Ardeidae) and Glossy Ibis (Threskiornithidae) in the Valencian Community, Spain.

Mariela Forti, Juan S. Monrós, and Pablo Vera
Limnetica (2021) 40(2): 417-433

Abstract

Valencian wetlands include 65 % of the region's priority habitats and most are protected areas. Waterfowl populations are used as indicators of the state of these environments. We calculated the linear population trend by species, per wetland, of five Ardeidae and *Plegadis falcinellus* (Threskiornitidae) species using data from the annual census between 1984-2015 for 11 selected wetlands. We constructed a matrix with 42 habitat and meteorological variables, and evaluated the relation between these variables and population trends by a Correspondence Analysis. We found an increasing trend for most species. The populations of the L'Albufera de Vàlencia Natural Park (NP) differed significantly from the rest. *Ardea cinerea*, *E. garzetta*, *B. ibis* and *A. ralloides* would be associated with large areas, and also with swamps and rice fields, while *A. purpurea* and *P. falcinellus* would be related to environments characterized by rainfall and the level of protection in the area. Rice fields and water management have been important for establishing breeding colonies.

Key words: population trends, breeding populations, Ardeidae, Mediterranean wetlands, protected areas, water birds counts, rice fields, heron populations

Introduction

Wetland ecosystems, which provide the population with lots of economic and intangible services, are the most threatened on the planet (Millenium Ecosystem Assessment, 2005; MedWet, 2016). Therefore, initiatives for their conservation are of vital importance (Millenium Ecosystem Assessment, 2005). Water bird trends are considered good indicators of wetlands status (Green & Figuerola, 2003; Gómez-López et al., 2006; Palomino & Molina, 2009). Nevertheless, their effective efficiency depends partly on their scale (Green & Figuerola, 2003). On lower scales, the physical characteristics of wetlands, such as size, form, presence and distribution of emergent vegetation or proximity to other wetlands, influence water bird diversity and abundance (Craig & Beal, 1992; Green & Figuerola, 2003). On a larger scale, landscape heterogeneity is closely related to species richness (Atauri & de Lucio, 2001).

On the Mediterranean coast of the Iberian Peninsula, many lagoons and marshes represent most of the total area of wetlands in this region. Wetlands in the Valencian Community, located east of the Iberian Peninsula, harbour 65% of the existing priority habitats and provide shelter for 50% of the rare, endemic and threatened species of their biota (Ferrer-Polo et al., 2006). These figures place these wetlands among the most valuable in the peninsula (Gómez-López et al., 2006), and most are included in the Natura2000 Network (Red Natura 2000) or the RAMSAR Convention. The majority of these environments are important breeding and wintering sites for waterfowl. The most important for both species richness and abundance are the wetlands of Prat de Cabanes-Torreblanca, L'Albufera de València, Marjal de Pego-Oliva, Salinas de Santa Pola, Lagunas de La Mata-Torrevieja and El Hondo (Martínez-Abrain et al., 2016). Considering only the group of herons, the wetlands in the Valencian Community harbour 9.3% of the winter population and 11.1% of the breeding population in Spain, and respectively occupy fourth and fifth place nationally (Garrido et al., 2012). L'Albufera de València is specifically the third most important site for heron reproduction in Spain (Garrido et al., 2012).

The heron species evaluated in this study are *Egretta garzetta* (Little Egret), *Bubulcus ibis* (Cattle Egret), *Ardeola ralloides* (Squacco Heron), *Ardea cinerea* (Grey Heron), *Ardea purpurea* (Purple Heron), and one Threskiornitidae, *Plegadis falcinellus* (Glossy Ibis). Most of these species appear in some national or international protection or conservation category. Internationally, these species are classified as Least Concern on the IUCN Red List (BirdLife International, 2016), and the Purple Heron and the Glossy Ibis are included in Appendix II of the Bonn Convention (Council Decision 82/461/EEC). Therefore, they are subject to regulations and international cooperation to keep their populations safe. Moreover, in the Birds Directive (Directive 2009/147/EC), five of the studied species, except the Cattle Egret and the Grey Heron, are listed as threatened, vulnerable, rare or require special attention (Appendix I). In the Red Book of the Birds of Spain (Madroño et al., 2004), the Squacco Heron is listed as Near Threatened and the Glossy Ibis as Vulnerable according to IUCN criteria. However, 16 years have passed since the last edition of the Red Book of the Birds of Spain, during which time the populations of some species may present changes; e.g., the Glossy Ibis, whose breeding and wintering populations have remarkably increased

(Santoro et al., 2013, 2016) which will probably change its conservation status in the next edition. The Squacco Heron is listed as Endangered on the National List of Endangered Species (Real Decreto 139/2011) and in the Valencia Catalogue of Endangered Fauna Species (Decreto 32/2004). On the same list, the Purple Heron is catalogued as Vulnerable. However, the overall breeding population of herons has increased from just over 2,500 pairs (in the 1980s) to about 7,000 in 2013 (Generalitat Valenciana, 2013), although their numbers have recently diminished by 43% (Generalitat Valenciana, 2016). Some of these species found in any protection category have significantly increased in the last few decades in Spain, such as Grey Heron, Purple Heron, Squacco Heron and Glossy Ibis (Pérez-Aranda et al., 2003; Figuerola et al., 2003; Garrido et al., 2012; Ramo et al., 2013), and even these last two have reached historic highs in the Valencian Community in 2015 and 2016 (Generalitat Valenciana, 2015; 2016). This increase has been considered a direct consequence of the environmental protection policies carried out in the wetlands of this region in the same time period (Martínez-Abrain et al., 2016).

Our objectives were to evaluate the trends of the breeding populations of the study species in Valencian Community wetlands, and to elucidate which characteristics of this habitat, along with some weather conditions (i.e. temperature and rainfall), contribute or determine the size of these species' reproductive colonies. This information will help to manage both the species and habitats they occupy, which are mostly protected areas.

Methods

Study area

The Valencian Community is located to the east of the Iberian Peninsula (Fig. 1). Thirteen of the 48 sites on the List of Wetlands in this region (Generalitat Valenciana, 2002a) are SPAs (Birds Directive, 2009/147 / CE) included in the Natura 2000 Network. Marshes, lagoons and deltas are the environments with the largest heron colonies, where they nest mostly in marsh vegetation like reeds (*Phragmites* sp.) and bulrushes (*Typha* sp.), and represent 43% of total breeding populations of these species in this region (Garrido et al., 2012). The habitat surrounding these sites consists of either meadows and grasslands or agricultural areas, and extensive rice fields that are key for the foraging of herons and the Glossy Ibis (Hafner et al., 1987, Fasola & Ruiz, 1996, Garrido et al., 2012).

Of the 48 wetlands defined by the List of Wetlands in the Valencian Community, we selected 11 with active breeding for at least 3 consecutive years (during the 1984-2015 period) and with a minimum of 10 pairs (Fig. 1). These wetlands are L'Albufera de Vàlencia Natural Park (LANP), Salinas de Santa Pola Natural Park (SPNP), El Hondo Natural Park (EHNP), Pego-Oliva Natural Park (PONP), Marjal de Almenara (MA), Marjal dels Moros (MM), Marjal de Xeresa-Xeraco (MXX), Marjal Hondo de Amorós (MHA), Beniarrés Dam (EB), La Pedrera Dam (ELP) and Embarcaderos Dam (EE). Currently, 97% of the entire breeding population of the Valencian Community nests in these localities (Generalitat Valenciana, 2015; 2018).

Figure 1. Location of the study wetlands to the east of the Iberian Peninsula. (Marjal de Almenara: MA, Marjal dels Moro: MM, Marjal Xeresa-Xeraco: MXX, Marjal Hondo de Amorós: MHA, L'Abufera de Valencia NP: LANP, Pego-Oliva NP: PONP, Salinas de Santa Pola NP: SPNP, El Hondo NP: EHNP, La Pedrera Dam: ELP, Beniarrés Dam: EB, Embarcaderos Dam: EE).

Population trends

Since 1984, SEO/BirdLife and the Conselleria de Medio Ambiente of the regional government have periodically conducted annual censuses using the same sampling technique. They derive the number of pairs from the number of nests or adults incubating, except in areas with difficult access, where they were estimated from the number of adult reproducers present (Goméz-Lopéz et al., 2006). In this study, we used the number of nesting pairs in the Valencian Community for the 32 years of consecutive censuses (1984-2015) and six species in all: Grey Heron, Purple Heron, Squacco Heron, Cattle Egret, Little Egret (Ardeidae), Glossy Ibis (Threskiornithidae).

The linear trend was calculated per species in each wetland and in the whole of the Valencian Community to observe breeding population trends in the long (32 years of censuses), mid (last 16 years) and short (last 8 years) terms. An autocorrelation analysis was performed on the number of breeding pairs per species in each wetland to verify that there was no spurious relation between population size and time (Santoro et al., 2010). If data were autocorrelated, we assumed that there was no population trend, unless the significance value of the linear trend was $P < 0.01$ (Hatfield et al., 1996; Santoro et al., 2010).

To evaluate whether there was a preference shown by some species for certain wetlands, and if it was significantly more abundant in some than in others, the non-parametric Kruskal-Wallis test was performed (only the data from two localities were normally-distributed). In this way it was possible to identify which wetlands would be the most important for the conservation of each particular species. The Mann-

Whitney post hoc test was used and box plots were generated. To determine if the populations of a given species covaried between different wetlands, the population sizes of each species in each wetland were analysed by a Spearman correlation with Bonferonni correction. We ran the analyses with version 3.14 of the Past3 programme (Hammer et al., 2001).

How species composition changed with time and the order of colonisation in the most important wetlands were also evaluated by taking the number of pairs per species in each one at three different times during the census period: at the beginning (1984 for the LANP, 1985 for EHNP and 1988 for the rest), halfway (2000) and for the last census (2015).

Habitat variables

We created a matrix with 42 habitat variables that could be related to the population trends in each wetland (Table 1). As freshwater wetlands and marshes are positively related to heron colonies (Hafner et al., 1987), the area of the marsh or flooded area (with or without vegetation) was included as a variable. This variable and the total area of the protected wetlands were obtained using GoogleEarth® (images from 2016), as was the distance from the wetland to the most important protected areas (L'Albufera de València and El Hondo). These wetlands house the largest heron populations (Garrido et al., 2012; Generalitat Valenciana 2015; 2018) and trends in these large populations can influence the population trends in the closest wetlands.

Table 1: Variables considered in the Correspondence Analysis between the population sizes of heron species and the habitat characteristics of the different wetlands.

Variable	Description	Abbreviation
Wetland/year	Location /year of census	Ejem: MA88
Total area	Total area of the protected area in hectares	TotalArea
Area of marsh	Surface area in hectares occupied by the water body, including lake vegetation	MarshesArea
Distance to L'Albufera NP	Distance in kilometres from the location in question to the L'Albufera de València Natural Park	Dist.PNA
Distance to El Hondo NP	Distance in kilometres from the location in question to the El Hondo Natural Park	Dist. PNEH
Precipitation	Accumulated rainfall between September and April each year, prior to the reproductive period	PPm
Average temperature	Average temperature between March and July each year (reproductive period)	Temp
Category	The locality's protection category (SPA birds, SCI, Natural Park, none)	Category
Protection	Years of protection	Protection
Percentage of water in 5, 10 and 15 km	Percentage of surface area covered by water (rivers, lagoons, estuaries, sea) within the radii of 5, 10 and 15 km around the colony	Water5Km Water10Km Water15Km
Percentage of marshes in 5, 10 and 15 km	Percentage of surface area covered by marshes within the radii of 5, 10 and 15 km around the colony	Marshes5Km Marshes10Km Marshes15Km
Percentage of salt flats in 5, 10 and 15 km	Percentage of surface area covered by salt flats within the radii of 5, 10 and 15 km around the colony	Sal5Km Sal10Km Sal15Km
Percentage of rice fields in 5, 10 and 15 km	Percentage of surface area covered by rice fields within the radii of 5, 10 and 15 km around the colony	Rice5Km Rice10Km Rice15Km
Percentage of other crops in 5, 10 and 15 km	Percentage of surface area covered by different crop types (permanent irrigation, fruit trees, olive trees, mixed) within the radii of 5, 10 and 15 km around the colony	OtherCrops5Km OtherCrops10Km OtherCrops15Km
Percentage of forest in 5, 10 and 15 km	Percentage of surface area covered by forest type vegetation (coniferous, broadleaf, mixed) within the radii of 5, 10 and 15 km around the colony	Forest5Km Forest10Km Forest15Km

Table 1: Variables considered in the Correspondence Analysis between the population sizes of heron species and the habitat characteristics of the different wetlands (cont.)

Variable	Description	Abbreviation
Percentage of other vegetation in 5, 10 and 15 km	Percentage of surface area covered by low vegetation (bushes, pastures) within the radii of 5, 10 and 15 km around the colony	OtherVeg5Km OtherVeg10Km OtherVeg15Km
Percentage of urbanism/industry in 5, 10 and 15 km	Percentage of surface area covered by buildings (urbanism, industrial and commercial areas) within the radii of 5, 10 and 15 km around the colony	Urb5Km Urb10Km Urb15Km
Percentage of beaches in 5, 10 and 15 km	Percentage of surface area covered by beaches and dunes within the radii of 5, 10 and 15 km around the colony	Beach5Km Beach10Km Beach15Km
Grey Heron population size	Number of breeding pairs of Grey Heron (*A. cinerea*) for each census year	TpAc
Purple Heron population size	Number of breeding pairs of Purple Heron (*A. purpurea*) for each census year	TpAp
Squacco Heron population size	Number of breeding pairs of Squacco Heron (*A. ralloides*) for each census year	TpAr
Cattle Egret population size	Number of breeding pairs of Cattle Egret (*B. ibis*) for each census year	TpBi
Little Egret population size	Number of breeding pairs of Little Egret (*E. garzetta*) for each census year	TpEg
Glossy Ibis population size	Number of breeding pairs of Glossy Ibis (*P. falcinellus*) for each census year	TpPf

Likewise, we considered the average monthly temperatures during reproduction (March-July), and also the total rainfall during the non-breeding season (September-April) because it may affect success in the following breeding season (Hafner et al., 1994; Lekuona, 2002). We obtained these weather data from the AEMET (Meteorology Statal Agency) database, available either on the web (AEMET OpenData) or provided by the agency. The conservation category and protection time of each locality were also considered as environmental protection policies and the protection status of colonies have an effect on population trends (Fasola et al., 2010; Martínez-

Abrain et al. 2016). We also took into account the proportions of land use within radii of 5, 10 and 15 km around nesting colonies, calculated with GVSig (version 2.2.0.2313) from data on the latest available CorineLandCover map (2012). They were chosen because the type habitat surrounding breeding colonies influences their size and population trend, as well as the reproductive and feeding success of herons (Hafner et al., 1987, Fasola et al. 2010, Manikowska-Slepwronska et al., 2016). Distances were selected by bearing in mind that herons feed mostly within a radius of between 5 and 10 km, but some species can move away as far as 15 km from the colony (Hafner et al., 1987; Manikowska-Slepwronska et al., 2019). We were unable to determine the variation in the area occupied by each land use type for the 30-year study period because only the 2012 update of maps was available. Nevertheless, as these environments are stable on the surface, we assumed that the difference in the total area occupied by each land use type over the years was not likely to significantly or substantially modify the results. We evaluated the relation between the habitat characteristic and the annual number of breeding pairs in each wetland with a Correspondence Analysis (CA) which, from a graphical point of view, allows the possible relations between a set of variables to be analysed. In this case, wetlands were compared in each census year (rows) with the selected variables and the population size of each species (columns). This analysis was run with version 3.14 of the Past3 programme (Hammer et al., 2001).

Results

Population trends

All the study species showed a growing trend between 1984 and 2015 (Table 2). For no species was an autocorrelation found between the numbers of nesting pairs in two consecutive years. Indeed, the P of the linear trend was always ≤ 0.01in those cases forwhich the coefficient of autocorrelation was > 0.80. Therefore, we considered that there was no autocorrelation.

Locally, the Purple Heron and Little Egret obtained the lowest r2 values that were, however, significant in the long term (Table 2). For wetlands, all the species in all the localities showed significant positive trends, except for the Purple Heron, which showed a negative trend in SPNP, EHNP and LANP, which was significant only in LANP (Table 2). The Little Egret presented no significant trend in EHNP or SPNP, nor did the Cattle Egret in LANP or MHA (Table 2). When considering the 16- and 8-year periods, throughout the Valencia Community only the Squacco Heron and Glossy Ibis continued to show a significant positive trend (Table 2). By analysing trends for wetlands, in the EHNP all species showed a significant trend in the mid and short terms, except for the Purple Heron (Table 2). The Grey Heron, Cattle Egret, Little Egret and Glossy Ibis showed a significant positive trend for both periods in MM, while the Squacco Heron and Little Egret did so in MXX (Table 2). In LANP, only the Glossy Ibis displayed positive trends in both the mid and short terms, whereas the Cattle Egret showed a significant negative trend during both periods, and the Grey Heron presented a negative trend during the 16-year period (Table 2).

Table 2: Trends of the breeding populations of all the species in the studied wetlands in the long (32 years), mid (16 years) and short (8 years) terms, including slope (b), coefficient of determination (r2) and the P values. (MM: Marjal dels Moro, MA: Marjal de Almenara, MXX: Marjal Xeresa-Xeraco, MHA: Marjal Hondo de Amorós, LANP: L'Albufera de Valencia Natural Park, PONP: Pego-Oliva Natural Park, SPNP: Salinas de Santa Pola Natural Park, EHNP: El Hondo Natural Park, EE: Embarcaderos Dam, EB: Beniarrés Dam, ELP: La Pedrera Dam).

Wetland	Years	Heron Species																	
		Grey Heron			Purple Heron			Squacco Heron			Cattle Egret			Little Egret			Glossy Ibis		
		b	r^2	*P*	b	r^2	*P*	b	r^2	*P*	b	r^2	*P*	b	r^2	*P*	b	r^2	*P*
MM	32	3.67	0.64	< 0.01	0.33	0.46	< 0.01				1.02	0.24	0.02	0.72	0.27	0.01	1.5	0.35	< 0.01
	16	12.29	0.89	< 0.01	0.14	0.04	0.43				7.25	0.50	0.03	4.15	0.51	< 0.01	9.08	0.58	0.01
	8	17.01	0.91	< 0.01	0,07	0.003	0.88				11.25	0.60	0.04	7.68	0.66	< 0.01	16.57	0.69	0.04
MA	32				0.44	0.45	< 0.01	0.56	0.53	< 0.01	0.88	0.35	< 0.01	1.77	0.53	<0.01			
	16				0.54	0.17	0.14	1.22	0.29	0.08	3.11	0.41	0.03	6.22	0.55	0.01			
	8				-0.78	0.10	0.44	0.26	0.009	0.82	4.14	0.33	0.14	6.96	0.35	0.16			
MXX	32	0.31	0.40	< 0.01	0.76	0.58	< 0.01	0.68	0.51	< 0.01	0.72	0.59	< 0.01	0.99	0.50	< 0.01	0.22	0.27	0.02
	16	0.09	0.01	0.68	0.76	0.44	< 0.01	1.90	0.66	< 0.01	1.86	0.60	< 0.01	3.54	0.70	< 0.01	1.42	0.47	0.04
	8	-1.38	0.42	0.08	1.20	0.34	0.13	3.62	0.70	0.01	1.36	0.17	0.31	5.24	0.67	0.01	2.71	0.58	0.08
MHA	8										56.79	0.31	0.19				5.86	0.31	0.25
LANP	32	13.24	0.29	< 0.01	-0.85	0.14	0.03	11.63	0.61	< 0.01	15.32	0.03	0.38	20.55	0.14	0.04	4.00	0.55	< 0.01
	16	-22.76	0.26	0.04	-0.77	0.06	0.37	11.92	0.21	0.07	-137.59	0.54	< 0.01	-23.18	0.08	0.29	21.77	0.85	< 0.01
	8	-36.21	0.27	0.19	5.81	0.82	< 0.01	46.06	0.49	0.05	-310.58	0.70	0.01	-37.11	0.08	0.51	34.43	0.98	< 0.01
PONP	32	0.57	0.29	< 0.01	0.73	0.21	0.01	0.59	0.76	< 0.01	0.72	0.49	< 0.01	2.71	0.53	< 0.01			
	16	0.10	0.002	0.84	-0.67	0.06	0.35	0.89	0.61	< 0.01	1.63	0.20	0.20	8.42	0.49	0.02			
	8	-2.63	0.32	0.14	-3.12	0.27	0.18	0.13	0.007	0.85	0.46	0.01	0.80	7.40	0.22	0.24			
SPNP	32	1.11	0.32	< 0.01	-0.38	0.11	0.11	1.70	0.41	< 0.01	49.85	0.36	< 0.01	-0.76	0.01	0.71	1.33	0.46	< 0.01
	16	-0.66	0.02	0.69	-1.75	0.33	0.05	0.36	0.004	0.85	-52.00	0.09	0.33	-0.61	0.008	0.76	1.48	0.10	0.30
	8	-7.25	0.56	0.05	-0.07	0.007	0.84	-4.06	0.15	0.34	-193.87	0.32	0.14	-5.54	0.31	0.19	-3.23	0.15	0.34
EHNP	32	0.64	0.18	0.06	-0.43	0.12	0.07	3.48	0.54	< 0.01	37.98	0.24	0.02	2.74	0.05	0.33	1.78	0.30	0.01
	16	7.75	0.53	0.06	-0.99	0.10	0.28	19.5	0.63	0.02	328.81	0.48	0.06	55.94	0.70	0.01	14.38	0.60	0.02
	8	7.75	0.53	< 0.01	1.76	0.30	0.16	24.36	0.69	0.02	500	0.74	0.01	69.64	0.77	0.01	17.75	0.64	0.03
EE	8	1.39	0.70	0.01															
EB	32	0.91	0.96	< 0.01															
	16	1.5	0.75	0.33															
	8	1.5	0.75	0.67															
ELP	32							0.31	0.60	< 0.01	3.19	0.66	< 0.01						
	16							-0.14	0.005	0.87	17.79	0.48	0.08						
	8							-1.4	0.56	0.08	10.91	0.28	0.28						
Valencia Region	32	18.53	0.48	< 0.01	1.03	0.13	0.04	17.39	0.73	< 0.01	102.33	0.55	0.01	26.48	0.23	< 0.01	83.42	0.44	< 0.01
	16	-9.90	0.06	0.36	-0.68	0.02	0.62	26.94	0.54	< 0.01	39.10	0.04	0.46	9.8	0.02	0.63	22.35	0.66	< 0.01
	8	-16.62	0.07	0.51	5.39	0.44	0.07	69.46	0.70	0.01	-4.75	0.0004	0.96	48.21	0.16	0.33	53.68	0.87	< 0.01

Fluctuations in species composition

During the 30-year census, species richness and abundance has varied in each wetland. At the beginning of the census, breeding colonies were recorded only in LANP, EHNP and SPNP (Fig. 2). In 1984, LANP had colonies of Cattle Egret (most abundant), Little Egret, and Purple Heron (least abundant). Although the Grey heron has nested in the park since 1984, the few pairs (13) are not visible in the graph (Fig. 2). For this initial period, pairs of Purple Heron, Little Egret, Grey Heron, and one pair of Cattle Egret, were recorded in EHNP, and 10 pairs of Purple Heron were present in SPNP (Fig. 2).

Halfway through the period (2000), the Purple Heron had the most breeding pairs in MM, MXX and PONP, and a few Grey Heron pairs also settled in MM and PONP (Fig. 2). In EHNP, Cattle Egret was one of the most abundant species (as in SPNP and LANP), followed by the Purple Heron, Little Egret and Squacco Heron (Fig. 2).

In the last census (2015), all the species were present in all the monitored wetlands, except for the Squacco Heron, which was missing in MM, as was the Glossy Ibis in PONP (Fig. 2). The Little Egret was the dominant species in LANP, PONP an MXX, while it was the Grey heron in MM. The Cattle egret remained the most abundant breeding species in SPNP and EHNP (nearby localities; Fig. 2). The Cattle egret population diminished in LANP and became the third most abundant species after the Squacco Heron (Fig. 2). The Glossy Ibis has colonised the studied wetlands only recently and its biggest breeding population was found in LANP in 2015.

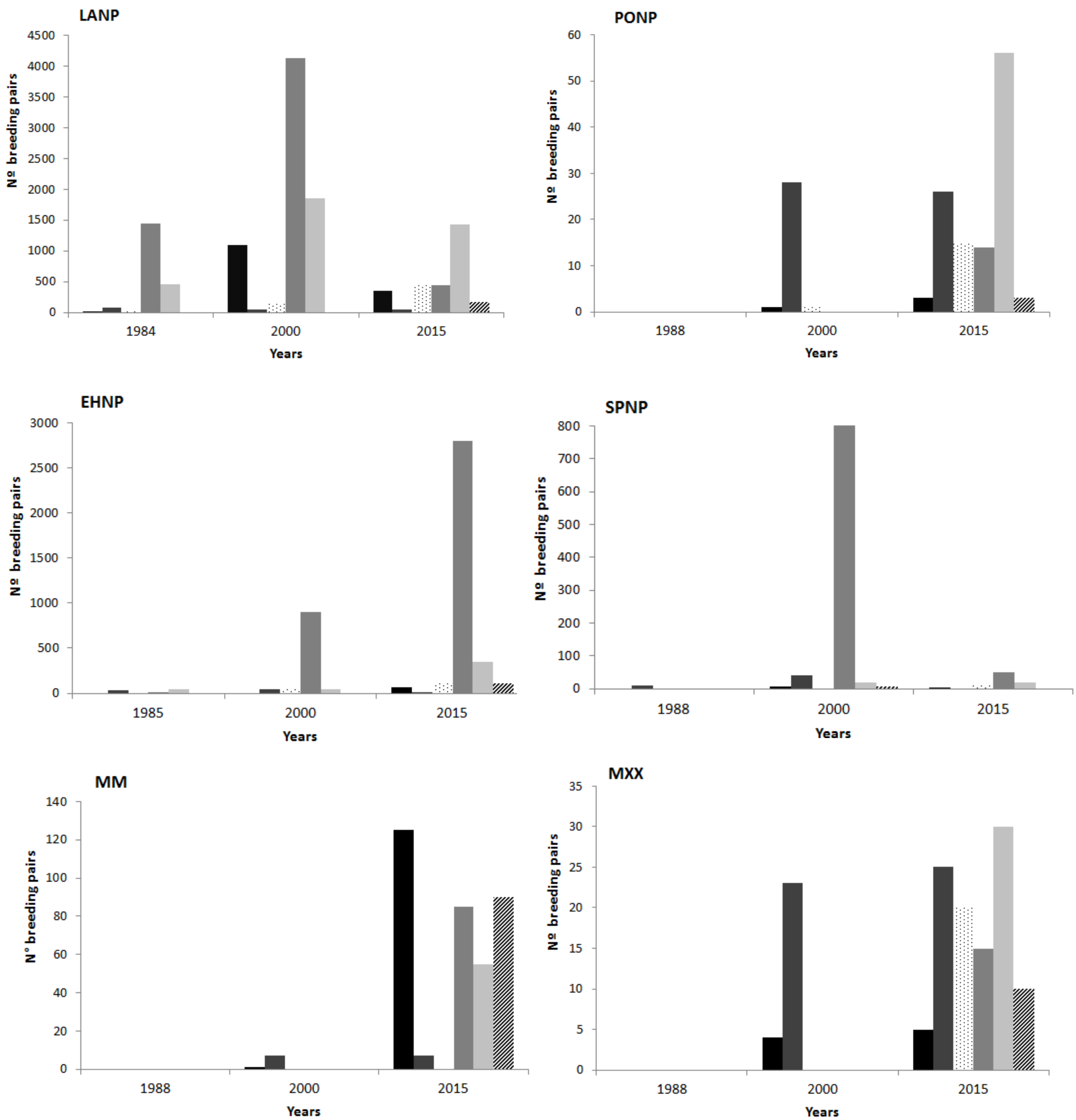

Figure 2. Number of breeding pairs per species at three different times during the 1984-2015 period for six wetlands in the study area (■ Grey Heron ■ Cattle Egret ■ Purple Heron ■ Little Egret ▒ Squacco Heron ▨ Glossy Ibis).

Relations among populations

The breeding populations of all the species present in LANP were significantly larger than the nesting populations of the same species in the other wetlands, except for the Glossy Ibis (Fig. 3), which indicates that it is the most important breeding colony of all those studied. For the Grey Heron, only the LANP population was significantly larger than in any other wetland. Otherwise, the EHNP and SPNP colonies were the second most important ones.

The number of breeding pairs of Squacco Heron, Cattle Egret and Little Egret in these wetlands were significantly higher than for the other marshes, but their abundances did not differ from one another (Fig. 3). The Purple Heron showed significant differences among several populations (Fig. 3).

The breeding populations of the Squacco Heron and Grey Heron in the different localities correlated positively and significantly in most cases (Table 3). The breeding populations of the Cattle Egret and Little Egret in LANP showed no relation with any of these populations in other localities, while the other species correlated with the populations of MM, MXX, PONP and SPNP to a greater or lesser extent. The Purple Heron correlated negatively with the MM population (Table 3). All the nesting species in MXX correlated significantly with the species of PONP, except for the Purple Heron and Glossy ibis. Likewise, the population sizes of all the species present in MA significantly correlated with those of PONP and MXX (Table 3).

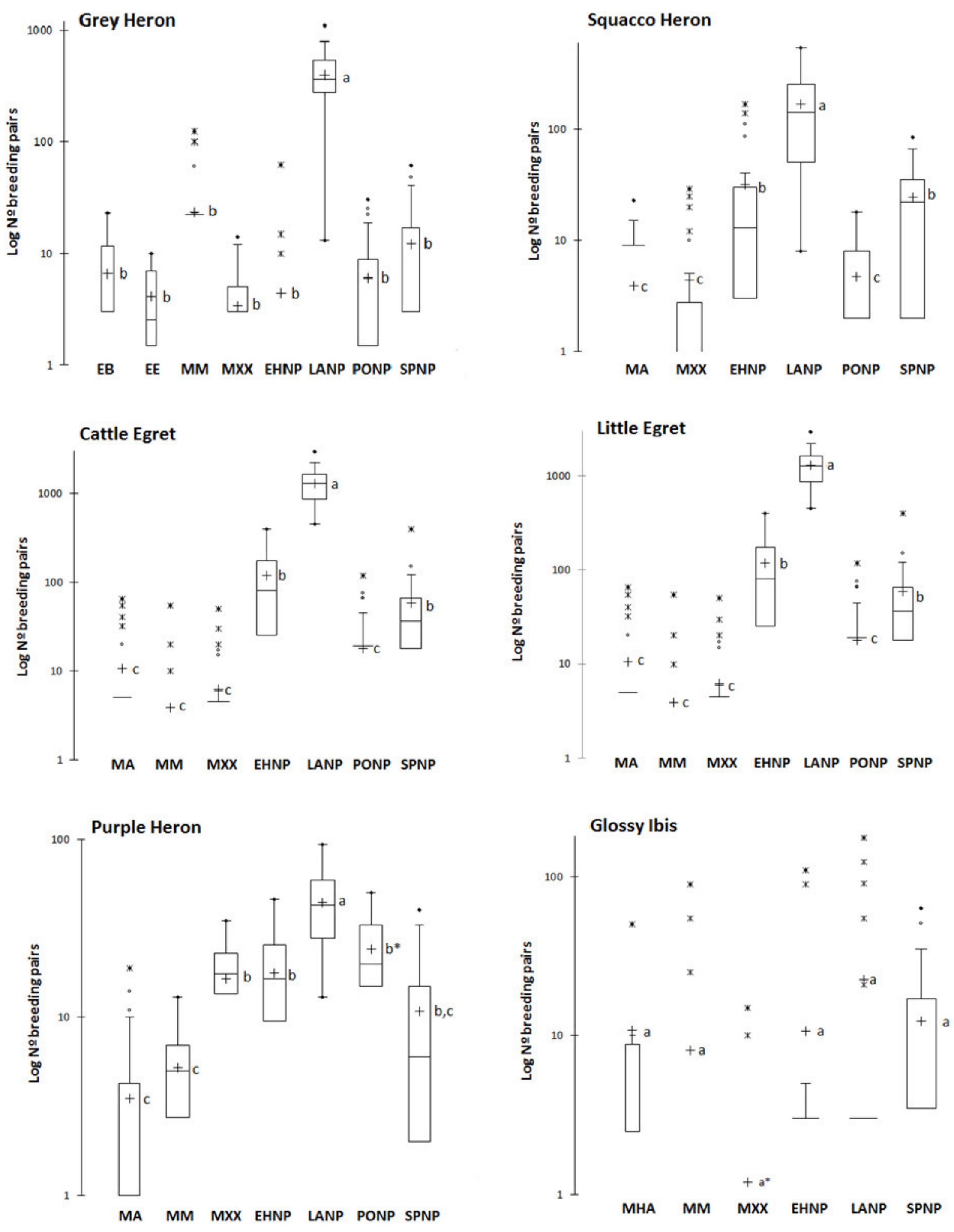

Figure 3. Nesting pairs per species between 1984 and 2015 in each studied wetland (+ mean, ⬥ minimum/maximum, —— median, ⊤ standard deviation, ○ atypical values ∗ extreme values. Same word: no significant differences, different word: significant differences. a* b* onlysignificantly differs from SPNP).

Table 3: Statistic and p values of the Correlation Analysis between the populations of each heron species in the different studied wetlands.

Grey Heron

St\p	PONP	MXX	EB	SPNP	EHNP	LANP	MM	EE
PONP		<0.0001	0	<0.001	0.07	<0.01	<0.0001	1
MXX	0.86		0	<0.001	0.19	<0.001	<0.01	1
EB	0	0		0	1	0.12	0	1
SPNP	0.83	0.78	0		1	0.28	<0.01	1
EHNP	0.64	0.58	0.11	0.37		0.25	0.04	1
LANP	0.64	0.74	0.78	0.54	0.57		0.05	1
MM	0.88	0.73	0	0.73	0.66	0.60		1
EE	0	0	0.86	0	0.25	0.69	0	

Purple Heron

St\p	MM	MXX	PONP	SPNP	MA	EHNP	LANP
MM		0.27	1	1	0.05	1	0.04
MXX	0.46		0.18	1	0.03	1	0.78
PONP	0.19	0.49		1	<0.0001	1	1
SPNP	-0.07	-0.27	-0.22		1	1	1
MA	0.59	0.62	0.86	-0.39		1	1
EHNP	-0.15	-0.30	-0.13	0.15	-0.18		1
LANP	-0.56	-0.40	-0.07	-0.20	-0.21	-0.28	

Cattle Egret

St\p	MM	MXX	PONP	SPNP	MA	EHNP	LANP	ELP	MHA
MM		0.06	0.24	1	0.77	0.16	1	0	1
MXX	0.63		<0.0001	1	<0.0001	1	0.49	1	1
PONP	0.56	0.94		1	<0.0001	1	0.16	1	1
SPNP	0.07	0.37	0.38		0.04	1	0.05	0.07	1
MA	0.50	0.85	0.86	0.66		1	0.16	0.87	1
EHNP	0.58	0.09	0.05	0.05	0.14		1	1	1
LANP	0.25	0.49	0.57	0.63	0.60	-0.03		0.87	1
ELP	0	0.50	0.50	0.70	0.54	0.19	0.54		1
MHA	0	0	0	0.67	0	0.67	-0.52	0	

Little Egret

St\p	MM	MXX	PONP	SPNP	MA	EHNP	LANP
MM		<0.01	0.03	1	1	1	1
MXX	0.72		<0.0001	1	<0.0001	1	0.54
PONP	0.64	0.91		1	<0.0001	1	0.38
SPNP	0.11	-0.04	0.06		1	1	1
MA	0.29	0.97	0.86	0.13		0.35	1
EHNP	0.42	0.06	-0.01	0.09	-0.53		1
LANP	0.32	0.45	0.49	0.26	0.16	0.26	

Squacco Heron

St\p	PONP	MXX	MA	SPONP	EHNP	LANP	ELP
PONP		<0.0001	<0.0001	1	<0.001	<0.01	0.35
MXX	0.91		<0.0001	1	<0.001	0.02	1
MA	0.91	0.97		0.04	0.02	0.12	1
SPONP	0.38	0.33	0.64		1	<0.01	0.3
EHNP	0.75	0.76	0.67	0.03		1	1
LANP	0.69	0.62	0.58	0.68	0.38		1
ELP	0.57	0.43	0.43	0.58	0.17	0.37	

Glossy Ibis

St\p	MM	MXX	MHA	SPNP	EHNP	LANP
MM		<0.0001	1	0.03	0.04	<0.01
MXX	0.79		1	0.21	0.57	0.09
MHA	0.00	0		1	1	1
SPNP	0.63	0.53	0		<0.01	<0.01
EHNP	0.64	0.47	0	0.77		0.06
LANP	0.69	0.58	0.42	0.69	0.62	

Habitat variables

In the CA, 82.14% of total variance was explained on the first three axes (67.18% on the first two). On the first axis (42.24%), the variables with a greater weight in positive absolute values (> 1) were Distance to the L'Albufera NP (DistLA), Precipitation (PP), Temperature (Temp), Protection category, Protection, Marshes, Other Vegetation, Other Crops, Beaches and Urbanism. Towards the negative side of the axis, the variables with the greatest weight were Water 10 km and Rice 15 km.

However, Total area, Rice 5 km and Water 10 km (the other negative values on the axis) contributed to pull the population size variables of the Grey Heron, Little Egret, Squacco Heron and Cattle Egret towards this sector (Fig. 4).

The LANP and EE wetlands were also located slightly towards the negative side of the axis, which were the two wetlands with the largest (total) area of those herein considered (Fig. 4). The population sizes of the Purple Heron and Glossy Ibis were associated with the variables located in the positive sector of axis 1, like marshes (MA, MM, MXX, MHA) and PONP (Fig. 4). The dispersion of points was basically due to the difference in rainfall in several years, and it was one of the variables with a greater weight (positive absolute value) on this axis. Marshes, mainly MM, MXX, MA and PONP, were apparently associated with the presence of Other Crops (not rice), Other Vegetation (non-forest), Urbanism, Marshes and Beaches (Fig. 4).

For axis 2, of the variables with a greater negative weight, which seemed to characterise environments, we found Saltpans and Marshes, which led SPNP and EHNP to be located towards this sector of the axis (Fig. 4).

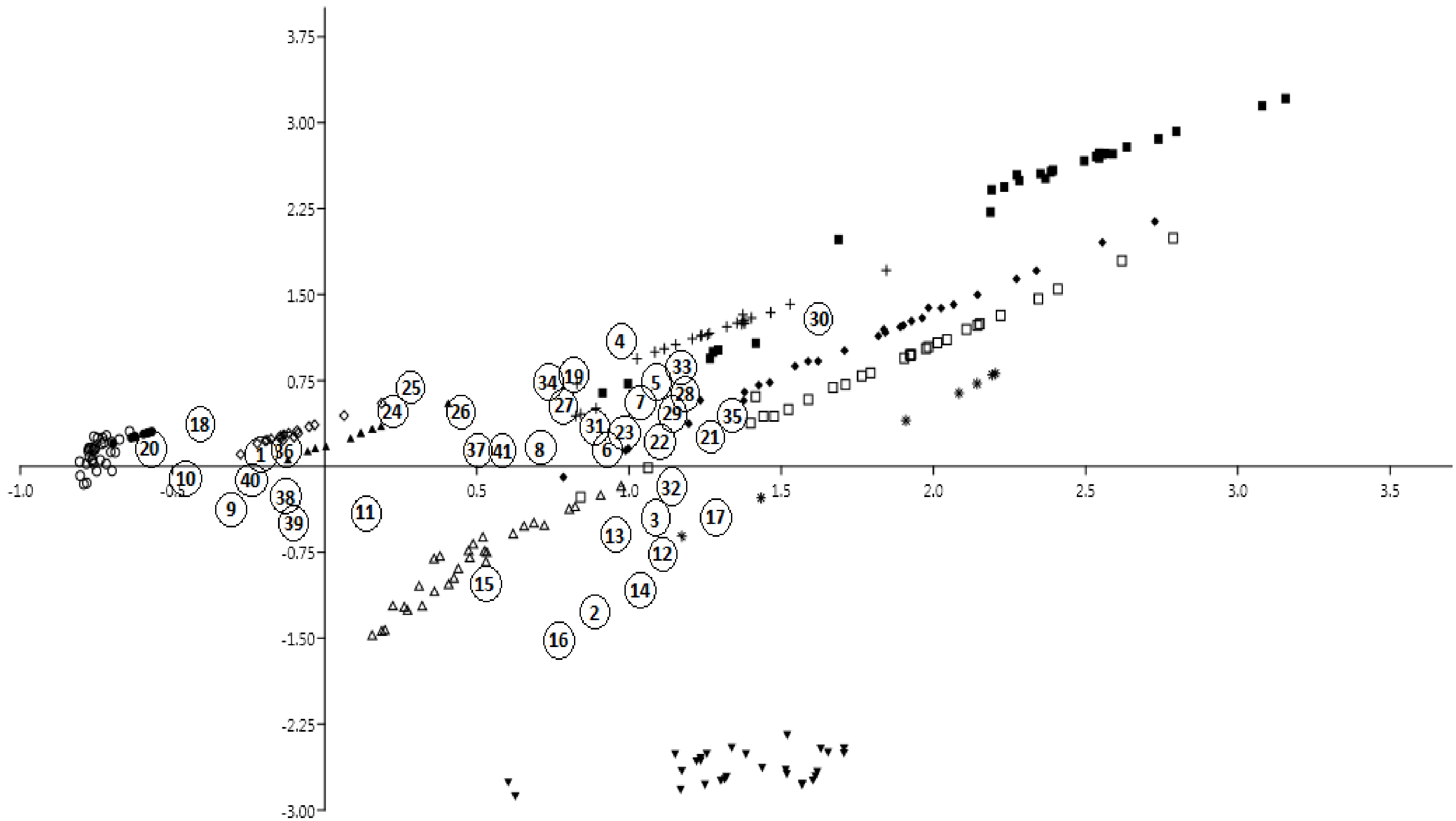

Figure 4. Correspondence analysis showing the relations between the studied wetlands and variables. Wetlands: ■ MM □ MXX + MA ✱ MHA ◆ PONP ○ LANP △ SPNP ▼ EHNP ● EE ▲ EB ◇ ELP / Variables: 1 TotalArea, 2 MarshesArea, 3 Dist.PNA, 4 Dist. PNEH, 5 PPm, 6 Temp, 7 Category, 8 Protection, 9 Water5Km, 10 Water10Km, 11 Water15Km, 12 Marshes5Km, 13 Marshes10Km, 14 Marshes15Km, 15 Sal5Km, 16 Sal10Km, 17 Sal15Km, 18 Rice5Km, 19 Rice10Km, 20 Rice15Km, 21 OtherCrops5Km, 22 OtherCrops10Km, 23 OtherCrops15Km, 24 Forest5Km, 25 Forest10Km, 26 Forest15Km, 27 OtherVeg5Km, 28 OtherVeg10Km, 29 OtherVeg15Km, 30 Urb5Km, 31 Urb10Km, 32 Urb15Km, 33 Beach5Km, 34 Beach10Km, 35 Beach15Km, 36 TpAc, 37 TpAp, 38 TpAr, 39 TpBi, 40 TpEg, 41 TpPf.

Discussion

The results of this study confirm that the reproductive populations of the six considered species have increased in the last three decades. However, this increase appears to have stopped in the last half of the period, except for the Squacco Heron and Glossy Ibis. Moreover, the Grey Heron, Cattle Egret, Little Egret and Squacco Heron species seem to be associated with the environments characterised by having a bigger area, nearby freshwater bodies and the presence of rice fields. The Purple Heron and Glossy Ibis species would be associated with environments influenced mostly by rainfall and with some form of protection. Of all these variables, management of water bodies and rice fields, and administration of protected areas, would be those to consider when devising conservation plans for these species.

Between 1984 and 2014, 80% of the reproductive water bird species in the Valencian Community, such as ducks, grebes and seagulls, have increased, of which 21% are herons (Martinez–Abraín et al., 2016; Garrido et al., 2012). All our heron species have displayed an increasing breeding population trend in the last 30 years, which has also been observed in Doñana (SW Spain) over the 1984-2010 period (Ramo et al., 2013) The populations of these species have increased in western Mediterranean wetlands since the 1970s (Galewski et al., 2011). The breeding populations of the Purple Heron, Grey Heron, Cattle Egret and Little Egret have displayed a significant positive trend, but not in the last 16 and 8 study years. Garrido et al. (2012) mentioned that in the Valencian Community, the Little Egret population seems to have stabilised in the last 10 years prior to their study (between 2000 and 2010) following a growth phase in the 1990s.

A coherent trend has also been observed in the populations of the Grey Heron and Little Egret in NW Italy (Fasola et al., 2010). Martinez-Abraín et al. (2016) found that the population trends of the Cattle Egret and Little Egret in the Valencian Community fit the logistic growth curve, which would be consistent with the fact that they have stopped showing a positive trend in the last 16 years. According to the same author, this would suggest that these species have recovered after the critical situation they were in at the beginning of the study, which was caused by the poor conditions of wetlands, and would have reached their carrying capacity. Their work also mentions that the Squacco Heron and Glossy Ibis are going through an exponential growth phase as they are the most recent colonisation (Martinez-Abraín et al., 2016). This would coincide with the fact that these species displayed significant increasing trends in all the considered wetlands throughout our study period. In 2016, both species had more than 700 pairs distributed in eight different localities, which denotes their extended local distribution (Generalitat Valenciana, 2016).

Although the Cattle Egret has maintained a significant growing trend in the Valencian Community, when considering the whole period, it has displayed a decreasing trend in recent years in LANP. However, it has increased in other wetlands, especially in EHNP, which compensates local declines thanks to their increasing numbers in nearby areas (Garrido et al., 2012).

The breeding populations of all the studied species in LANP were significantly more numerous than those in the other wetlands, and were the first colonies to be established in the region, which confirms the importance of this wetland for the reproduction of this species group. The Purple Heron was the first species to colonise the wetlands closest to LANP from the 1990s to a decade later, when other species began to arrive. The colony being established could be conditioned by the state of vegetation, which would offer adequate coverage and density (Santoro et al., 2010), along with the presence of a small population to attract other individuals of the same species or of others (Pechuan, 1971; Prósper, 2000; Delord et al., 2003; Santoro et al., 2010). The last in this group of wetlands to be colonised was MM. In the wetlands of MXX and PONP, which are close to one another, the Purple Heron is the second most abundant species. Therefore, these protected areas play an important role in this species' conservation, considered to be Vulnerable in the Valencia Catalogue of Endangered Fauna Species.

Between 2006 and 2016, the most numerous nesting populations in LANP have dropped by 43% due to the declining number of pairs of the Grey Heron, Little Egret and Cattle Egret (Generalitat Valenciana, 2016). However, populations have considerably increased in EHNP and, together with SPNP, could be concentrating part of the breeding population of the Cattle Egret and Little Egret of LANP. (Generalitat Valenciana, 2016). The number of both the Cattle Egret nests and Little Egret colonies is positively associated with the area occupied by rice fields (Tourenq et al., 2000), and they depend on water conditions and variations in water quality (Hafner et al., 1987; Bartolomé et al., 1997; Garrido et al., 2012). Therefore, the decline in the Cattle

Egret and Little Egret populations in LANP could be indicative of a deterioration in rice field conditions as this variable characterizes this wetland. In contrast, both species are present in larger numbers in EHNP, which may be a response to better water management (Generalitat Valenciana, 2016). The EHNP from 2011-2012 made improvements to the hydraulic infrastructure and changes in water management, which have favored the increased quantity and quality of the water bodies in the park (Generalitat Valenciana, 2012). These species have benefited from this management as they find more water resources (marshes, ponds, irrigation canals), where they can further use as feeding areas. These water bodies have been shown an important association with size of colonies and these species' reproductive success (Hafner et al. 1987, Bartolome et al., 1997, Parejo et al., 2001, Garrido et al., 2012).

Most wetlands are characterised by the presence or proximity of other types of crops, shrub and grassland type vegetation (non-forests), urbanism and industry, marshes and beaches, especially coastal wetlands like MM, MXX, MA and PONP. Rainfall seems to considerably influence the environment of marshes as this variable causes different flood conditions, which would determine the availability of feeding areas in different years (Bancroft et al., 1988; Hafner et al., 1994). Colony size and reproductive success are positively related to the freshwater habitat area, which constitutes their feeding habitat and this, in turn, is affected by rainfall (Hafner et al., 1987; Hafner et al., 1994; Bennets et al., 2000; Ramo et al., 2013). Spring rains would potentially have a stronger effect on these natural wetlands than on artificial ones (rice fields) like LANP (Sánchez-Guzmán et al., 2007; Fasola et al., 2010).

Four of the studied species (Grey Heron, Little Egret, Cattle Egret, Squacco Heron) were associated with the presence of rice fields and freshwater bodies, and with the total site area. This species may prefer similar environments to nests, where these three variables are the most important. Of these, the Grey Heron seems to be more associated with rice fields than the other three species, whereas the remaining three appear to be slightly more associated with permanent marshes (Hafner et al., 1987). Rice fields are an important source of food for many waterfowl species, including herons and ibises (Fasola & Ruiz, 1996; Prósper& Hafner, 1996; Generalitat Valenciana, 2002b; Toral et al., 2012), especially during the reproductive period when paddies relate positively to the size of breeding colonies (Hafner et al., 1987; Lekuona 2002). LANP, in addition to rice fields, is also characterised as the most extensive total area of the considered wetlands. This would explain why LANP is the site with the most breeding pairs (Pérez-Aranda et al., 2003; Garrido et al., 2012; Generalitat Valenciana, 2013). However, certain factors like reducing the flooding period or winter drainage intensification for soil preparation can negatively affect these species' populations (Prósper& Hafner, 1996; Ibañez et al., 2010).

The Purple Heron and Glossy Ibis are more associated with marshes, which are, in turn, associated with rainfall (Toral et al., 2012). These species seem to have a closer relation with protecting nesting areas. This relation is particularly important for the endangered Purple Heron, which has been able to recover only in recent years. In NW Italy, the protection status of breeding colonies was significantly related to population trends, as were feeding habitats (Fasola et al., 2010). In our case, some species had permanently established in some wetlands 2-4 years after being declared protected areas.

The increase in heron populations, including threatened or vulnerable species, highlights the importance and effectiveness of conservation initiatives and protection policies, which are more critical locally during the reproductive season (Generalitat Valenciana, 2013; Martinez-Abraín et al., 2016).

Reproductive success is typically higher in the colonies surrounded by rice fields and freshwater marshes (Hafner et al., 1987; Delord et al., 2003). Therefore, how paddies are managed will be a determining factor to maintain positive environmental externalities, such as the feeding, nesting and productivity of different bird species, including herons (Picazo-Tadeo et al., 2009). This is especially true for LANP, whose production is adapting to more competitive markets and an increasingly strong pressure on water resources distribution (Picazo-Tadeo et al., 2009). We also highlight the importance of conserving the wetland network (Red Natura 2000) with management plans that incorporate measures for these nesting bird populations. Water management is a major aspect to consider in any management plan for these areas. Maintaining sufficiently flooded areas, which may be either artificial like rice fields or reservoirs, or natural like ponds and marshes, in breeding colonies' area of influence is vital for their conservation. The management plans of these protected areas should be reviewed to evaluate this aspect, and to invest, if necessary, in infrastructure and research to ensure good water resources management. These populations should always be considered a priority within the regional framework, and continuing with the typical metapopulations and source-sink dynamics processes that might occur must be ensured.

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CAPÍTULO 4

Effects of Rice Field Phenology on Breeding Parameters of Heron Colonies in the East of the Iberian Peninsula

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Abstract

Rice fields have traditionally been considered key feeding grounds for many waterbird species, including herons. Studies show that field management and flooding cycles influence the reproductive parameters of these birds. L'Albufera de València on the east coast of the Iberian Peninsula, has large areas of rice fields and is home to the third largest breeding colony of herons in Spain. Changes in water and rice field management that have occurred since the colony was last assessed (1990) may have affected the colony's reproductive performance. Clutch, brood size and hatching, nesting and breeding success were estimated for Grey Heron *Ardea cinerea*, Purple Heron *Ardea purpurea*, Cattle Egret *Bubulcus ibis*, Little Egret *Egretta garzetta*, Squacco Heron *Ardeola ralloides* (Ardeidae) and Glossy Ibis *Plegadis falcinellus* (Threskiornithidae), in 2015-2017. The extent of flooding and cultivation of the rice fields was assessed from February 2016 to June 2017. Reproductive parameters were related to the state of the rice fields. All reproductive output parameters were lower than those reported in the literature. In 2016, laying started earlier (at the end of April), when the fields were still dry and hatching started from May, after flooding. In 2017, peak hatching occurred in June, when the fields were sown. A significant relationship was found between breeding success and the area of sown fields, except for the Squacco Heron. We found that birds that initiated egg laying closer to the date of flooding had a relatively higher breeding success for the Little Egret, Glossy Ibis, Cattle Egret and Purple Heron. The success of nesting populations in this type of artificial wetland requires water management plans that synchronize flooding

regimes and maintenance of flooded areas with the biological requirements of these species.

Key words: Ardeidae, breeding parameters, Mediterranean wetlands, rice fields, reproductive population, heron colonies, artificial wetlands

Introduction

Wetlands are ecosystems that provide important of services to the human population, both economic and ecological, but during the last century many wetlands have been transformed for cultivation (Zedler & Kercher 2005). Therefore, wetlands have been a focus of conservation initiatives as they are considered to be one of the most threatened ecosystems on the planet (Millennium Ecosystem Assessment 2005, MedWet 2016). In many countries natural wetlands have largely been replaced by rice paddies (Shine & Klemm 1999, Czech & Parsons 2002), these are considered to be artificial wetlands (Elphick 2000). Rice fields have traditionally been viewed as key feeding sites for many waterbird species (Fasola & Ruiz 1996, Czech & Parsons 2002, Kloskowsky et al. 2009), with obvious conservation implications (Sánchez-Guzmán et al. 2007, Toral & Figuerola 2010, Katayama et al. 2014, Sebastián-González & Green 2015, Sesser et al. 2016, Cardarelli et al. 2017). Herons and egrets (Ardeidae) are one of the groups of waterfowl that have established a stronger link with these artificial habitats (Hafner et al. 1987, Fasola et al. 1996, Tourenq et al. 2004, Mugica et al. 2006, Kazantzidis & Goutner 2008, Fasola & Brangi 2010, Fasola et al. 2010, Fujioka et al. 2010, Cardarelli et al. 2017). The reproductive success, nest survival and nestling body condition of these birds have been shown to be affected by the quality of their foraging habitat (Hafner et al. 1987, 2001, Delord et al. 2003), so their reproductive parameters, together with their population trends, can be good indicators of wetland conditions.

There are many studies on the breeding biology of herons and egrets in different parts of Europe. Perhaps the largest amount of information has been generated in Camargue (France) (e.g. Hafner 1980, Hafner et al. 1994, Thomas et al. 1999, Bennets et al. 2000, Hafner et al. 2001, Barbraud et al. 2001, Tourenq et al. 2001, Delord et al. 2003). More recently are studies on Grey Herons Ardea cinerea in Central Europe (Manikowska-Slepowronska et al. 2015, 2016) and North Africa (Nefla et al. 2012, 2014, Nedjah et al. 2010, 2014). The reproduction of herons has also been studied in Spain, such as in the studies conducted in Extremadura (Bartolomé et al. 1997), in the Duero region (Campos 1984, Campos & Fernandez-Cruz 1991) and in Cantabria and Navarra (Lekuona 2002, Navedo et al. 2004), in addition to those carried out by Prósper in the Albufera de València (Prósper & Hafner 1996, Prósper 2000), among others.

L'Albufera de València is a European Union Natura 2000 site and one of the main wetlands of the Iberian Peninsula, as well as being one of the most important wetlands in the western Mediterranean, both for its size (21,120 ha) and for its valuable biodiversity of conservation interest (Generalitat Valenciana 2002). This wetland is the third most important breeding site for herons in Spain (Garrido et al. 2012). Seven species of herons are considered regular breeders in this area, with a total population of up to 5,000 pairs (Generalitat Valenciana 2015, 2016). On a regional scale, this wetland hosts more than 50% of the breeding pairs of five species out of the seven that breed in the region (Generalitat Valenciana, 2016). Pechuán (1965, 1971) carried out the first studies on the breeding biology of herons in the wetland. Subsequently, Prósper & Hafner (1996) and Prósper (2000) studied the biology of nesting species, including the breeding success of Grey Heron, Cattle Egret and Little Egret between 1988 and 1990. Thereafter, no further studies on their breeding biology have been carried out. In view of the increase in the breeding population observed in recent years, according to the annual census carried out by SEO/BirdLife and the Conselleria de Medio Ambiente of regional goverment, a new review of these parameters at the colonies is desired. There is no information on whether the increase in the number of breeding pairs has affected in the breeding success of the colony. However, there is evidence that nest density or the increase in nesting pairs is inversely related to clutch size or reproductive success in several heron species (Hafner 1980, Bennets et al. 2000, Hafner et al. 2001). Therefore, we expect that reproductive success will be lower than in previous years when the population was smaller.

The high density of breeding pairs in this wetland is favoured by the extension of rice fields that occupy almost 70% of the protected area. These rice fields constitute an important feeding habitat for waterfowl during breeding, specifically for herons (Hafner et al. 1987, Fasola & Ruiz 1996, Fasola et al. 1996, Toral et al. 2012). The management of the rice fields consists of two annual flooding periods (summer and winter), which leads to a large flooded areas during most of the year, which favours the availability of food for the herons (Prósper & Hafner 1996, Martínez-Abraín 1998, Prósper 2000, Generalitat Valenciana 2002). Several reproductive aspects of the herons are related to the timing of flooding. Prósper & Hafner (1996) report that the laying phenology of most heron species in L'Albufera, is related to the dates of flooding and the condition of these crops. Likewise, the number of nests, colony size and breeding success were associated with the presence of rice fields (Hafner et al. 1987, Tourenq et al. 2001, Lekuona 2002, Delord et al. 2003). Competition with international markets and changes in the subsidy mechanisms used by the Common Agricultural Policy (CAP) have increased pressure on water allocation for rice cultivation in search of higher profitability (Girona 1998, Picazo-Tadeo et al. 2009, Martínez 2018). How these changes in the management of flooding and rice cultivation cycles may affect the reproductive parameters of the colony has not been assessed.

In this study, two mixed colonies of Grey Heron, Cattle Egret, Little Egret, Purple Heron, Squacco Heron *Ardeola ralloides* and Glossy Ibis *Plegadis falcinellus* (Threskiornithidae) were monitored for three years. The results obtained for the main reproductive parameters during the breeding periods of 2015, 2016 and 2017 are reported. The main objective of this study is to analyze the effects of the state of the rice fields (phase of the crop cycle) surrounding the colonies on reproductive parameters of the herons. If the phenology of the rice fields changes between years, this may affect reproductive success, affecting colony productivity, which is a major issue for the management of this site and of other breeding areas directly related to the rice fields.

Methods

Study area

L'Albufera de València is located in the Valencian Community, in the east of the Iberian Peninsula on the Mediterranean side (39°20'N, 00°20'W) (Figure 1). It is an important European area for birdlife, regularly hosting some 240 species throughout the year, 90 of which are common breeders and 75 of which are waterfowl. For this reason, L'Albufera has been included in the "Wetlands of International Importance" (RAMSAR) since 1989 and has also been recognized as a "Special Protection Area for Birds" (SPA) since 1991. The protected area has a total surface area of 21,120 ha, of which 2,837 ha is made up of a coastal lagoon and 14,500 ha of surrounding rice fields. The maintenance of the rice fields involves the management of the waters of the rivers Júcar and Turia, which in turn feed the lagoon through canals used for agricultural purposes. The rice fields follow a flooding regime, which takes place twice a year (May-September and October-February), while in the months of March-April the fields are dry to prepare the land, as well as in September-October when the harvest takes place.

The lagoon has several islands or vegetation formations (matas) covering some 290 ha, which are used by herons and other birds to establish their nesting colonies. The colonies studied are located at Mata El Fang (hereafter MEF) and Replaza de Sacarés (hereafter RS) (Figure 1). MEF is a reserve area located on the eastern shore of the lake and is the largest (c. 30 ha), while RS is located on the southern shore of the lake and has an area of c. 11 ha. The predominant vegetation in these matas are

Common Reed *Phragmites australis*, Cat-tails *Thypha domingensis*, Seashore Mallow *Kosteletzkia pentacarpos* and Swamp Sawgrass *Cladium mariscus*. On this vegetation, the herons establish their heterospecific colonies, except in the case of the Purple Heron, which forms single-species colonies.

Since the beginning of May of each year, field-observations were conducted from the surroundings of the matas (reedbed) to determine the location of the colonies, looking for adults flying and resting. Subsequently, aerial photographs were taken from an ultralight (25/06/2015, 19/07/2016 and 23/06/2017) that allowed the determination of locations of other small colonies, and to confirm that no relevant colony had been missed out.

Several nesting clusters were recorded within each reed bed. Some of these clusters were very difficult to access, so they were not included in the monitoring. In total, three colonies were surveyed at MEF and three at RS. Some of them varied in location, at the same island, from year to year.

Breeding parameters

Visits to the different nesting colonies were made every 7-10 days during the breeding period (May-July) 2015, 2016 and 2017. Most nests in the main colonies were marked with numbered tape and geo-referenced. As many nests as possible were followed up. Each nest was identified by species and its contents (eggs, shells, unhatched eggs, nestlings, dead nestlings and nestling condition) were recorded at each visit.

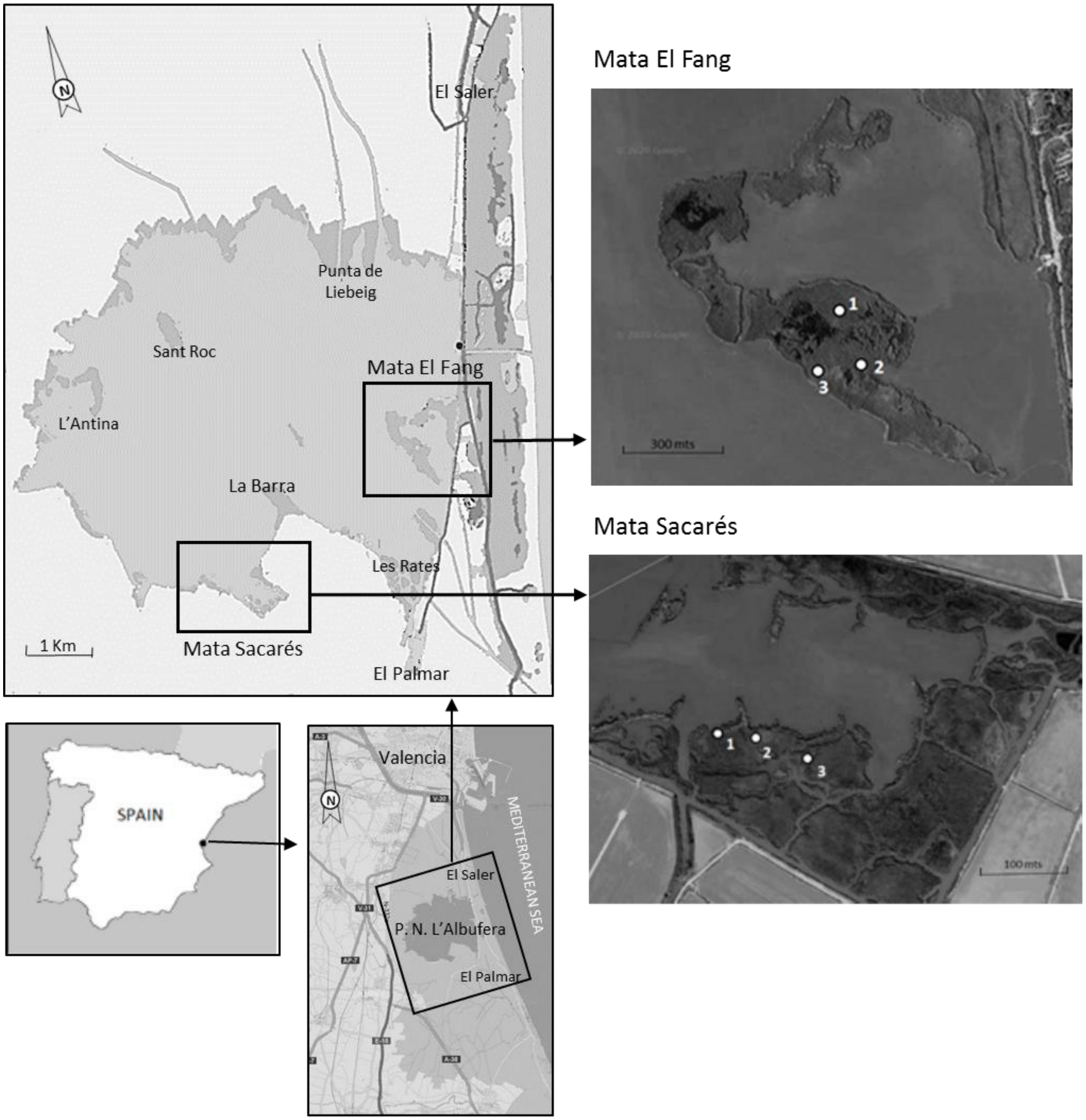

Figure 1: Location of nesting colonies in *matas* El Fang and Sacarés in L'Albufera de València.

Colonies were visited after they were established, to avoid interfering with the nesting process (Prósper & Hafner 1996, Caballero 1996). Clutch size was established as the largest number of eggs observed in the nest that remained unchanged until the next visit. If the nest contained only newly hatched or few-day-old chicks, clutch size was assumed to be equal to the number of chicks. The onset of egg laying was estimated by counting back the days of incubation from the hatching date of the chicks, considering 25 days for Grey Heron (Hankock & Kushlan 1984), 26 days for Purple Heron (Tomlinson 1975), 23 days for Cattle Egret and Glossy Ibis (Blaker 1969, Del Hoyo et al. 1992) and 22 days for Little Egret and Squacco Heron (Sterbetz 1962, Hafner 1980).

Brood size, was recorded as the number of nestlings still alive at 15 days of age (Hafner 1980, Bartolomé et al. 1997, Hafner et al. 2001, Nedjah et al. 2010, Nefla et al. 2014). After this time, nestlings may move along branches or jump to the ground, making them difficult to observe and making it impossible to assign to the nest to which they belong. In the case of the Grey Heron, chicks stay longer in the nest, so chicks up to 20 days old were also counted (Jakubas 2005, Ashoori et al. 2009). Chicks found dead after this time, were recorded as unsuccessful.

Hatching success (number of hatched eggs/total number of eggs), nesting success (number of successful chicks/number of hatched chicks) and breeding success (number of successful chicks/total number of eggs) per nest and for each species were estimated.

Rice fields status

To assess the influence of the flooding cycle and cultivation phase on the colony's reproductive parameters, rice fields were surveyed every two weeks. The northern and southern areas of the lagoon were visited between February 2016 and June 2017. Twenty-six observation points were selected along a 22 km route in the southern zone and 15 points along a 9 km route in the northern zone, established on roads crossing the rice fields. A total area of 1,839 ha of the rice fields was covered. The selection of points and routes depended on the accessibility during the hunting season, when several roads and fields are closed to the general public. During the surveys, the condition of a rice field was recorded by classifying it as dry, muddy/wet, semi-flooded, flooded, sown or harvested (Table 1).

Table 1: Categorization of the state of rice fields in L'Albufera de València.

Category	**Description**
Dry	Totally dry field, presence of cracks, ploughed or not.
Muddy/wet	Field with wet earth, mud, with small spatially dispersed pools of water, worked with machines or not. There are no dry areas.
Semi-flooded	Field with some areas covered with water, very shallow, but the water does not cover the total extent of the field.
Flooded	Field with the entire area flooded, resembling a lagoon, without visible vegetation.
Sown	Field with water cover but with rice plants, in all stages (freshly planted up to > 70 cm).
Harvest	Field with remnants of the crop, fallow, burned or not.

The proportion (by area) of each category in each month was calculated. The number of individuals of each species of interest was also recorded for each survey. For the analyses, records from February to June (before and during the breeding season) were used.

Statistical analysis

Reproductive parameters for each species were compared using a Kruskal-Wallis test to determine if there were significant differences between years. Past3 version 3.14 was used for statistical analyses. Reproductive parameters of nests were compared between before and after flooding and between before and after sowing, in the years in which the rice fields were followed (2016 and 2017), using Kruskal-Wallis tests. For the analysis of brood size and breeding success, nestlings hatched in May (flooded fields from the second week) and in June (sown fields) were excluded because all nestlings hatched at or after flooding.

To assess whether the condition of the rice fields has an effect on the breeding success of the colony, we used a Generalized Linear Mixed Model (GLMM) with a Binomial distribution. The condition of rice fields was defined by two continuous variables: percentage (%) of number sown fields and percentage (%) of number flooded fields. The response variable was the breeding success (proportion), and the predictors were the percentage of number sown fields, percentage of number flooded fields (rescaled as the arcsine of the square root of the proportion) and the species of heron. We compared seven models with different combinations of predictors and the study year as a random effect. We selected the best explanatory model using the

Akaike Information Criterion corrected for small sample size (Burnham & Anderson 2004). The model with the lowest AICc value (delta threshold AIC = 0) was selected. Models within delta AIC < 2 where considered equally plausible, however after model selection none of the other considered models fell within this range (see: supplementary material; Harrison et al. 2018).

In the same way, a GLMM was used to assess the effect of the timing between first egg laying and flooding, and between hatching and seeding of the rice fields on breeding success. The timing was defined by “days to flooding” (days elapsed between the date of first egg laying and the onset of flooding) and “days to sowing” (days elapsed between hatching and the onset of sowing of the rice fields). These variables together with the heron species were the predictors and the breeding success (proportion) was the response variable. Data of the Squacco Heron was not included in this analysis since in all cases egg laying and hatching occurred after flooding and sowing, respectively. The same was true for Grey Heron, Purple Heron and Glossy Ibis in 2017. Six models were compared with different combination of predictors and the study year included as a random effect. Again, the AICc was used to select the best model as described above. All analyses were performed using R (R Core Team 2020).

Results

All colonies surveyed were mixed, except for one Grey Heron colony at MEF observed in 2015 and the Purple Heron colony. The Purple Herons settled only at RS, while the Grey Herons established their entire nesting population at MEF.

Phenology of egg laying and hatching

A total of 734 nests were monitored during the study. The onset of egg-laying began in late April and continued through May. During the three years of the study, most heron species had the highest number of nests with eggs in the third and fourth week of May. In 2016, egg laying in Grey Heron, Cattle Egret, Purple Heron and Glossy Ibis started from the third week of April, whereas in 2015 and 2017 it started in May (Figure 2). Despite observing this earlier egg laying in 2016, for these four species, only the Grey Heron significantly advanced egg laying (Kruskal-Wallis test: $H = 5.4$ $p = 0.02$). Squacco Heron was the exception, maintaining the onset of laying in the second week of May and extending it until the first week of June during the three years of the study, without significant changes. In terms of peak laying, Grey Heron, Cattle Egret and Purple Heron peaked in the last week of April during 2016, while peak laying in the other years was in May and June (Figure 2).

All species had hatching peaks in June during the three study years. However, in 2016, the Grey Herons and Purple Herons had the highest hatching peaks in the last week of May, while the Cattle Egrets had a second peak at this time.

In 2016, due to the earlier onset of egg laying, the first hatching occurred from the second week of May in the Grey Heron, Cattle Egret, Purple Heron and Glossy Ibis, and from the third week of May in the Little Egret. In 2015 and 2017 hatchings was concentrated in June. No significant differences were found in the number of hatched eggs per month between years, except in the case of the Squacco Heron (see Table S1).

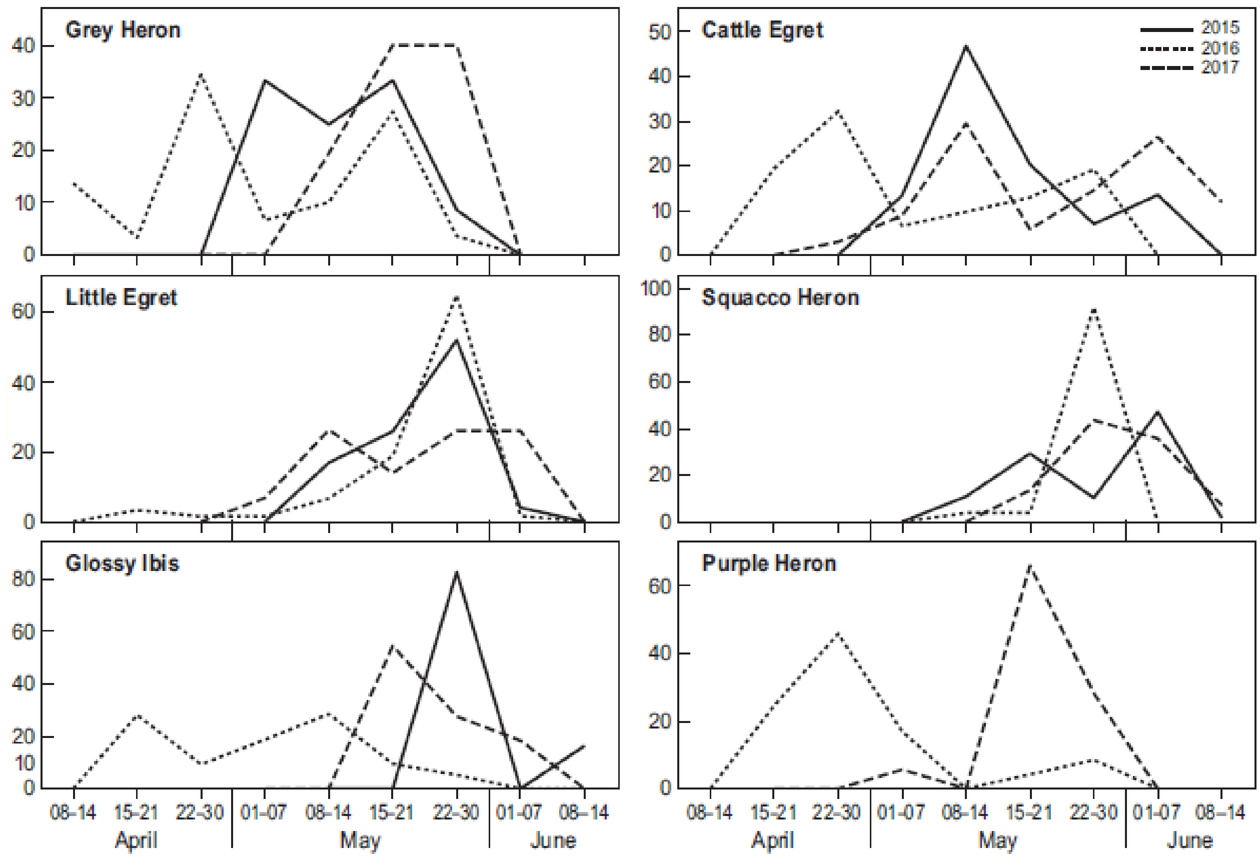

Figure 2: Phenology of egg laying of six species of herons and Glossy Ibis during three years of study (2015-2017), within L'Albufera de València.

Clutch and brood size

The mean clutch size was between 2 and 4 eggs, depending on the species. The Squacco Heron had the largest mean clutch size (4.16 eggs; Table 2). This species also had the highest mean number of successful chicks per nest (2.33 chicks/nest), while the Grey Heron had the lowest number (0.72 chicks/nest). Only the Cattle Egret showed significant differences in clutch size between years, with larger clutches in 2015 (Table 2). In terms of the mean number of eggs hatched, only two species showed significant differences between years: Squacco Heron had the lowest mean clutch size in 2017 and the Grey Heron in 2016 (Table 2). In relation to brood size, most species showed significant differences between years, with the smallest brood size in 2016, with the exception of the Purple Heron and the Squacco Heron (Table 2).

Table 2: Mean clutch size, number of hatchlings and brood size (successful nestlings) per nest for each species, in the 2015-2017 breeding period, within L'Albufera de València and results of the Kruskal-Wallis test (* significant differences).

	Grey Heron	Purple Heron	Squacco Heron	Little Egret	Cattle Egret	Glossy Ibis
Clutch size						
2015	2.56 ± 0.73	–	4.21 ± 0.84	3.85 ± 0.66	3.44 ± 0.89	3.57 ± 1.27
2016	2.82 ± 0.77	2.89 ± 0.79	4.16 ± 0.67	3.64 ± 0.80	2.86 ± 0.68	3.00 ± 0.77
2017	3± 0.71	2.64 ± 0.92	4.12 ± 0.81	3.63 ± 0.8	2.83 ± 0.77	3.2 ± 0.77
Total	2.78 ± 0.76	2.76 ± 0.82	4.16 ± 0.80	3.67 ± 0.78	2.96 ± 0.79	3.13 ± 0.86
H (P)	1.99 (0.27)	0.64 (0.39)	0.59 (0.71)	1.85 (0.33)	5.46 (0.04)*	3.37 (0.14)
Number of hatchlings						
2015	2 ± 0.93	–	3.42 ± 0.83	2.85 ± 0.72	2.88 ± 0.5	2.57 ± 1.27
2016	1.31 ± 1.28	2.2 ± 1.21	3.28 ± 1.29	2.75 ± 1.19	2.64 ± 0.87	2 ± 1.37
2017	2.4 ± 0.55	2.45 ± 1.13	2.27 ± 1.15	2.96 ± 0.96	2.52 ± 0.8	1.94 ± 0.94
Total	1.5 ± 1.22	2.44 ± 1.10	3.10 ± 1.26	2.86 ± 1	2.61 ± 0.76	1.96 ± 1.28
H (P)	7.76 (0.02)*	0.03 (0.8)	15.55 (< 0.01)*	0.50 (0.76)	2.15 (0.28)	2.15 (0.32)
Brood size						
2015	1.47 ± 0.99	–	2.35 ± 1.23	2.04 ± 1.14	1.87 ± 0.83	2.17 ± 1.33
2016	0.41 ± 0.91	1.06 ± 1.16	2.64 ± 1.73	0.82 ± 1.31	0.38 ± 0.74	0.89 ± 0.93
2017	1.33 ± 0.58	1.8 ± 0.84	1.67 ± 1.11	4.71 ± 0.97	2.29 ± 1.11	2.1 ± 0.88
Total	0.72 ± 1.02	1.04 ± 1.12	2.33 ± 1.40	1.45 ± 1.38	1.32 ± 1.17	1.74 ± 1.20
H (P)	16.99 (< 0.01)*	1.90 (0.62)	3.84 (0.06)	17.58 (< 0.01)*	17.62 (< 0.01)*	7.57 (< 0.01)*

Hatching, nesting and breeding success

During the study period, the Grey Heron had the lowest values for hatching, nesting and breeding success (Table 3). The Cattle Egret had the highest hatching success, but was one of the species with the lowest nesting and breeding success. In contrast, Squacco Heron and Glossy Ibis had the highest nesting and breeding success (Table 3). In terms of hatching success, only the Grey Heron and the Squacco Heron showed significant differences between years, being lower in 2016 for the Grey Heron, and in 2017 for the Squacco Heron (Table 3).

Table 3: Mean hatching, nesting and breeding success per nest for each species, in the 2015-2017 breeding period, within L'Albufera de València and the results of the Kruskal-Wallis test (* significant differences).

	Grey Heron	Purple Heron	Squacco Heron	Little Egret	Cattle Egret	Glossy Ibis
Hatching success						
2015	0.81 ± 0.32	–	0.82 ± 0.16	0.75 ± 0.18	0.87 ± 0.18	0.65 ± 0.32
2016	0.46 ± 0.43	0.76 ± 0.38	0.73 ± 0.34	0.76 ± 0.29	0.91 ± 0.17	0.65 ± 0.40
2017	0.82 ± 0.17	0.91 ± 0.2	0.54 ± 0.25	0.82 ± 0.21	0.83 ± 0.32	0.77 ± 0.31
Total	0.58 ± 0.43	0.81 ± 0.35	0.75 ± 0.31	0.78 ± 0.25	0.87 ± 0.24	0.64 ± 0.35
H (*P*)	8.78 (< 0.01)*	0.51 (0.36)	10.82 (< 0.01)*	2.92 (0.2)	0.23 (0.84)	1.75 (0.38)
Nesting success						
2015	0.66 ± 0.42	–	0.67 ± 0.32	0.69 ± 0.35	0.67 ± 0.31	0.75 ± 0.42
2016	0.19 ± 0.38	0.39 ± 0.42	0.71 ± 0.44	0.30 ± 0.44	0.18 ± 0.35	0.50 ± 0.49
2017	0.5 ± 0.17	0.38 ± 0.39	0.79 ± 0.37	0.73 ± 0.67	0.38 ± 0.46	0.95 ± 0.12
Total	0.32 ± 0.43	0.39 ± 040	0.71 ± 0.37	0.52 ± 0.52	0.40 ± 0.41	0.67 ± 0.45
H (*P*)	13.67 (< 0.01)*	0.02 (0.89)	2.93 (0.18)	10.44 (< 0.01)*	11.93 (< 0.01)*	4.96 (0.04)*
Breeding success						
2015	0.63 ± 0.41	–	0.56 ± 0.24	0.53 ± 0.31	0,57 ± 0.28	0.58 ± 0.38
2016	0.14 ± 0.45	0.35 ± 0.37	0.63 ± 0.41	0.20 ± 0.35	0,15 ± 0.30	0.34 ± 0.35
2017	0.39 ± 0.10	0.38 ± 0.39	0.39 ± 0.24	0.47 ± 0.35	0,35 ± 0.43	0.92 ± 0.14
Total	0.28 ± 0.39	0.36 ± 0.37	0.55 ± 0.34	0.36 ± 0.37	0,34 ± 0.36	0.56 ± 0.40
H (*P*)	16.08 (< 0.01)*	0.02 (0.87)	5.93 (0.048)*	12.3 (< 0.01)*	11.3 (< 0.01)*	20.11 (< 0.01)*

Both nesting and breeding success showed significant differences between years for most species. During 2016, the lowest values for these parameters were recorded in all cases. The exception was the Purple Heron, which did not show significant differences in any case. In the case of the Squacco Heron, the lowest value for breeding success was recorded in 2017, while the lowest value for nesting success was recorded in 2015, but this was not statistically significant (Table 3).

Rice fields status

In February and March 2016 (before the start of the breeding period) the proportion of dry fields was higher than in 2017 (Figure 3). In March there were no longer any totally flooded fields, only some with mud or small puddles representing 18% of the rice fields surveyed in 2017 and 4% in 2016. During April (when egg laying started in 2016), all rice fields (100%) were dry in both 2016 and 2017. In these two years, the fields were flooded again in May and by June most of them were already sown. Flooding started from the second week of May in both years (Figure 3). However, in 2016 the proportion of flooded fields by that date was higher than in 2017 (51% versus 31% respectively).

On the other hand, fields that started to be flooded (muddy or semi-flooded) were also found in higher proportion in 2016 (36%) than in 2017 (14%). Sowing of the fields started in the last week of May and, in 2016, 27% of the fields were sown by this time (Figure 3). There is no data on the start of sowing for 2017, as for logistical reasons observations could not be made during this period. By the first week of June, 93% of the fields were already sown in 2016 and 98% by the second week of June in 2017. Although in 2017 the sampling ended in June, based on the results of 2016 and the already known dynamics and management of the rice fields, it can be stated that during July and August (last months of the reproductive period), 100% of the fields were sown.

The number of individuals of the monitored heron species present in the rice fields was highest in May and June, coinciding with the hatching and rearing of chicks.

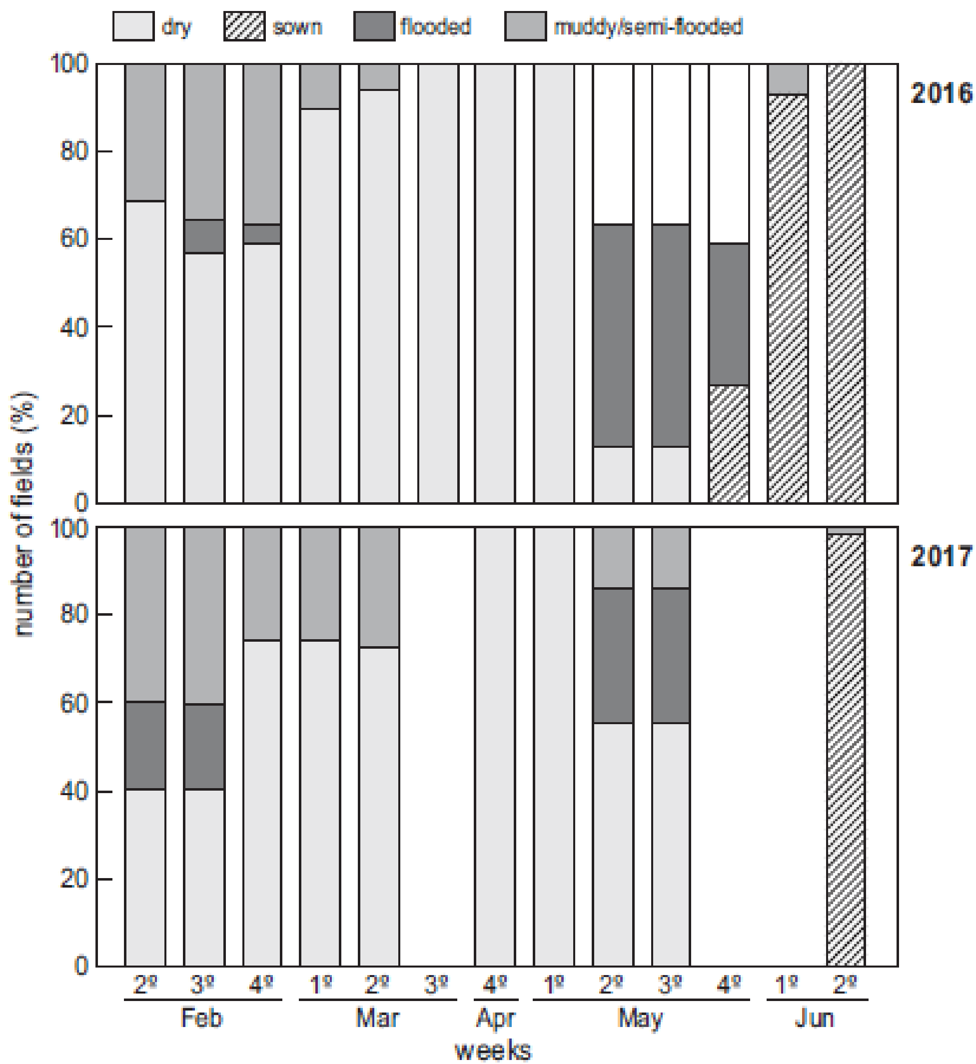

Figure 3: Changes in the state of the monitored rice fields over the breeding period of the studied heron species and the Glossy Ibis (2016-2017) in L'Albufera de València.

Effect of rice field status on breeding parameters

In 2016, egg laying for four of the six species studied started at the end of April, when the rice fields were completely dry. In 2017, they started in May, when the fields started to flood (Figure 2 and Figure 3). Hatching started from the second week of May in 2016 (except for Little Egret and Grey Heron), when there were still 13% dry fields. In 2017, hatching occurred in the last week of May, when fields were flooded or sown. Hatching peaks were entirely concentrated in the month of June during 2017, when all fields were already sown, whereas in 2016 there were hatching peaks in the last week of May (Figure 4). Nesting and breeding success was significantly lower in 2016 (Table 3), when the first hatchings occurred when fields were flooding or just starting to be sown. In 2017, when nesting and breeding success was higher, hatching occurred mostly when all fields were already sown.

There were no significant differences in clutch size between nests established before and after the flooding of the fields (second week of May). In all cases, although some nests were established before the flooding of the fields, all eggs hatched occurred after the flooding. There were also no significant differences in clutch size and breeding success between chicks hatched in May and June for any of the monitored species (Table 4). Only Little Egrets showed significant differences in all parameters, due to the null survival (dead chicks) or loss (empty nest) of the few chicks hatched in May 2017 (Table 4).

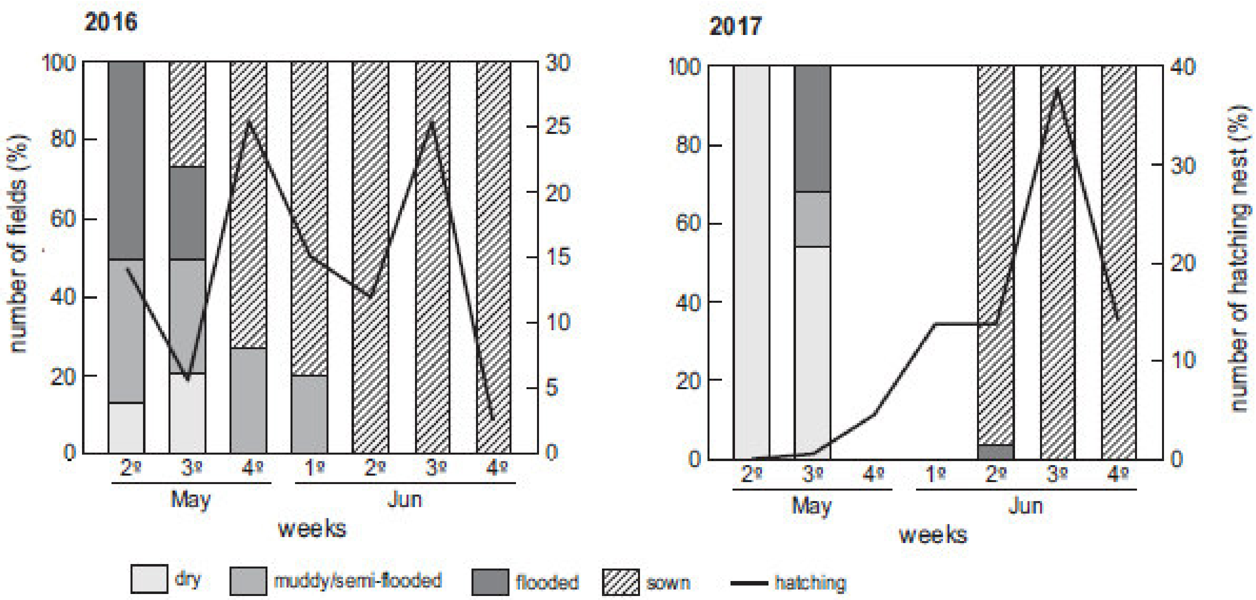

Figure 4: The mean hatching percentage of the studied species (dark solid lines) in relation to the state of the rice fields (bar graphs) in L'Albufera de València during the reproductive period of the years 2016 and 2017.

We found a significant relationship of breeding success and the proportion of sown rice fields in all species except the Squacco Heron, and with the proportion of flooded rice fields only in the case of the Glossy Ibis (Table 5). Breeding success increased with an increasing area of sown fields, in the case of the Purple Heron, Cattle Egret, Little Egret and Glossy Ibis. The opposite was true for Grey Herons (Table 5). For the Glossy Ibis, reproductive success decreased with an increasing area of flooded fields (Table 5).

Table 4: Mean clutch size before and after the flooding of the fields (April and May), mean brood size (successful nestlings) and breeding success before and after sowing (May and June), for each species in the 2016-2017 breeding period, within L'Albufera de València and the results of the Kruskal-Wallis test (* significant differences).

	Grey Heron	Purple Heron	Little Egret	Cattle Egret	Glossy Ibis
Clutch size					
April 2016	2.5 ± 1	2.5 ± 1	3.33 ± 0.58	2.8 ± 0.42	2.8 ± 0.42
May 2016	2.84 ± 0.76	2.75 ± 0.74	3.66 ± 0.81	2.88 ± 0.77	3.12 ± 0.67
H (P)	0.32 (0.5)	1.22 (0.22)	0.58 (0.41)	0.12 (0.68)	2.03 (0.1)
April 2017	-	2.8 ± 1.10	2.89 ± 0.78	3.13 ± 1.13	-
May 2017	-	2.5 ± 0.84	2.75 ± 0.65	3.73 ± 0.76	-
H (P)	-	0.13 (0.67)	6.68 (< 0.01)*	0.52 (0.43)	-
Brood size					
May 2016	1.5 ± 1.29	0.95 ± 1.13	0.17 ± 0.41	0.16 ± 0.5	0.84 ± 0.90
June 2016	0.27 ± 0.67	0.80 ± 1.01	0.48 ± 1.04	0.38 ± 0.89	1.10 ± 1.12
H (P)	0.61 (0.27)	0.06 (0.79)	0.06 (0.72)	0.20 (0.46)	0.40 (0.50)
May 2017	-	0.8 ± 1.3	0	3.33 ± 0.58	-
June 2017	-	1.25 ± 0.96	2.5 ± 0.97	2.5 ± 0.97	-
H (P)	-	0.18 (0.65)	16.62 (< 0.001)*	3.86 (0.04)	-
Breeding success					
May2016	0.5 ± 0.43	0.44 ± 0.39	0.06 ± 0.14	0.08 ± 0.20	0.29 ± 0.29
June 2016	0.09 ± 0.23	0.39 ± 0.42	0.15 ± 0.31	0.15 ± 0.32	0.32 ± 0.32
H (P)	0.83 (0.19)	0.58 (0.43)	0.13 (0.62)	0.13 (0.6)	0.04 (0.83)
May 2017	-	0.63 ± 0.18	0	0.78 ± 0.2	-
June 2017	-	0.72 ± 0.25	0.62 ± 0.26	0.62 ± 0.26	-
H (P)	-	0.08 (0.76)	16.62 (< 0.01)*	3.86 (0.05)	-

Table 5: Model estimates of two selected GLMM models in which the effect (β coefficients) of the percentage of sown rice fields (Model 5) and the percentage of flooded rice fields (Model 6) on the breeding success of the different heron species was tested. See Table S2 for of all tested candidate models (* significant effect: confidence interval does not include 0).

Species	Sown fields (Model 5) Random effect year (θ) = 0.641				Flooded fields (Model 6) Random effect year (θ) = 0.652			
	B	Std. Error	95% Confidence Interval		β	Std. Error	95% Confidence Interval	
Grey Heron	-2.256	0.634	-3.657	-1.122*	0.490	0.668	-1.347	2.411
Purple Heron	1.585	0.739	0.215	3.153*	1.184	1.217	-1.235	3.567
Squacco Heron	0.616	1.330	-2.056	3.237	1.157	1.5039	-1.794	4.163
Cattle Egret	1.981	0.763	0.563	3.595*	-0.777	1.308	-3.407	1.756
Little Egret	3.198	0.982	1.461	5.378*	-1.349	1.310	-4.053	1.134
Glossy Ibis	3.911	0.851	2.352	5.722*	-3.370	1.386	-6.204	-0.728*

The best explanatory model (Model 5) included the percentage of sown fields together with species and the interaction between both variables (AICc = 623.6; Table S2). Nevertheless, we also examined also the model that considers the effect of the percentage of flooded fields and heron species and the interaction between both variables (Model 6), as this allowed us to show the effect of flooded fields on the breeding success of each heron species. This model was the second-best explanatory model (AICc = 641.8; Table S2). The two variables (percentage of sown fields and flooded fields) were not included in a single model as they turned out to be collinear (r = 0.70).

Considering the effect of timing of egg laying relative to the date of rice field flooding on breeding success, there was a negative effect on breeding success (lower breeding success) in all species, except Grey Heron (Table 6). The negative effect of timing (more days between egg laying and flooding) was significant for Cattle Egret, Little Egret and Glossy Ibis. In the case of the Purple Heron, the effect was not significant (95% confidence interval include 0), but the upper limit of the interval exceeds zero only by 0.009 and could therefore be considered a trend (Table 6). The selected explanatory model included the predictor variables "days to flooding", species and the interaction between both variables (AICc = 520.5; Table S3).

Table 6: GLMM model estimates of the effect (β coefficients) of the number of days between first egg laying and flooding of the rice field on the breeding success of the different heron species. See Table S3 for all tested candidate models (* significant effect: confidence interval does not include 0).

Species	Days to flooding (Model 5) Random effect year (θ) = 0.961			
	β	Std. Error	95% Confidence Interval	
Grey Heron	0.117	0.027	-4.490	0.384
Purple Heron	-0.060	0.036	-0.133	0.009*
Cattle Egret	-0.068	0.039	0.147	0.006*
Little Egret	-0.420	0.129	-0.821	-0.235*
Glossy Ibis	-0.179	0.038	-0.258	-0.107*

Discussion

Changes in breeding pairs and colony numbers

In L'Albufera de València, we found that the heron species we studied have, in line with earlier work, continued to nest in mixed colonies with the nests very close together (Pechuán 1971, Prósper & Hafner 1996). The only exception was the Purple Heron which establishes its own colonies with spatially more dispersed nests (Giménez & Aguirre 2003, Nedja et al. 2010). The Fang area (MEF) remains an important nesting site and since at least 1963 has maintained breeding populations there every year (Prósper 2000). On the other hand, the Sacarés area (RS) began to be used annually as a breeding site only in 1991 (Prósper 2000) and currently hosts a considerable number of breeding pairs, including a Purple Heron colony. Previously, colonies had been recorded in other reedbeds in the lagoon, some of which were important in terms of the number of colonies during the 1990s (Prósper 2000). However, no sign of these colonies was found during the years of our study.

Changes in reproductive timing of herons in relation to rice field management

In recent years, the start of the flooding of the rice fields has been delayed, starting up to three weeks later compared with when they were flooded in the 1990s. This coincides with the delay also observed in the start of egg laying of the nesting herons in L'Albufera de València relative to previous periods (Prósper & Hafner 1996, Prósper 2000, Dies et al. 2001) and with what has been reported in other wetlands

(Parejo et al. 2001, Belamendia et al. 2003, Galarza 2020). In L'Albufera, nest building and egg laying of the Cattle Egret, Little Egret, Squacco Heron and Purple Heron has been reported to start at the end of April (Prósper & Hafner 1996, Prósper 2000, Dies et al. 2001) as in other areas of Spain (Parejo et al. 2001, Belamendia et al. 2003, Galarza 2020). In our study, the onset of egg laying coincides with the third week of April in 2016, although in 2015 and 2017 all species started nesting from the first week of May. These results are different from those reported for the period 1988-1990, in the case of the Squacco Heron and Cattle Egret. In those years they had two egg laying peaks, one in April-May and one in June-July (Prósper & Hafner 1996). During our study period (2015-2017) the peak egg-laying period for the Cattle Egret was in the second week of May and the first week of June, while the Squacco Heron only had a peak in the last week of May, as did the Little Egret. This difference may be related to changes in the onset of flooding, as flooding currently occurs later. Prósper (2000) mentions that the fields were flooded between April and May and the start of sowing took place at the beginning of May, coinciding with the first peak of egg laying in the period 1988-1990. On the other hand, Oltra et al. (2001) mention that in the 1970s and 1990s the flooding of the rice fields to start cultivation began in mid-April and that the fields were completely flooded at the beginning of May. Currently, the fields begin to flood in early May and sowing starts at the end of the month, two to three weeks later than in the 1990s. It was observed in both studies, that the flooding of the rice fields coincides with the egg laying peaks for most species, especially in the case of the Cattle Egret and the Little Egret (Prósper 2000).

The Squacco Heron always started egg laying in May, while there was greater variability in start date in the period 1988-1990, which the author attributed to high variation in temperature and rainfall during autumn preceding the breeding season (Prósper 2000). The Squacco Heron was the last to initiate breeding in the colony in our study, starting egg laying about a week later than the other species, as has been described in other colonies (Pechuán 1971, Hafner 1980, Prósper 2000, Delord et al. 2003). This species possibly requires prior settlement of the other species that establish the core and create the right conditions in the colony (Pechuán 1971, Prósper 2000). The first species to establish modifies the vegetation in the core of the colony, while the Squacco Heron establishes on the periphery of the colonies where the vegetation is denser (Pechuán 1971, Hafner 1980). Moreover, although the core may offer better conditions, competition is likely to be greater here than on the periphery, where the Squacco Heron nests are located (Hafner 1980).

On the other hand, the Grey Herons started nesting in January and carried out staggered egg laying until May (Prósper & Hafner, 1996, Belamendia et al. 2003). In our study we only considered breeding in the spring-summer period (May-July), so the Grey heron clutches observed in our study correspond to the last sporadic clutches of the breeding period (Prósper & Hafner 1996). In 2017, breeding must have ended earlier as by June almost no Grey Heron nests were found; whereas in previous years nests with newly hatched chicks could still be found in June.

There is no information on the breeding phenology of Glossy Ibises in Spain, but studies carried out in North Africa mention that laying would start from mid-April or early May (Boucheker et al. 2009, Nefla et al. 2012), which approximately coincides with what was observed during our study.

Changes in reproductive parameters and possible explanations

Regarding reproductive parameters, the number of successful chicks per nest recorded in our current study was lower than that reported by several other authors. For L'Albufera, for example, clutch size values reported for the period 1988-1990 were, on average, higher for the Cattle Egret (2.83 chicks/nest), Little Egret (3.46) and Grey Heron (3.48; Prósper & Hafner 1996). In other colonies, both in Spain and elsewhere in Europe, values higher than 2 chicks/nest and in some cases higher than 3 chicks/nest are recorded for Cattle Egret (Hafner 1980, Bartolomé et al. 1997, Parejo et al. 2001, Si Bachir et al. 2008, Dragonetti & Giovanchini 2009), Little Egret (Hafner 1980, Bartolomé et al. 1997), Grey Heron (Jakubas 2005, Ashoori et al. 2009); Purple Heron (Barbraud et al. 2001, Nedja et al. 2010) and Glossy Ibis (Boucheker 2009, Nefla et al. 2012), while in our study these values were between 0.7 and 1.7 chicks/nest. Only in the Squacco Heron were values higher than 2 chicks/nest, but other authors cite values higher than 3 chicks/nest (Hafner 1980, Nefla et al. 2014). This low breeding success, seen mainly in those species most dependent most on rice fields, such as Grey Herons, Cattle Egret and Little Egret, has been related to the decline of food resources in rice fields, such as the Red Swamp Crayfish *Procambarus clarkii*, and the increase in the use of other resources to feed chicks, such as dragonfly

(Anisoptera) larvae, that may not satisfy their energy requirements (Antón-Tello et al. 2021).

The low values of breeding success for the whole period of 2015-2017 were mainly determined by the low values during 2016. Low brood sizes translate into low values for nesting and breeding success in general, in all cases lower than those reported in the literature (Hafner 1980, Barbraud 2001, Delord et al. 2003, Si Bachir et al. 2008, Ashoori et al. 2009, Nefla et al. 2012, Nefla et al. 2014). Values related to egg survival, such as the average number of hatched eggs or hatching success, did not show significant differences between the three years, except in the Grey Heron and Squacco Heron. From these results it is clear that the critical phase in the breeding period was chick rearing. In the case of Grey Heron, it can be said that both egg viability and chick rearing were affected in 2016. The same can be said for the Squacco Heron in 2017, when hatching peaked one to two weeks earlier compared to the other two years (second week of June). In this year, in the Little Egret chicks, which hatched in May, none reached the age to be considered successful. It is not certain whether this was due to high mortality in the nest or to the loss of chicks from nest (by jumping or falling out), as only empty nests were found. Predation in the colony is anecdotal and only on one occasion was a nest observed where the nestlings were covered with ants, which eventually led to their death (pers. obs.).

In 2016, although the fields were flooded from May onwards, as in 2015 and 2017; June and July were extremely dry (AEMET). Although flooding levels in rice fields could be considered stable during the year, the low and almost zero rainfall in 2016 may have influenced flooding conditions in surrounding areas and irrigation systems, which contribute to macroinvertebrate diversity in rice fields (Lupi et al. 2013, Marques Pires et al. 2015). Such decreases in food availability can directly affect reproductive performance (Owen 1960, Hafner et al. 1987, 1994). In contrast, in 2015, rainfall in the breeding months (May-July) was the highest of the three years (AEMET). It was also the year with the highest breeding success for all species except Glossy Ibis and Squacco Heron. In 2017, rainfall was not abundant but not as low as in 2016, with July being the driest month with very low values. Other studies have found that reproductive success is positively related to rainfall (Hafner et al. 1994, Si Bachir et al. 2008, Nefla et al. 2012).

According to the GLMM analyses, the area of flooded fields had no effect on the breeding success of most of the species studied, except in the case of the Glossy Ibis, where the area of sown fields had an effect. In areas with emergent vegetation cover or mature rice fields there is a greater abundance of aquatic insects, such as Odonata and Diptera larvae, which constitute an important part of the diet of these heron species and their chicks (Marques & Vicente 1999, De Szalay & Resh 2000, Mugica et al. 2006, Antón-Tello et al. 2021).

Breeding success for most species did seem to be associated with the time elapsed between egg laying and the onset of flooding. According to our GLMM results, the number of days between egg laying and the onset of flooding negatively affected the breeding success of all species, with the exception of the Grey Heron, which starts its reproductive period in January. A significantly lower breeding success was obtained in 2016, when egg laying started before flooding, in the last two weeks of April, and hatching started in the second week of May, when fields begin to flood. In general, the peak of egg laying was between the second and third week of May, when the rice fields were already flooded, and the hatching peaks occurred mainly when they were already sown, from the second week of June. The fact that colony settlement and the onset of egg-laying occurred earlier in 2016, despite the fact that rice fields conditions were the same, may suggest that the start of egg laying is more related to weather conditions than to the flooding regime of the paddy fields (Hafner et al. 1994, Caballero, 1996, Prósper 2000, Parejo et al. 2001).

The rice fields are progressively flooded throughout the wetland, resulting in a time lag between the different fields, which produces a contagious distribution, in groups, of herons feeding on the rice fields (Martínez-Abraín 1998). The number of individuals in the rice fields is highest in May and June, coinciding with the hatching and rearing of chicks. Several authors have already reported the importance of this type of habitat as a source of food in the breeding stage of herons (Hafner et al. 1987, Fasola & Ruiz 1996, Fasola et al. 1996, Longoni 2010, Pierluissi 2010, Fasola & Brangi 2010), especially in years of very low rainfall, when natural marshes dry up (Tourenq et al. 2001). According to Hafner et al. (1987), there is usually an invertebrate explosion one month after the flooding of rice fields and there would be an abundance of small prey for chicks. Also, prey biomass generally increases one month after flooding when the rice has already emerged (Marques & Vicente 1999). Likewise, small prey are more abundant and increase their biomass from the early stages of flooding until they reach their maximum in fields with mature rice (Mugica et al. 2006). Similarly, the highest fish biomass values were recorded in these fields, while crustacean biomass was found to be highest in muddy/wet fields (Mugica et al. 2006).

On the other hand, macroinvertebrate diversity has been positively related to the time of flooding of rice fields and to the emergent vegetation cover in seasonal wetlands (De Szalay & Resh 2000, Lupi et al. 2013). Thus, the highest prey availability in L'Albufera would have been in June in both study years, as the flooding of the fields started in May and rice plants emerge and grow during this month. However, in 2016, most of the chicks hatched during the flooding of the fields, so the rearing of these chicks could have been affected by the lack of available food in the rice fields, which may explain the lower nesting and breeding success that year.

Conclusions

Our results show that L'Albufera de València is still a very important breeding site for herons based on the large number of breeding pairs nesting in the wetland. However, the breeding success of some of the species recorded in this study was low, especially in 2016 and 2017. Squacco Heron and Glossy Ibis are the species that seem to be doing best in this respect. A decline in the Cattle Egret population had already been reported for L'Albufera (Generalitat Valenciana 2016). Its population decline in the area may be due to the dispersal of a fraction of the breeding population to other colonies due to their experienced low breeding success (Serrano et al. 2001, Santoro et al. 2013).

Herons depend on the presence and condition of rice fields to feed their chicks, as well as other freshwater bodies (Hafner et al. 1987, Delord et al. 2003). The way rice cultivation is managed and the flooding regime, as well as extreme weather conditions such as droughts, could affect the breeding populations and reproductive success of heron species nesting in L'Albufera (Prósper & Hafner 1996, Lekuona 2002, Generalitat Valenciana 2002, Garrido et al. 2012, Cardarelli et al. 2017). Rice cultivation in L'Albufera has had to adapt to competition from international markets, which has affected its profitability (Girona 1998, Picazo-Tadeo et al. 2009, Martínez 2018), leading to increasing pressure on the distribution of water resources (Picazo-Tadeo et al. 2009). The demand on the irrigation system is growing, due to the reduction of available resources in the basin and the changes in use in recent decades (Palop, 2015). At times when the profitability of rice cultivation is sought, competition for the resources among irrigators (other crops, housing developments, industry, the lagoon itself), together with the cost of pumping the fields empty in the lower areas and flooding in the upper areas, will determine when and how the rice fields will be flooded. Therefore, the reproductive success of the colonies will be affected in one way or another, depending on the decisions that are made in the timing, amount and duration of flooding.

The biological needs of species of conservation concern, such as those in our study, must be taken into account when drawing up management plans and agri-environmental plans for this type of artificial wetlands (rice paddies). Based on our results, such as those obtained on the effect of the time between egg laying and the start of flooding on breeding success, we conclude that water management, flooding schedules and maintenance of flooded areas must be synchronized with the needs of the colonies to ensure the conservation and success of these breeding populations.

To this end, it is also necessary to keep information on the reproduction of these species up to date, as changes in cultivation techniques and in the flooding regime, as well as changes in the rainfall regime caused by climate change, could affect the reproductive performance of the colonies studied.

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Supplementary material

Differences in the number of hatching per nests per month between 2016 and 2017

TS1: Average of hatching per nests in May and June 2016 and 2017 and results of the Kruskal-Wallis test (* significant differences).

	Grey Heron	Purple Heron	Squacco Heron	Little Egret	Cattle Egret	Glossy Ibis
May 2016	1,55 ± 1,10	2,44 ± 1,04	-	3 ± 0,63	2,48 ± 0,68	2,32 ± 1,25
May 2017	-	-	-	2,56 ± 0,73	2,67 ± 0,71	2
H (p)	-	-	-	1,39 (0,20)	0,15 (0,67)	0,12 (0,72)
June 2016	1,78 ± 1,17	2,07 ± 1,27	3,25 ± 1,40	2,74 ± 1,18	2,68 ± 0,89	1,75 ± 1,48
June 2017	2,4 ± 0,55	2,45 ± 1,13	2,27 ± 1,15	3,05 ± 0,96	2,45 ± 0,86	1,94 ± 0,97
H (p)	1,25 (0,24)	2,23 (0,12)	11,56 (0,0004)*	1,33 (0,23)	0,44 (0,48)	0,13 (0,71)

Effect of the area of sown and flooded fields on breeding success

TS2: Multi-model selection based on the Akaike Information Criterion (the most explanatory modelis the one with ΔAICc = 0, but models with ΔAICc < 2 where considered equally plausible if present). The response variable was breeding success, the predictors were the % of sown fields, % of flooded fields and the species of heron. Seven biologically meaningful models where fitted with different combinations of predictor variables, all models included year as random effect. In bold the selected model is indicated (model 6 was also used to assess the effect of flooded fields on the breeding success of each species). -LogLik = log Likelihood function, AICc = Akaike Information Criterion with correction for large models, ΔAICc = AICc of each model – AICc of the best model.

Model	Predictors	-LogLik	AICc	d.f.	ΔAICc
Model 5	% sown fields x species of heron	-298.0	623.6	13	0
Model 6	% flooded fields x species of heron	-307.1	641.8	13	18.2
Model 3	% sown fields + species of heron	-315.7	648.0	8	24.4
Model 4	% flooded fields + species of heron	-316.4	649.5	8	25.9
Model 7	null model	-342.3	688.7	2	65.1
Model 1	% sown fields	-341.8	689.6	3	66.0
Model 2	% flooded fields	-342.3	690.7	3	67.1

Effect of the timing of egg laying relative to the time of rice field flooding on breeding success

TS3: Multi-model selection based on the Akaike Information Criterion (the most explanatory modelis the one with ΔAICc = 0, but models with ΔAICc < 2 where considered equally plausible if present). The response variable was breeding success, the predictors were “days to flooding” and “days to sowing” and heron species. Six biologically meaningful models where fitted with different combinations of predictor variables, all models included year as random effect. In bold the selected model. -LogLik = log Likelihood function, AICc = Akaike Information Criterion with correction for large models, ΔAICc = AICc of each model – AICc of the best model.

Model	Predictors	-LogLik	AICc	d.f.	ΔAICc
Model 5	days to flooding x species of heron	-248.6	520.5	11	0
Model 6	days to sowing x species of heron	-250.4	523.9	11	3.5
Model 4	days to sowing + species of heron	-274.7	564.0	7	43.5
Model 3	days to flooding + species of heron	-275.6	565.8	7	45.3
Model 2	days to sowing	-295.3	596.7	3	76.2
Model 1	days to flooding	-296.2	598.5	3	78.0
Model 0	null model	-298.6	601.2	2	80.7

CAPÍTULO 5

Effects of Rice Field Water Cycles on the Breeding Biology of Grey Heron (*Ardea cinerea*) and Conservation Implications

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Abstract.

Wetlands are among the most threatened ecosystems on the planet, largely due to their conversion to agricultural or dry land. L'Albufera de Vàlencia is characterized by a large expanse of rice fields (c. 14,000 ha), which hosts the most important colony of Grey Heron *Ardea cinerea* on the Mediterranean coast of Spain. The colony was visited every 10 days during February-April of 2016 to 2018 and during May-July of 2015 to 2017. The reproductive parameters were estimated for each year and season. We also monitored the available habitat and habitat use of the species in the rice fields from February 2016 to June 2017. The condition of the rice field was related to reproductive parameters. The breeding period was divided into two stages per year. In 2016 all reproductive parameter were lower values, coinciding with a larger area of dry fields in winter and low rainfall in summer. Breeding success was found to be positively associated with the muddy/semi-flooded fields and negatively associated with the sown fields. Like Grey Heron, other waterbirds species nesting in L'Albufera de Valencia could depend on the condition of the rice fields for breeding success. Their reproductive requirements should be considered in rice cultivation management.

Key words: Ardeidae, breeding parameters, habitat use, Mediterranean wetlands, rice fields.

Introduction

Wetlands are among the mostvaluable ecosystems in the socio-economic, ecological and biodiversity sense, but they are also the most threatened ecosystems on the Meditarrean Region (The Millennium Ecosystem Assessment 2005; MedWet 2016). Globally, large areas of these environments have been converted to agricultural systems, mainly rice paddies (Czech and Parsons 2002). In 2018, approximately 167 million hectares of land worldwide were used for rice cultivation, of which 625,000 ha were in Europe (FAOSTAT 2020). This decline in natural wetlands results in a threat to the conservation of a wide diversity of species associated with this type of habitat, including waterbirds (MedWet 2016). The development of rice fields, which could be considered artificial wetlands since they have replaced the natural ones, have benefitted some waterbird species but others have been negatively affected (Fasola and Ruiz 1996, Elphick 2000, Czech and Parsons 2002, Elphick 2010, Giosa et al. 2018). Many of the species that have benefited, mainly waders, shorebirds and ducks, obtain a substantial fraction of their food in these types of agroecosystems, especially during the breeding season (Hafner et al. 1987, Fasola and Ruiz 1996, Fasola et al. 1996, Elphick el al. 2010). Similarly, the presence and extent of rice paddies has been related to population trends, colony size and reproductive success (Hafner et al. 1987, Tourenq et al. 2000, Fasola et al. 2010, Fasola and Brangi 2010, Fujioka et al. 2010, Ramo et al. 2013, Forti et al. 2021a, Fasola et al. 2022). However, these aspects of waterbird biology are associated with the rice cultivation practices and rice flooding regime (Ibañez et al. 2010, Cardarelli et al. 2017, Forti et al. 2021b). Substitution of rice fields by another crops or the change to practices where the months of flooding or the depth of the water sheet are reduced, may have negative effects on the populations of some species and their reproduction (Toral et al. 2012, Cardarelli et al. 2017, Fasola et al. 2022).

In the Mediterranean, the loss of natural wetlands has been estimated at 48% between 1970 and 2013 (Ramsar 2018), partly due to their conversion to rice paddies (Longoni 2010, MedWet 2016). Rice cultivation has increased its area by more than 30% globally since 1960 (Ramsar 2018). Rice fields in Doñana, L'Albufera de València and the Ebro Delta in Spain, La Camargue in France and the Po basin in Italy are important breeding and feeding areas for several waterbird species, as well as wintering and resting sites for migratory species (Fasola and Ruiz 1996, Hafner and Fasola 1997, Rendón et al. 2008, Ramo et al. 2013).The dynamics of rice cultivation throughout the area are basically the same, in most cases starting in April with the flooding of the land, followed immediately by sowing and ending in September-October with harvesting, after the fields have dried out (Longoni 2010). Water levels during cultivation can vary depending on specific agricultural management, i.e. administration of pesticides and fertilizers (Longoni 2010). Rice cultivation faces several challenges, such as changes in the mechanisms established in the Common Agricultural Policy (CAP), pressures on water distribution, dependence on international market prices and public support to the farmer, which could change cultivation practices or decrease rice production (Picazo-Tadeo et al. 2009, Martinez 2018).

L'Albufera de València is one of the main wetlands in the east of the Iberian Peninsula. Due to its vast extension (21,120 ha) and high biodiversity, it is considered one of the most important wetlands in the western Mediterranean. The large extension of the rice field in L'Albufera has favored the establishment of 20,000-30,000 breeding pairs of different species of waterbirds, among which herons can be highlighted. L'Albufera de València is the third most important heron breeding site in Spain (Garrido et al. 2012) and hosts 61% of the egrets and herons nesting in the whole Valencia Region, including the Grey Heron as the third most numerous species (Generalitat Valenciana 2018, Forti et al. 2021a). This Grey Heron breeding colony, established in 1984 (Gómez-Lopéz et al. 1985, Prósper 2000) has been the most important colony on the Spanish Mediterranean coast for the last 20 years (Campos et al. 2001, Prieta and Campos2003, Garrido et al. 2012) and represents 48% of the nesting Grey herons in the Valencia Region (Generalitat Valenciana 2021) and 11% in Spain, according to the last published national census (Garrido et al. 2012).The breeding population of L'Albufera had been experiencing a significant increase until 2013, reaching 1095 breeding pairs in 2000 (GeneralitatValenciana 2013). However, in recent years its nesting numbers decreased, with only 215 pairs found in the last local census in 2021 (Generalitat Valenciana 2021).

The breeding population of L'Albufera was formerly studied from 1988 to 1990 (Prósper and Hafner 1996, Prósper 2000), where it was established that the species starts nesting in January, with peak clutches at the end of the month when the rice fields are still flooded. However, in recent decades, rice field management has varied in terms of the start and duration of flooding periods during the annual period and in agronomic practices during the growing season, with flooding starting later and for shorter periods, among others. These changes have affected negatively both the quality of the feeding habitat for herons and other birds, as well as the reproductive success of some species such as the Little Egret (*Egretta garzetta*) or Cattle Egret (*Bulbucus ibis*) (Antón-Tello et al. 2021, Forti et al. 2021b). According to these studies, it is to be expected that the reproductive biology of the Grey Heron in L'Abufera de Vàlencia could have been affected, both in phenology and reproductive success, due to the effect of new practices in rice cultivation, which could also be related to the population declines that have been reported for the area (Generalitat Valenciana 2021, Forti et al. 2021a). Over the last 30 years no further studies have been carried out on this breeding colony and how changes in the management of the rice field have influenced its breeding parameters, so a new assessment is needed. Therefore, the aim of this study is to analyze the effects of current rice field management practices and their inter-annual variations on the breeding parameters of the Grey Heron. Although the Grey Heron does not present conservation problems, since it is a widely distributed and easily adapted species, there are other heron species that nest in the study area that are in some conservation category, such as the Purple Heron, the Squacco Heron and the Glossy Ibis (Real Decreto 139/2011, Decreto 32/2004, Madroño et al 2004). Probably, the condition of the rice fields is also related to the reproduction of these and other species of waterbirds nesting in L'Albufera. With this information, rice field management measures can be proposed to maintaining healthy breeding populations of waterbirds within this important nesting area.

Methods

Study Area

L'Albufera de València is a Mediterranean coastal wetland, located between the mouths of the Júcar and Turia rivers, in the Gulf of València (39°17′ N, 0°20′ O) (Fig. 1). Since 1989 l'Albufera has been included in the "Wetlands of International Importance" (RAMSAR site), and since 1992 it has formed part of the Natura 2000 Network, having been declared a "Special Area for the Protection of Birds" (SPA) and "Site of Community Importance" (SCI). L'Albufera de Vàlencia covers an area of 21,120 ha, of which 2,800 ha correspond to a shallow lagoon and 290 ha of marshland vegetation, which is fed by crop returns and water from the fluvial systems of the Júcar and Turia rivers. The rice fields cover 14,000 ha and represent an important habitat for the waterfowl community, both resident and migratory, especially during the breeding season, as they are the main feeding area for the latter (Fasola and Ruiz 1996, Fasola et al. 1996, Dies and Dies 1998, Prósper 2000, Toral and Figuerola 2010, Antón-Tello et al. 2021, Forti et al. 2021b). The hydrological dynamics of the paddy fields depend on the amount of water that enters the system twice a year. At the beginning of May, the paddy fields are flooded for rice cultivation, which lasts until the end of September or early October. This is followed by a draining period for rice harvesting. In November, as an environmental measure and to create places for waterfowl hunting, the rice fields on the perimeter of the lagoon are flooded again, remaining with different levels of water until the end of the hunting period, at the end of January. From then on, the rice fields are progressively dried, in accordance with current agronomic practices, to prepare the land for sowing (Prósper 2000, Oltra et al. 2001).

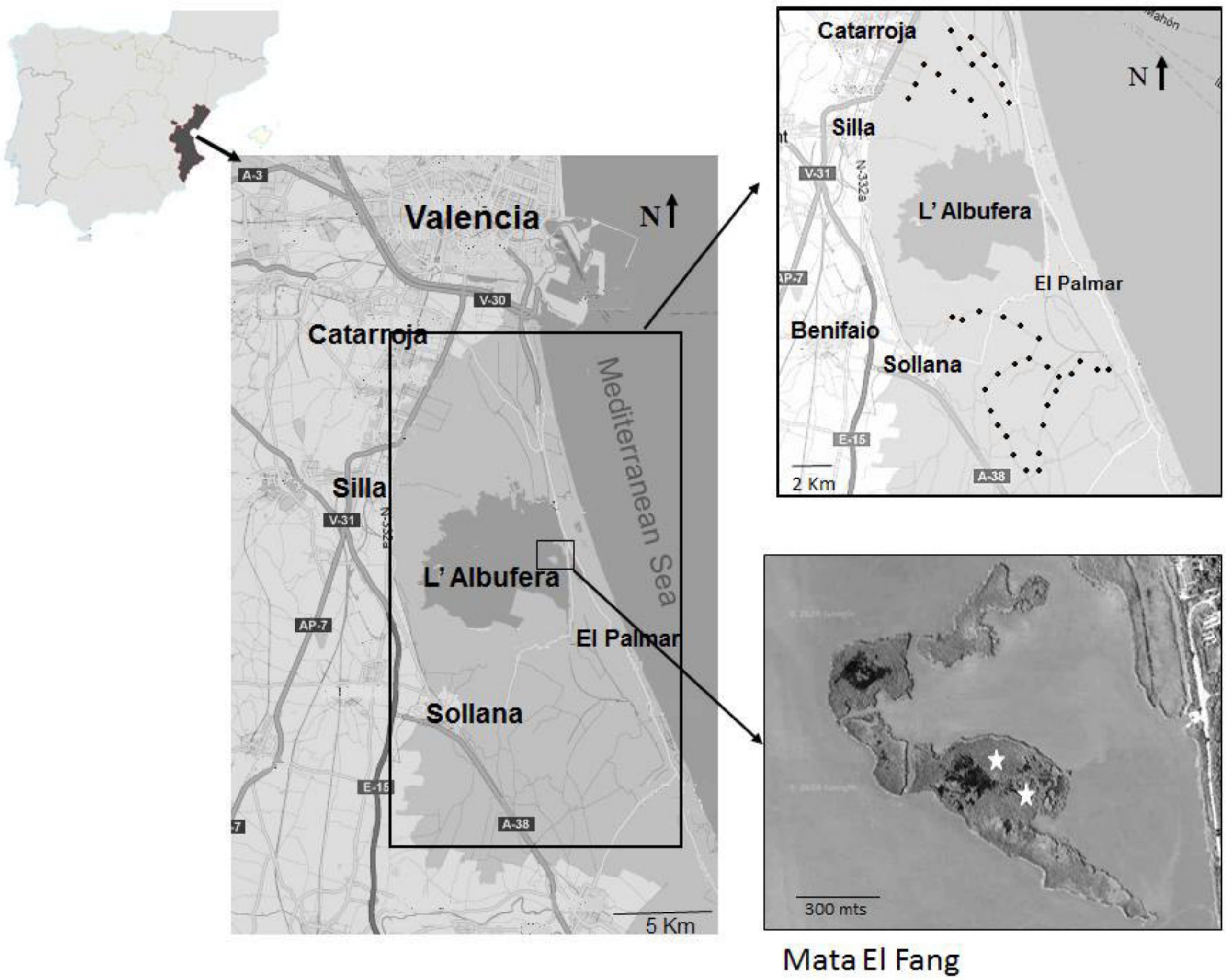

Figure 1: Location of Grey Heron breeding colony in the "mata" of El Fang and census points in the rice fields of L'Albufera de València.

The marsh vegetation consists mainly of Common Reed (*Phragmites australis*), Cat-tails (*Typha domingensis*), Swamp Sawgrass (*Cladium mariscus*), and Bulrush (*Scirpus lacustris*, S. *tabernamontani*, *S. holoschoenus*), which group together to form islands known locally as "matas" and which constitute refuges for birds and a nesting substrate for herons. Grey Heron colony are located in the Mata El Fang, located on the eastern shore of the lake (Fig. 1).

Breeding Parameters

Grey Heron colonial cores were visited every 10 days between February and April in the years 2016 to 2018 (hereafter referred to as early breeding season) and between May and July 2015 to 2017 (referred to as late breeding season). Sampling was conducted on these dates because these are the nesting periods reported for this species in the locality (Prósper and Hafner 1996, Prósper 2000). All nests found were marked with numbered tape and geo-referenced. On each visit, the number of eggs, number of hatched chicks and age of each chick in the nest were recorded. The clutch size was set as the maximum number of eggs observed, which did not vary on subsequent visits. Clutch size was assumed to be equal to the number of chicks when the nest contained newly hatched or 2-3 day old chicks. Egg laying date was estimated by counting backwards 25 days of incubation from the hatching of the first chicks in the nest (Hankock and Kushlan 1984). Brood size was taken as the number of successful chicks per nest. Successful chicks were defined as those that survived until 20 days after hatching (Jakubas 2005, Ashoori et al. 2009). Nests that produced at least one successful chick were considered successful nests.

With the data obtained, hatching success (number of hatched eggs/total number of eggs), nesting success (number of successful chicks/number of hatched chicks) and breeding success (number of successful chicks/total number of eggs) were estimated per nest.

Habitat Availability and Use

The rice fields were visited fortnightly, making routes in both the northern and southern areas of the lagoon, between February 2016 and June 2017. Sampling routes were established along the roads that run through the rice fields, where observation points were selected approximately 500 m apart, resulting in 26 sampling points in the southern zone and 15 points in the northern zone (Fig. 1). The field condition was established by categorizing each observed field according to its status, as dry (totally dry field, ploughed or not), muddy/wet (field with wet soil, mud, with small scattered puddles of water, worked with machines or not), semi-flooded (field with some areas covered with water, very shallow, but not covering the whole area), flooded (field with the whole area flooded, resembling a lagoon), sown (field with water cover but with rice plants, in all stages), and harvested (field with remnants of the crop, fallow, burned or not). For each month, the percentage of fields in each of the categories was calculated. In this case, the months of the reproductive period (January-June) were considered. July was not included as no data were available for this month in 2017.

The number of Grey herons present at each observation point was also recorded during the same surveys. The total number of individuals observed on each date and for each field condition (dry, mud/wet, semi-flooded, flooded and sown) was quantified, as well as those observed in irrigation ditches and canals. Because the number of surveys was not equal in the two years, the data were standardized by dividing the number of individuals observed, in each field condition, by date, by the number of surveys conducted during the year, in order to make comparisons.

Data Analysis

To compare reproductive parameters between years and between seasons within years, generalized linear models of the Binomial family were used for breeding success, hatching and nesting success, and Poisson for egg numbers. As predictors we used the interaction between Year and Season (Buckley 2015). Because these are categorical predictors, we calculate the marginal means of the parameters from the regression coefficients to facilitate the interpretation of the interaction between predictors (Searle et al. 1980).

Reproductive parameters were estimated for each breeding period (early and late), and within each season, corresponding to egg laying peaks and hatching maxima. These parameters were estimated separately for broods hatched in February and March (winter) and in May and June (spring). Due to the small sample size for each grouping (Year:Season:Month) we used the non-parametric method of Bootstrapping simulation with 10,000 randomizations to calculate means and 95% confidence intervals for these parameters for comparisons within seasons.

To assess the association between field condition and distance to the colony with the number of individuals at observation points, as well as the relationship between field condition and breeding success, generalized linear mixed models (GLMM) of the Poisson family were used for the number of individuals, and Binomial for reproductive success (Bolker 2015). For the Poisson model, we used year and the location of the observation point with respect to the colony (north, south)as random effect variables, while for the Binomial model we used year and season. Due to the high collinearity between field-related variables (dry/sown, r = -0.83; flooded/semi-flooded, r = 0.76), a reduction of variables was performed through a Principal Component Analysis with orthogonal rotation, which maximizes the variance explained by the components (Vejmelka et al. 2015).

Variable and model selection was achieved through the maximum likelihood approach based on AICc (Burnham and Anderson 2004). This analysis was performed in the bbmle R-package (B. M. Bolker, bbmle: Tools for general maximum likelihood estimation, https://cran.r-project.org/web/packages/bbmle/index.html). The effect of each predictor was estimated from the standardized regression coefficients and the maximum likelihood confidence interval was calculated for each coefficient (Harrison et al. 2018). Coefficients whose confidence interval is different from zero are considered significant.

Statistical analyses were performed in GNU R 4.1.1. (R Core team 2021).

Results

Breeding parameters

Laying and hatching phenology. In general, Grey Herons presented two differential egg laying periods, which are not necessarily the same individuals nesting in both periods (not a second clutch). The first period occurs in January-February and the second in April-May (Fig. 2a). In turn, in the early months of the year (early season), clutches were concentrated mainly in the third week of January and in the second and last week of February. In the late season, the highest proportion of clutches was found mainly in the third week of May (Fig. 2a).

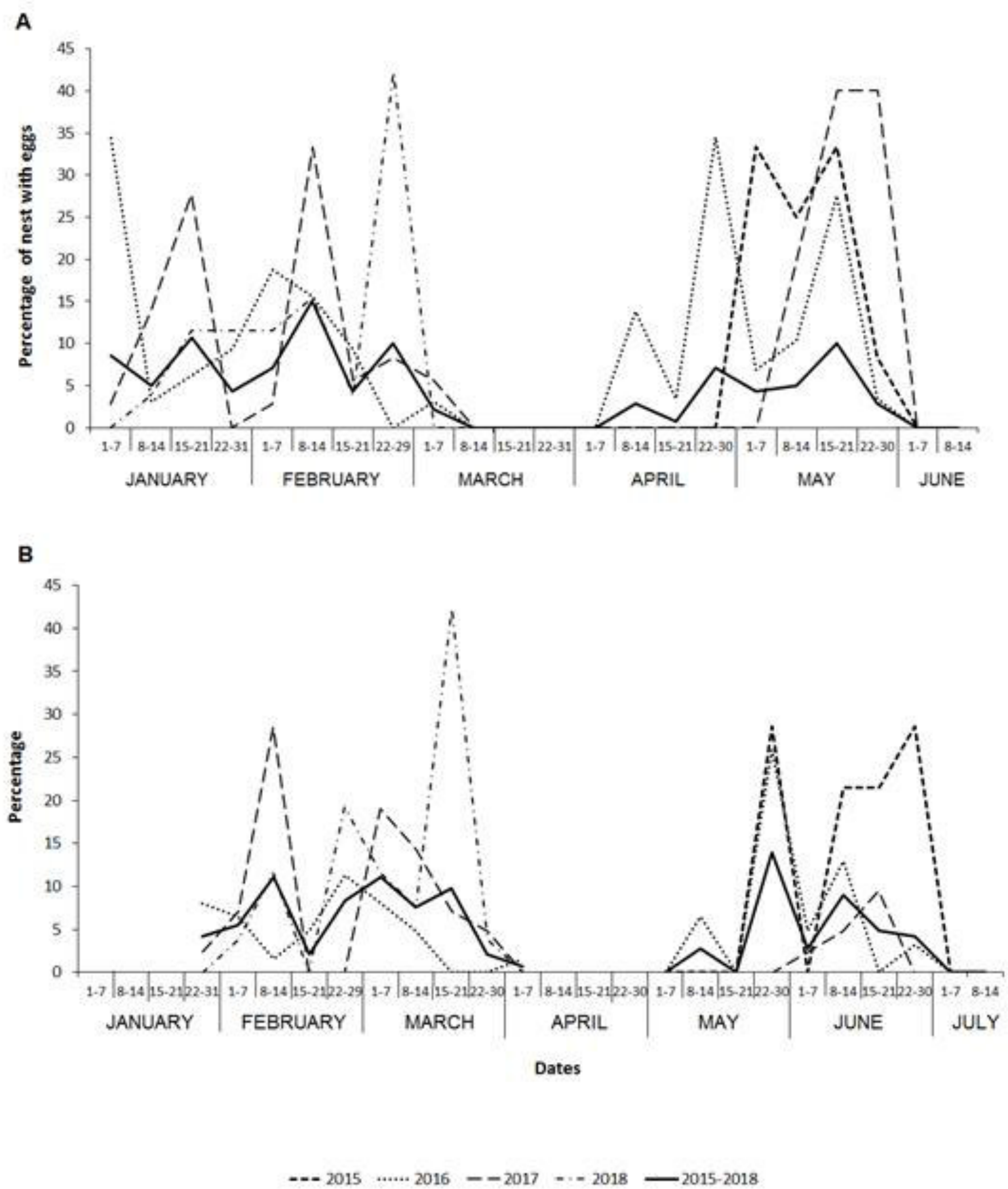

Figure 2: Grey Heron egg laying and hatching phenology during the period 2015-2018 in L'Albufera de València (A: egg laying phenology, B: hatching phenology).

Hatching occurred in greater proportion during the second week of February and the first and third weeks of March in the early season, while in the late season the dates with the highest percentage of hatchings were the last week of May and the second week of June(Fig. 2b).

Hatching, nesting and breeding success. Values for both clutch size and brood size were higher in 2017 than in 2016 (Table 1).Marginal means of GLMs showed significant differences in clutch size between late season 2016 and 2017, and for brood size between the 2016 and 2017 early season (Fig. 3a and b). Within each year there were only significant differences in clutch size between early and late season 2017 (Fig. 3a).

Concerning hatching success, the values within each season were higher in 2017 for both, early and late (Table 1). During the early season, significant differences were found between the 2017 and 2018 marginal means, but there were no differences in the late season (Fig. 3c).

Within the early season, 2018 had the highest nesting success, while for the late season the highest values were in 2015 (Table 1). Significant differences were found between the late season in 2015 and 2016, being lower in 2016, while in the early season there was no difference (Fig. 3d).

The highest values of breeding success for the early season were found in 2015, and in 2017 for the early season (Table 1). Between years, there were only significant differences in the late season between 2015 and 2016, with the lowest breeding success found in the latter (Fig. 3e). No significant differences in hatching, nesting and breeding success were found between seasons (early and late) within each year (Fig. 3c, 3d and 3e).

In the early season of 2016 and 2017, hatching, nesting and breeding successes were significantly higher in February than in March (Fig. 4). There were no significant differences between the late season months (May and June) (Fig. 4). In 2017 all chicks hatched in June. Hatchings were not analyzed separately before and after the flooding of the fields, as all hatchings occurred from May onwards (post-flooding).

Table 1: Reproductive parameters for the Grey Heron in the period 2015-2018 within L'Albufera de València.

	Nests marked	N° of successful nests	Clutch size	N° of hatched eggs	Brood size	Hatching success	Nesting success	Breeding success
2016	97	26 (27%)	2,88 ± 0,78	1,55 ± 1,30	0,46 ± 0,84	0,55 ± 0,43	0,22 ± 0,36	0,16 ± 0,29
2017	51	31 (61%)	3,19 ± 0,61	2,21 ± 1,33	1,13 ± 1,19	0,70 ± 0,39	0,37 ± 0,36	0,34 ± 0,34
Winter period								
2016	43	15 (34%)	2,95 ± 0,79	1,95 ± 1,28	0,59 ± 0,89	0,66 ± 0,40	0,23 ± 0,35	0,21 ± 0,32
2017	46	28 (60%)	3,19 ± 0,61	2,21 ± 1,33	1,15 ± 1,22	0,69 ± 0,40	0,38 ± 0,39	0,36 ± 0,37
2018	40	18 (45%)	3,00 ± 0,64	1,29 ± 1,20	0,82 ± 1,01	0,42 ± 0,38	0,55 ± 0,46	0,26 ± 0,35
Spring period								
2015	16	13(81%)	2,56 ± 0,73	2,00 ± 0,93	1,47 ± 0,99	0,81 ± 0,32	0,66 ± 0,42	0,63 ± 0,41
2016	54	11 (20%)	2,82 ± 077	1,25 ± 1,25	0,41 ± 0,91	0,46 ± 0,43	0,19 ± 0,38	0,14 ± 0,45
2017	5	3 (60%)	3,00 ± 0,71	2,4 ± 0,55	1,33 ± 0,58	0,82 ± 0,17	0,5 ± 0,17	0,39 ± 0,10
TOTAL	204	88 (43%)	2,95 ± 0,73	1,72 ± 1,29	0,77 ± 1,01	0,59 ± 0,42	0,35 ± 0,40	0,26 ± 0,35

Habitat Availability and Use of Rice Paddies

Overall, during the first breeding season of the year (February and March), the proportion of fields that were still waterlogged (muddy and semi-flooded) was higher in 2017 than in 2016 (Fig. 5a).

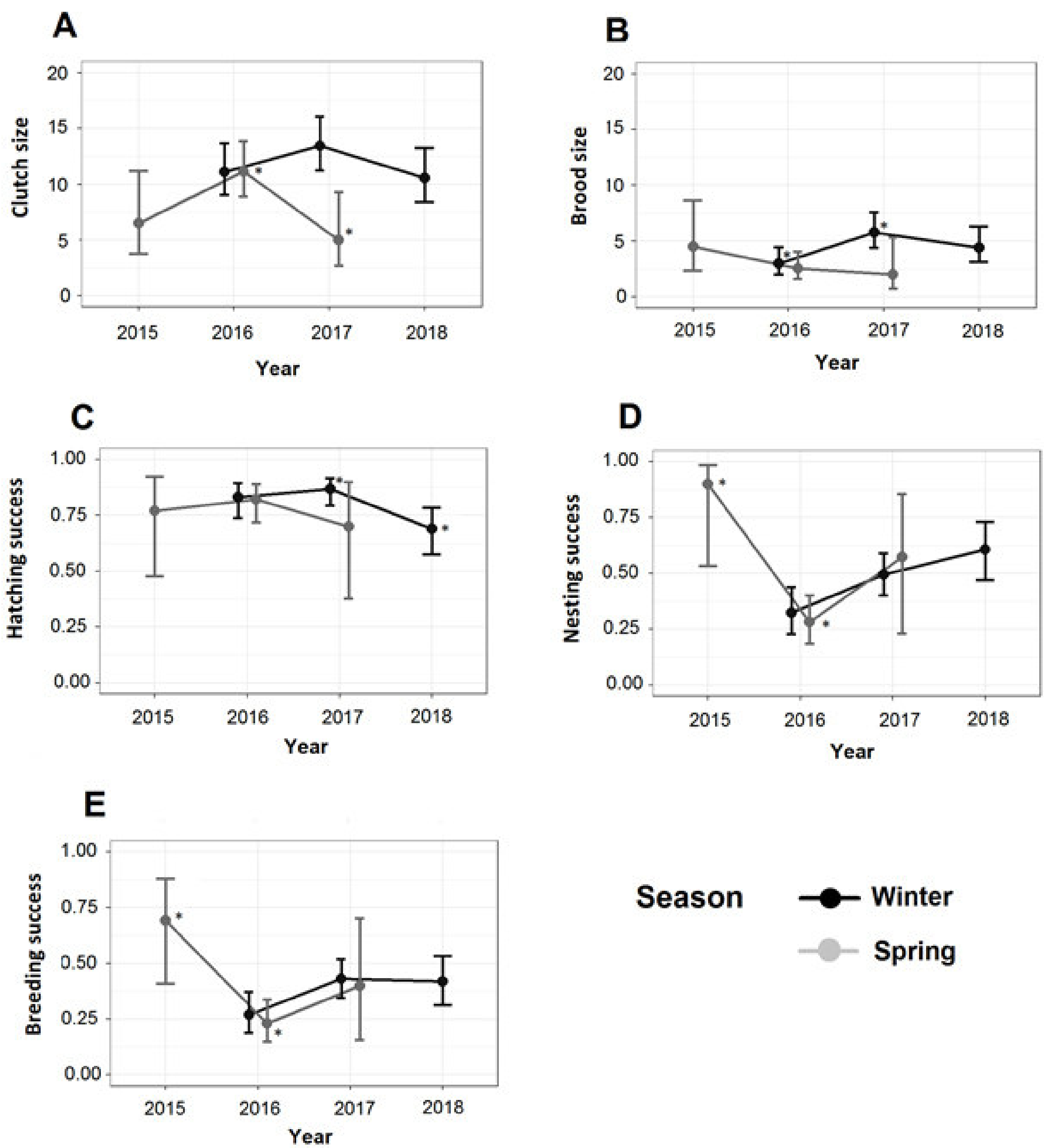

Figure 3: Marginal means of Grey Heron breeding parameters in the 2015-2018 breeding period in L'Albufera de València, obtained from the generalized linear models (* significant differences).

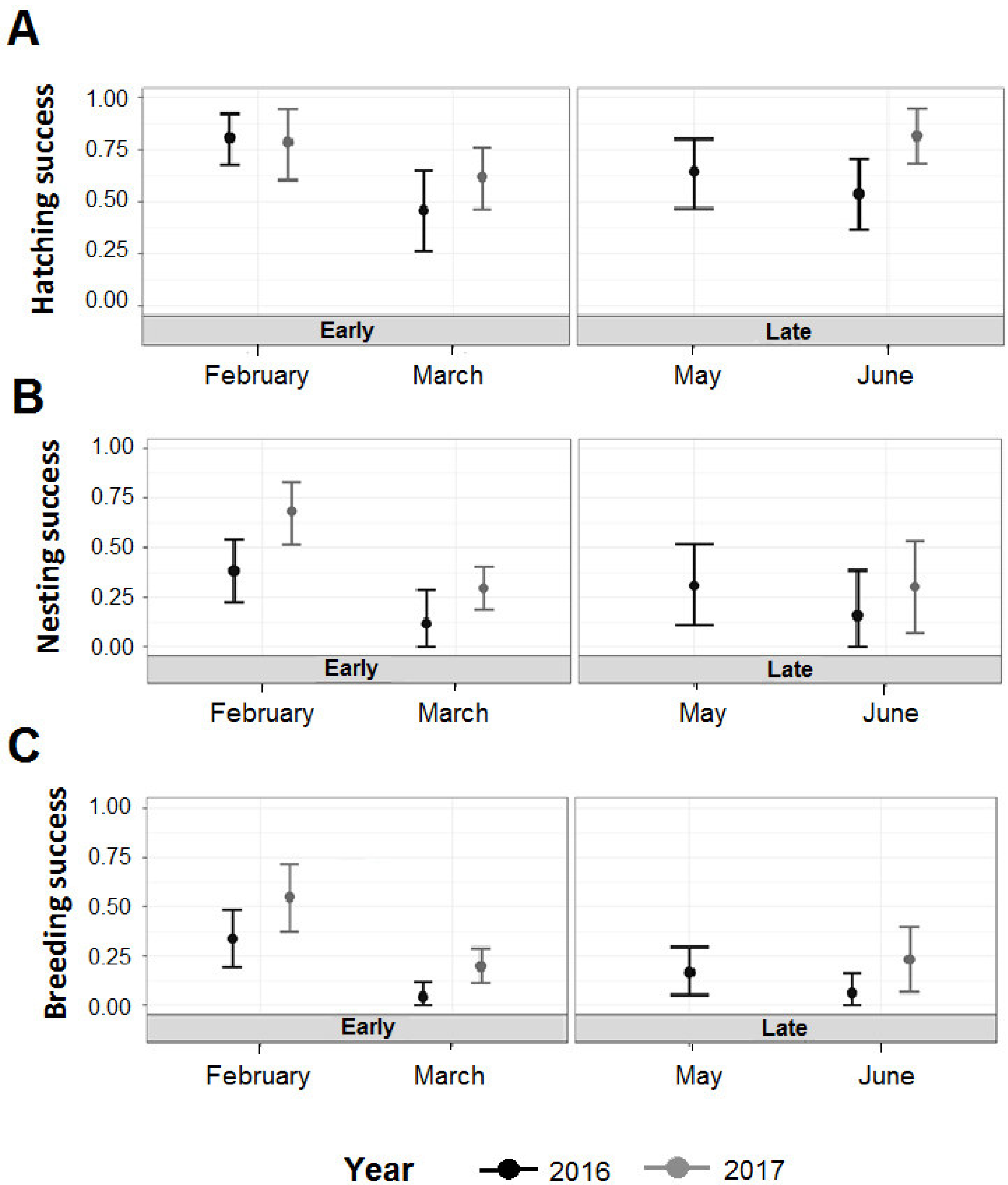

Figure 4: Mean and 95% confidence interval by Bootstrapping of hatching, nesting and breeding successes within the early (February-March) and late (May-June) breeding seasons of Grey Heron in the 2016-2017 breeding period in L'Albufera de València.

In 2016, the proportion of these fields decreased from 43%in the third week of February to 6% in the second week of March, while in 2017, muddy and semi-flooded fields occupied 60% of the area by the same week of February and only dropped to 4% in the fourth week of March. In 2016 the fields were completely dry from the third week of March (Fig. 5a).

In the late season (May-June), there was a higher proportion of muddy and flooded fields in May 2016 (22% and 24% respectively) than in 2017 (6% and 13% respectively) (Fig. 5b). Specifically, in 2016 the flooding of fields started in the second week of May, while in 2017 it started in the third week (Fig. 5b). The sowing of fields also started later in 2017, as by the third week of May the proportion of fields sown in 2016 was 20% while in 2017 it is 0%. The 100% of fields sown is reached in the second week of June in 2016 and one week later in 2017 (Fig. 5b).

The highest number of individuals was recorded in February, coinciding with the highest percentage of muddy/semi-flooded fields, while the lowest number of herons was recorded in April, when 100% of the fields were dry. At this stage, the number of individuals using the irrigation ditches increased.

Statistical analyses support this observation. The best model explaining the abundance of individuals included the variables of muddy/semi-flooded, flooded and dry fields, and the interactions between them (model 4, Table 2). In the GLMM coefficient analysis, muddy fields had a high positive effect (highest regression coefficient) on the presence of individuals, followed by flooded fields, while dry fields were shown to have a negative effect on heron abundance (Fig. 6a).

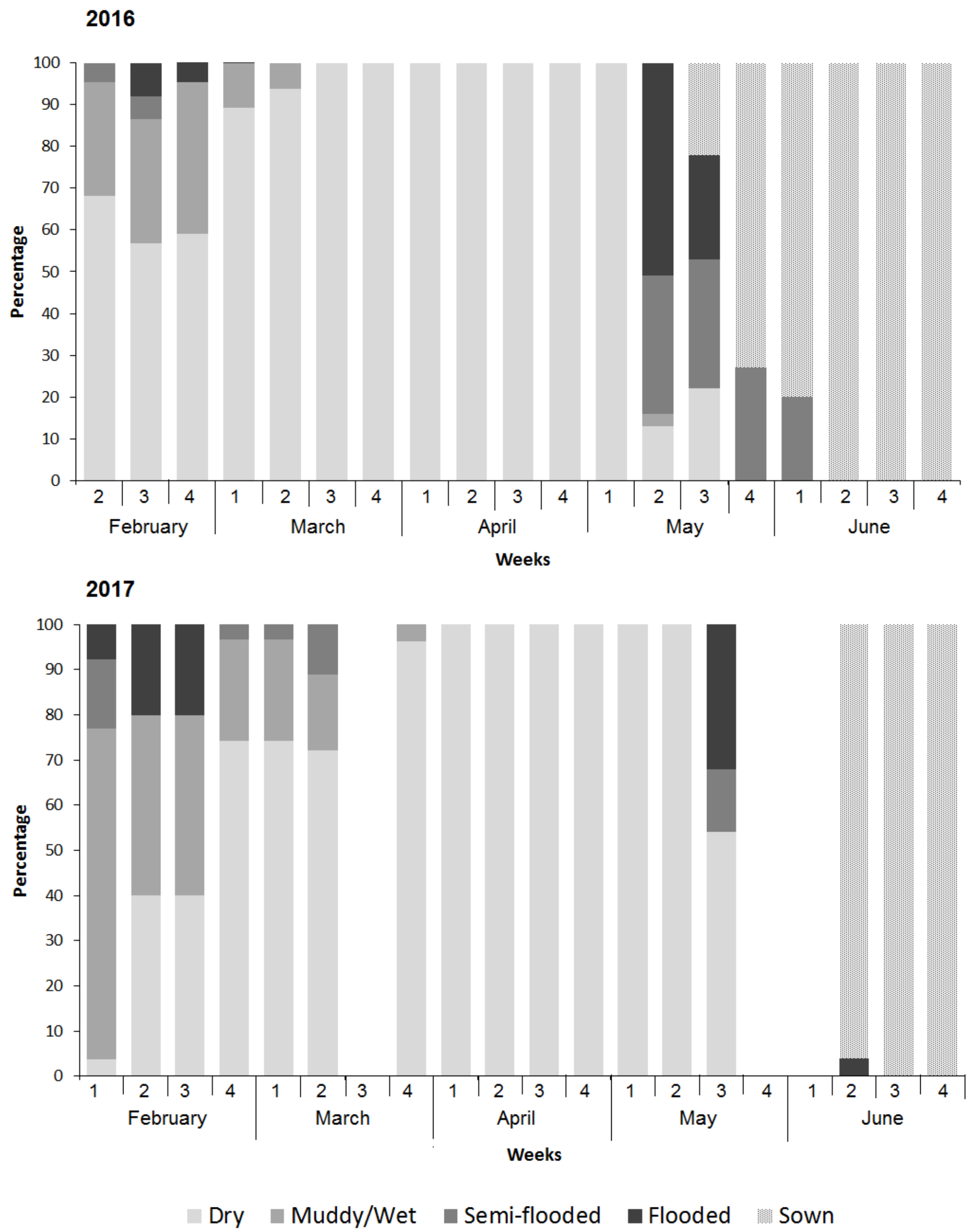

Figure 5: Status of rice fields in 2016 and 2017 in L'Albufera de València (gaps are weeks without data).

Table 2: Multi-model selection (GLMMs) for Grey Heron abundance in the rice field, using different combinations of fixed predictors (standardized field conditions and distance to the colony) and year and location of the fields (north or south) as random effect. Selection based on the Maximum Likelihood Approach. In bold the selected model is indicated (- LogLik = log Likelihood function, AICc = Akaike Information Criterion with correction for large models, ΔAICc = AICc of each model - AICc of the best model).

Model	Fixed effects	LogLik	AICc	ΔAIC	d.f
Model 4	Distance + Muddy/Wet + Flooded/semi-flooded + Dry	-4886.4	9786.9	0.0	7
Model 3	Distance + Muddy/Wet + Flooded/semi-flooded +	-5051.4	10115.0	328.1	6
Model 2	Distance + Muddy/Wet	-5070.6	10151.2	364.4	5
Model 1	Distance	-5721.2	11450.4	1663.5	4
Model 0	Null	-6192.6	12391.2	2604.3	3

Distance: normalized score of distance
PC1 scores: Dry
PC2 scores: Flooded/Semi-flooded
PC3 scores: Muddy/Wet
see table S1

Distance to the colony was also a variable that is related to the number of individuals present (model 4, Table 2), having a strong negative effect (high negative regression coefficient) on the presence of individuals (Fig. 6a). The highest concentration of herons occurred in the fields closest to the colony, within a radius of

8.5 km from the colony, while in the fields furthest from the colony the presence of the birds was lower (Fig. 7).

In late season, when all fields were equally flooded (May) or sown (June), herons extended their range to about 11 km from the colony, although the number of individuals using these fields remained low in relation to those using the fields closer to the colony (Fig. 7).

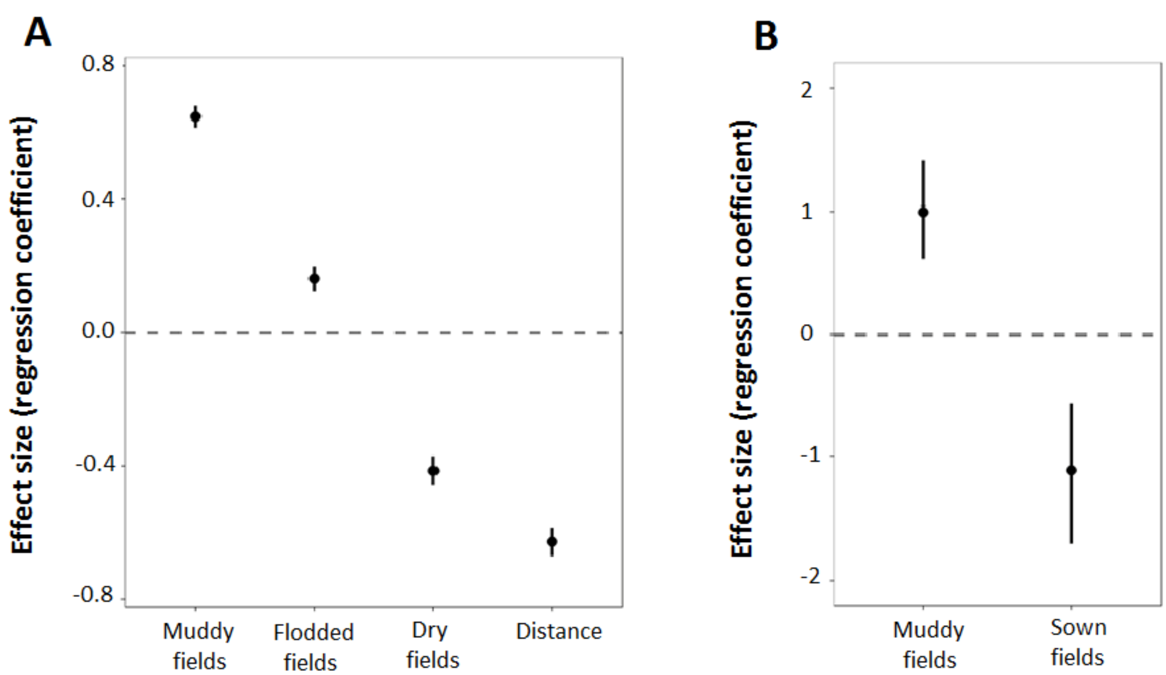

Figure 6: Effect (regression coefficient) of field condition and distance on number of individuals (A) and of field condition on breeding success (B).

Rice Field Condition and Reproductive Parameters

The model that best explains the relationship of field condition with breeding success was the one that includes the variables of sown fields and muddy/semi-flooded fields and their interactions (model 9, Table 3).

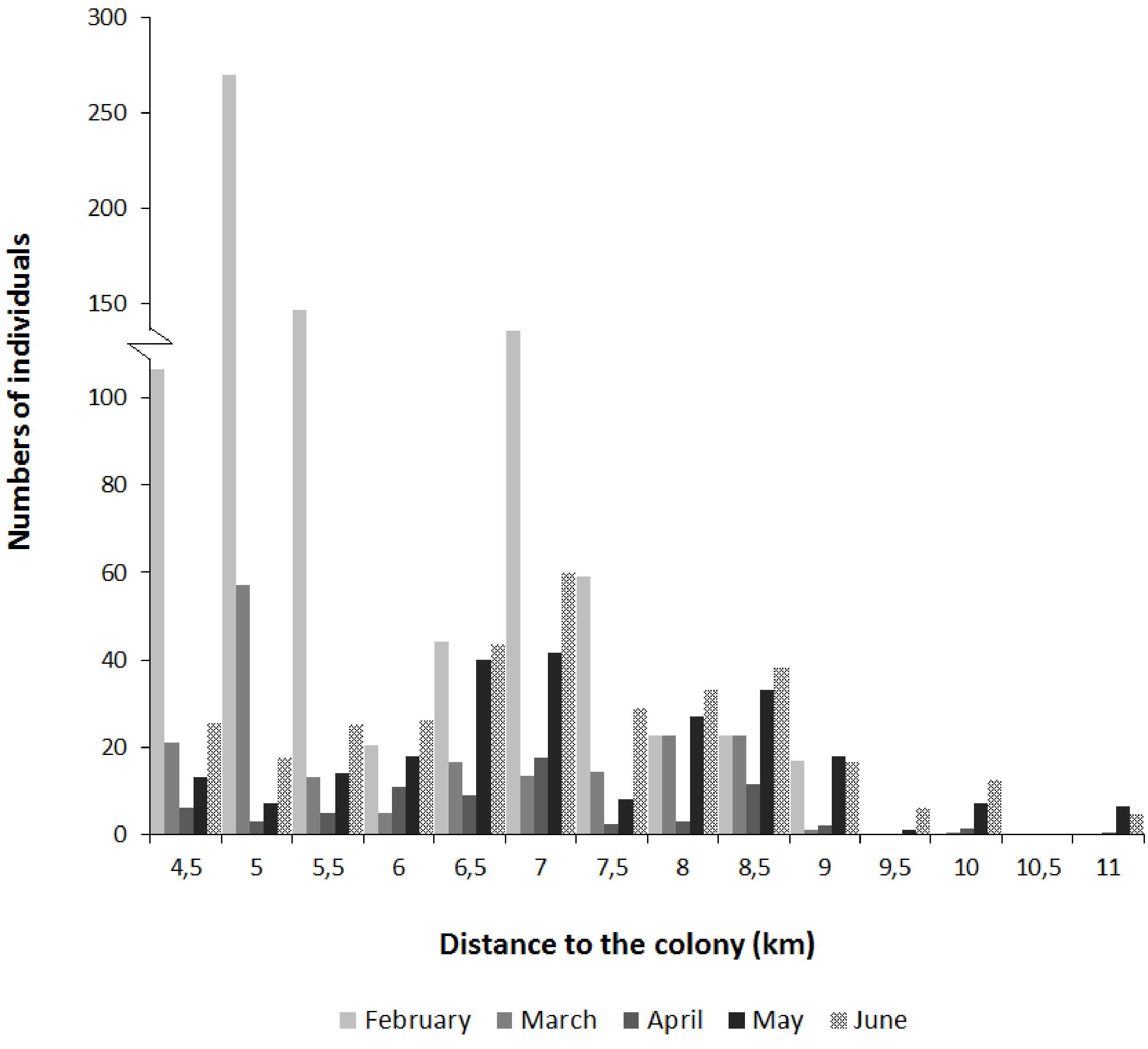

Figure 7: Average number of Grey Heron individuals recorded at different distances from the colony in L'Albufera de València during the breeding period 2016-2017 (mainland starts from 4 km from the colony).

Table 3: Multi-model selection (GLMMs) for Grey Heron breeding success using different combinations of fixed predictors (standardized field conditions) and year and season as random effect. Selection based on the Maximum Likelihood Approach. In bold the selected model is indicated (- LogLik = log Likelihood function, AICc = Akaike Information Criterion with correction for large models, ΔAICc = AICc of each model - AICc of the best model).

Model	**Fixed effects**	**LogLik**	**AICc**	**ΔAIC**	**d.f**
Model 10	Sown + Muddy/Wet + Flooded/Semi-flooded	-37.4	92.8	0.0	6
Model 9	Sown + Muddy/Wet	-39.7	93.5	0.7	5
Model 8	Muddy/Wet + Flooded/Semi-flooded	-40.7	95.4	2.6	5
Model 6	Flooded/Semi-flooded	-44.7	99.8	7.0	4
Model 7	Flooded/Semi-flooded+ Sown	-44.4	102.8	10.1	5
Model 5	Null	-54.0	115.4	22.6	3

PC1 scores = flooded and semi-flooded fields
PC2 scores = sown fields
PC3 scores = muddy/wetfields
see table S2

Although model 10 had the same explanatory weight, model 9 was selected, following the principle of parsimony, as it had fewer variables. According to the coefficient analysis of the GLMMs, muddy/semi-flooded fields had a positive effect on reproductive success (high positive regression coefficient), while sown fields had a negative effect (Fig. 6b). A higher number of hatchlings, of those born in February, in both 2016 and 2017, reached the age to fledge the nest (higher reproductive success, assigned to hatching date) coinciding with a higher percentage of muddy/semi-flooded fields(Fig. 8).

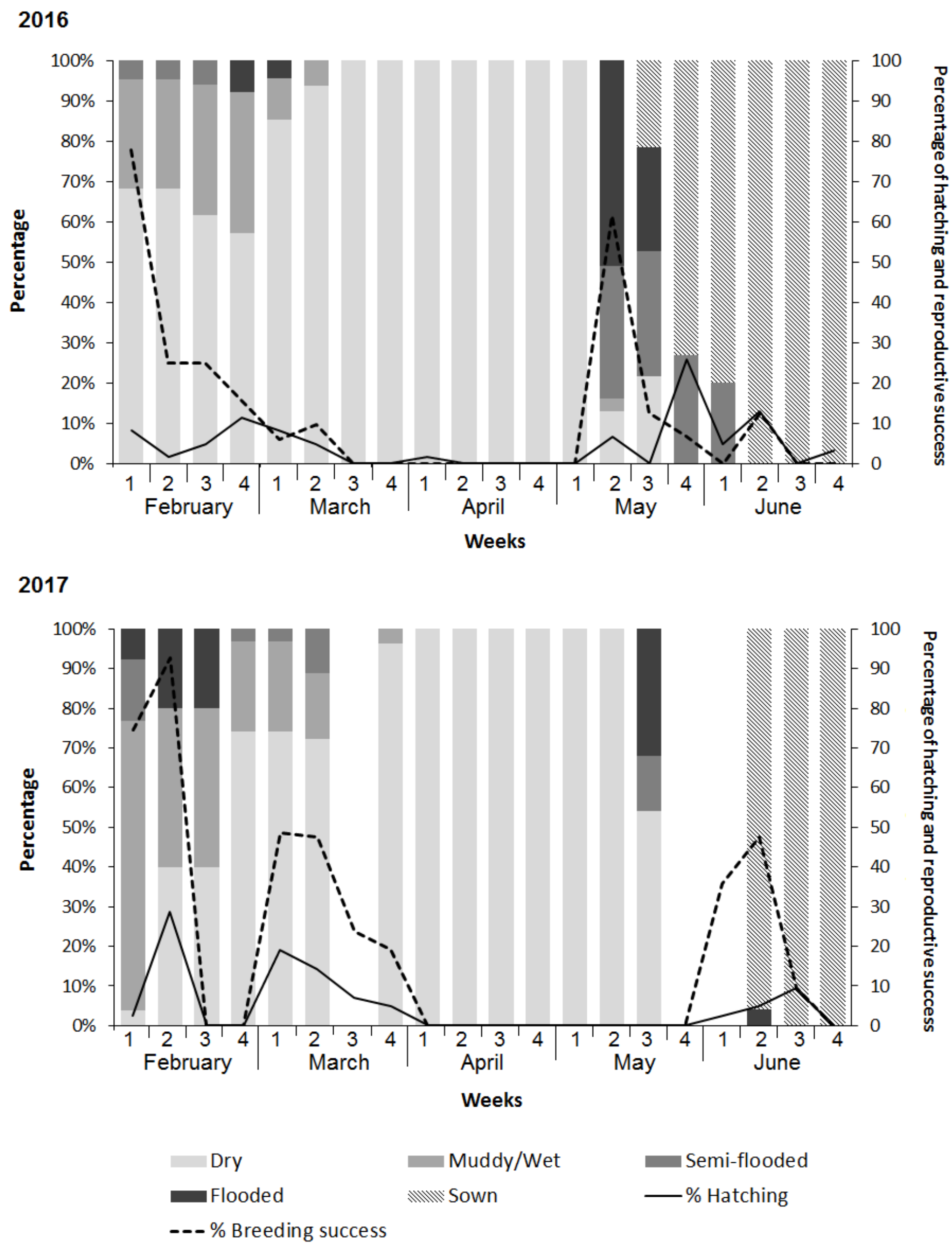

Figure 8: Percentage of hatching and breeding success of Grey Heron and condition of the rice field in L'Albufera de València during the breeding period of 2016 and 2017 (gaps are weeks without data)

For chicks hatched in March, reproductive success was lower compared to that of hatchlings born in February. However, between years, reproductive success for March 2017 was higher than in 2016, as was the proportion of muddy/semi-flooded field..

In the first two weeks of March 2017, muddy/semi-flooded fields occupied 27% of the paddy area, while in 2016 such fields occupy only 9% (Fig. 8).

Similarly, during the late season, chicks that hatched when there were still muddy/semi-flooded fields were more likely to fledge successfully. This was the case for hatchlings born in the second week of May in 2016 and in the second week of June in 2017 (Fig. 8). Likewise, breeding success decreased in those cases when chicks were hatched at the time when most of the fields were sown (Fig. 8). For these cases the reproductive success is assigned to the hatching date of each nest.

Discussion

Reproductive Phenology

Two laying seasons were observed during the study period, the first between January and February, and the second between April and May. The same pattern was observed in the 1988-1990 breeding season, although on that occasion there was a peak egg laying season in March, followed by sporadic clutches in April and May (Prósper and Hafner 1996). This pattern has also been observed in the Duero River Basin, though the onset of egg laying does not begin until early March (Campos and

Fernández-Cruz 1991). These authors attribute the second peak of clutches, which occurs in this locality in late April and early May, to the late arrival of breeding pairs and the second (replacement) clutches of couples that failed to lay their first clutch. In other regions of northern Spain, although the breeding season begins in January with nest building, egg laying is staggered from February to May (Belamendia et al. 2003).

In the case of L'Albufera, the earliest onset has been attributed to the availability of food during the winter months due to the agro-environmental practices of flooding of thesurrounding rice fields (Prósper 2000) and to the less critical winter temperatures compared to other areas in Spain and Europe (Campos and Fernández-Cruz 1991, Caballero 1996, Prósper 2000).On the other hand, the fact that in L'Albufera the reproductive period is divided into two separate seasons may be due to the management of the rice paddies, which keeps the fields completely dry for about a month and a half, which was not the case in previous decades. Previously, in the 1980s and 1990s, flooding of rice fields in L'Albufera began in April, while planting began in early May (Prósper 2000, Oltra et al. 2001, Goméz de Barreda 2009), whereas during the study period, flooding did not begin until early May and planting at the end of the month. The interruption of the flooding regime during the month of April (and part of March) could be the reason why the breeding period is divided. Like other bird species, herons may have modified the onset of reproduction in response to the change in the timing of peak food abundance (McKinnon et al. 2012, Visser et al. 2012, Funk 2013).

Reproductive Success and Rice Field Management

Paddies and irrigation canals are important foraging habitats for breeding herons and egrets(Hafner et al. 1987, Fasola and Ruiz 1996, Fasola et al. 1996, Delord et al. 2003, Elphick et al. 2010) and more so, when marshes and natural freshwater bodies dry up (Tourenq et al. 2001). Although rice fields are flooded independently of rainfall, the flooding regime for rice field management may affect the availability of flooded feeding areas and consequently breeding success (Prósper and Hafner 1996, Lekuona 2002, Cardarelli et al. 2017). In L'Albufera, reproductive parameters were higher in February than in March (in both years), when most of the fields still had some water level due to the flooding and drying schedule of the rice field, despite the lower rainfall in that month (AEMET). However, in the spring, the lowest reproductive success was obtained in 2016, when rainfall was lower, reaching zero in the month of June, and the highest was achieved in 2015 when rainfall was the highest of the three study years (AEMET). Although the effect of rainfall on reproductive success was not directly assessed in this study, other studies have found that rainfall is associated with a higher value of this parameter (Hafner et al. 1994, Bennets et al. 2000, Si Bachir et al. 2008, Nefla et al. 2012), which could partly explain the results obtained during the late season (spring).

The total surface area of flooded fields has been linked to food availability and this in turn to reproductive success (Owen 1960, Hafner et al. 1987, Hafner et al. 1994, Manikowska-Slepwronska et al. 2016). Similarly, this influences the number of visits to the nest by parents to feed chicks or the quantity/quality of food offered at each visit (Owen 1955), which is directly related to mortality of larger chicks and fledglings

(Jakubas 2005). In this study, reproductive success was positively associated with the presence of fields with a certain level of water (muddy and semi-flooded). On the one hand, when the fields begin to drain in February and March, potential prey, such as crustaceans, amphibians and fish, were concentrated in the remaining water (semi-flooded fields), which made them more accessible to herons and thus provided a high feeding opportunity (Marques and Vicente 1999, Mugica et al. 2006). Before all the water is removed, the muddy fields are ploughed blending the mud in surface, which also allows the entry of external energy, which also produces an increase in the availability of prey, mainly crustaceans, which are more abundant at this stage of the crop (Mugica et al. 2006). This type of field (muddy ploughs) is where the highest prey consumption (Kg/ha/day) has been recorded throughout the year in the rice fields of Cuba (Mugica et al. 2006). By March most of the fields were already dry. Thus, chicks hatched in the last week of February (in 2016) and the first weeks of March (in 2017) find the rice fields mostly dry. As March and April progressed, the availability of fields with a certain level of water decreased, reducing the availability of foraging areas where parents obtain food for their offspring. This translates into the low survival rate found in the chicks born at this stage. The suitable and abundant food habitat found at the beginning of the reproductive cycle disappears completely with the drying of the fields.

In relation to the late season, breeding success was also higher in the months with a higher proportion of muddy/semi-flooded fields, as was the case in 2016, when hatchings occurred at the beginning of the floods, in the month of May. In 2017 all the chicks hatched in June so they found with most of the fields sown. However, those hatched at the beginning of the month still had some area of muddy/semi-flooded fields available. In May, the fields began to be flooded to prepare the land for cultivation by means of new mud-ploughing operations. Due to the increase in weight and size of the organisms, the biomass of prey increases as the crop progresses, reaching its maximum in mature rice fields, where there are also a greater number and diversity of prey (Gonzalez-Solís et al. 1996, Marques and Vicente 1999, Mugica et al. 2006). The highest fish biomass is found at this stage of the crop (Mugica et al. 2006), and the cover of emergent plants can also favor the colonization of macroinvertebrates, as has been observed in seasonal wetlands (De Szalay and Resh 2000). However, the high cover of rice plants at this stage makes it difficult to capture prey, so they are consumed at a low rate (Gonzalez-Solís et al. 1996, Mugica et al. 2006, Ibañez et al. 2010, Nam et al. 2015). Thus, great herons, such as Grey Heron, are rarely found in dense paddy fields and are more associated with flooded fields after mud-ploughing (Nam et al. 2015). Decreasing prey availability in sown fields as cultivation progresses could be the cause of the low reproductive success associated with this rice field condition. For this reason, it would be advisable, as agricultural management, to leave spaces on the edges or margins of the fields with lower sowing density in order to encourage the feeding of this and other species.

Because prey availability varies seasonally and is related to the flooding regime and cultivation practices (Ibañez et al. 2010, Cardarelli et al. 2017), changes in water management and the flooding cycle of the rice field, such as reducing the flooding period or intensifying winter drainage for soil preparation, may negatively affect the reproductive performance of this species (Prósper and Hafner 1996, Generalitat

Valenciana 2002, Ibañez et al. 2010). In L'Albufera de Vàlencia, the management of winter flooding, both in extent and duration, acquires a relevant importance in the reproductive success of the Grey Heron. However, in recent decades, the area flooded in this period has been decreasing, as well as the volume of flood water by approximately 6% (Soria et al. 2015). On the other hand, rice field management is currently facing increasing pressure on the distribution of water resources, which is a determining factor in the maintenance of feeding and nesting of different bird species (Picazo-Tadeo et al. 2009). The development of agricultural activities other than rice cultivation, in areas surrounding the rice field, increases the demand on irrigation systems that depend entirely on the Jucar and Turia rivers, as well as the lagoon itself (Palop 2015). This is combined with the effects of climate change, which is causing a decrease in water supplies due to the reduction of the resource at the basin level as a result of reduced rainfall (Palop 2015). Given this situation, the way in which water management planning and rice field management, including flooding regimes, is undertaken takes on greater importance, particularly at this time when production is adjusting to more competitive markets and is facing declining profitability (Girona 1998, Picazo-Tadeo et al. 2009, Martinez 2018).

Conclusions

L'Albufera de València is the most important Grey Heron colony in eastern Spain (Campos et al. 2001, Prieta and Campos2003, Garrido et al. 2012). The reproductive success of the Grey Heron in L'Albufera de València is related to the fact that the rice fields maintain a certain level of water so that they serve as a food source for the young. The early drainage of the fields in winter and the prolonged time that the fields remain dry, results in high mortality of chicks, which translates into low reproductive success. Hence the importance of proper management of winter flooding, in terms of extent, water volume and duration. On the other hand, reproductive success in spring is favored when the crop cycle is synchronized with the reproductive cycle of the species, so that the start of summer flooding and rice sowing should coincide with the hatching and rearing of the young.

The Grey Heron is a widely distributed species and adapted to different types of habitat, so there are no real conservation problems. However, there are numerous species of aquatic birds that also nest in the area, including species with some conservation category. These species, which also feed in the rice field during their reproductive season, could also be affected by rice field management, as has been observed in other heron species in the area (Forti et al. 2021b). Therefore, the success of the breeding populations in L'Albufera de València requires planning and management of the protected area that considers the biological and reproductive requirements of the species. In this case, based on the results of this study, water management, the timing and duration of floods must be synchronized with the needs of the colony to ensure reproductive success. It is also important to maintain certain areas with low plant density to allow for adult foraging success.

On the other hand, it is also necessary to keep information on this colony up to date to show the effects that changes in cultivation techniques and water management, as well as the effects of climate change (changes in rainfall patterns), could have on the reproductive performance of this population.

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Capítulo 6

Discusión General

Replaza de Zacarés
Foto: Mariela Forti

Los humedales de la Comunidad Valenciana son de un alto valor natural, tanto por la amplia extensión que abarcan como por la alta biodiversidad que alberga, lo que los ubica entre las zonas húmedas más importantes del Litoral Mediterráneo Español y de la Comunidad Europea (Ferrer-Polo et al., 2006). En varios de estos humedales se han establecido colonias reproductoras de garzas, que difieren en número y composición, las cuales han ido incrementando su población, tanto invernantes como nidificantes, en las últimas décadas, al igual que otras especies de aves acuáticas (Garrido et al., 2012; Martinez-Abraín et al., 2016). La cantidad total de parejas reproductoras, de garzas y morito, dentro de la Comunidad Valenciana se relaciona directamente con el número de parejas reproductoras que nidifican en el P. N. L'Albufera, el cual sigue siendo la colonia más importante de la región (Generalitat Valenciana, 2022). Esta área protegida tiene la particularidad de ser un mosaico de espacios naturales y campos de arroz, que ocupan el 70% de la superficie del parque natural y son la principal fuente de alimento de las garzas que nidifican en el área (Prósper y Hafner, 1996;Prósper, 2000; Antón-Tello et al., 2021). Lo mismo ocurre en otros humedales de la Península, donde amplias extensiones de arrozales incluidas en áreas protegidas albergan grandes colonias de garzas y otras aves acuáticas, como los parques naturales del Delta del Ebro y Doñana (Ramo et al., 2013; Curco y Begnoli, 2019). Por lo mismo, la reproducción exitosa de estas aves, dentro de L'Albufera, está ligada al manejo del arrozal, tal como se demuestra en este trabajo.

En este contexto, quisimos evaluar, en primer lugar, las tendencias poblacionales de las colonias reproductoras en los humedales más importantes de la Comunidad

Valenciana, y esclarecer las características del hábitat y condiciones meteorológicas que podrían estar determinando el establecimiento y tamaño de dichas colonias. Para ello, utilizamos los registros de los censos de garzas nidificantes en un periodo de 30 años (1984-2015) para establecer las tendencias poblacionales de las principales colonias reproductoras de la región, a la vez que se las relacionó con ciertas características del hábitat de los humedales donde están establecidas, como usos del suelo y variables climáticas, entre otras. Este estudio, permitió, además, vislumbrar cómo ha sido la dinámica o secuencia de la colonización, por especies, de los distintos humedales a través del tiempo, pudiendo establecer relaciones entre ellos. Esta información permite realizar propuestas de acciones de manejo de hábitat para la conservación de estas especies, en los humedales que lo requieran y en caso de ser necesario, a una escala territorial más amplia que la de los propios humedales concretos en los que habitan.

En segundo lugar, se quiso evaluar el efecto del ciclo del cultivo del arroz sobre los parámetros reproductivos de las garzas que nidifican en L'Albufera de València. Este problema se abordó de dos maneras. Una de ellas fue estudiando el ciclo reproductivo del conjunto de especies, para estimar sus parámetros reproductivos y asociarlos con la fenología del cultivo del arroz, mientras que, por otro lado, nos enfocamos en una sola especie (Garza real) y su uso del hábitat (arrozal) a lo largo de su periodo de reproducción, que abarca la mayor parte del ciclo del cultivo. Con los resultados obtenidos, como el hecho que el inicio y duración de las diferentes etapas del cultivo, especialmente la inundación de los campos, afectan el éxito reproductivo de las especies estudiadas, se pueden plantear estrategias de manejo del arrozal y de la gestión del agua que favorezcan la reproducción exitosa de estas especies.

En cuanto a la tendencia de las poblaciones reproductoras de aves acuáticas de la Comunidad Valenciana, incluyendo las garzas, muestran un incremento desde que se iniciaron los censos, en 1984 hasta 2015 (Garrido et al., 2012; Martinez–Abraín et al., 2016). Las seis especies de garzas consideradas en este estudio, de las nueve que nidifican en la Comunidad Valenciana (si incluimos el Morito común), exhiben una tendencia positiva significativa, dentro de la región, a lo largo de los 30 años de estudio. Sin embargo, a mediano y corto plazo (16 y 8 años), estas tendencias se estabilizan para cuatro de ellas (Garza real, Garcilla bueyera, Garceta común y Garza imperial), mientras que, la Garcilla cangrejera y el Morito común conservan su tendencia positiva. En el caso de la Garceta común, sus poblaciones reproductoras parecen haberse estabilizado entre los años 2000 y 2010, después de una fase de crecimiento en la década de los 90 (Garrido et al., 2012). Por otro lado, el hecho que las tendencias positivas de esta especie junto con la de la Garcilla bueyera, se hayan detenido en los últimos 16 años, indican que estas poblaciones estarían mostrando un crecimiento ajustado a la curva logística, mientras que las poblaciones de Garcilla cangrejera y Morito común se ajustarían a un crecimiento del tipo exponencial, propio de una especie de reciente colonización (Martinez-Abraín et al., 2016).

La mayor cantidad de parejas reproductoras se encuentran en el P. N. L'Albufera, con mucha diferencia del resto de los humedales estudiados y fue la primera colonia que se estableció en la región, confirmando la importancia de este lugar como sitio de reproducción para todas las especies y como motor de la dinámica poblacional a escala regional. Aunque, estas poblaciones disminuyeron un 43% entre 2010 y 2016, debido principalmente a la caída en el número de parejas reproductoras de Garza real, Garcilla bueyera y Garceta común (Generalitat Valenciana, 2016), en los últimos años se ha observado un incremento de 600 parejas, aproximadamente, para la Garcilla bueyera y de casi 300 parejas, en el caso de la Garceta común, superando ambas las 1000 parejas nidificantes en L'Albufera, durante el 2021 (Generalitat Valenciana, 2021).Por lo mismo, sería interesante ampliar el periodo de estudio en un nuevo análisis, incluyendo los datos de estos últimos años, para evaluar si estos aumentos se reflejan de alguna manera en las tendencias poblacionales de dichas especies, o de lo contrario, se mantienen igual.

Por otra parte, las poblaciones de estas especies han incrementado considerablemente en el P.N. El Hondo, especialmente la Garcilla bueyera y Garceta común, lo que puede ser resultado de concentrar parte de las poblaciones que han disminuido en el P. N. L'Albufera. Este aumento en dichas poblaciones puede estar asociado al hecho que en el P. N. El Hondo se han realizado trabajos para la mejora del manejo del agua como parte del proyecto para la restauración del hábitat de aves acuáticas (Generalitat Valenciana, 2012). Estos trabajos han favorecido el incremento en la cantidad y calidad de los cuerpos de agua, mediante la limpieza de los drenajes que alimentan la laguna, la mejora en la infraestructura hidráulica y rehabilitación de los circuitos de entrada y salida de agua, para permitir una buena circulación de la misma. Por otro lado, el parque cuenta con un Plan de Gestión Hídrica, aprobado en acuerdo con los usuarios del recurso (Comunidad General de Riegos de Levante), en donde se establece la reutilización de aguas provenientes de la depuración, regulación de los caudales de los embalses y restricciones en el nivel del agua embalsada para garantizar unos niveles óptimos para las especies protegidas que nidifican en el sitio (Generalitat Valenciana, 2012). Con la aplicación de estas medidas se beneficia a estas especies, como la Garcilla bueyera y la Garceta común, que dependen de las condiciones y las variaciones en la calidad del agua (Hafner et al., 1987; Bartolomé et al., 1997; Garrido et al., 2012). Las cifras de parejas reproductoras del P. N. El Hondo lo ubican en el segundo lugar de importancia dentro de la región.

Por otra parte, el número de parejas nidificantes de Garcilla bueyera y Garceta común, así como el número y tamaño de sus colonias, se han asociado positivamente con la cantidad de arrozales y el área que éstos ocupan, encontrándose mayor cantidad de nidos y colonias más grandes, incluso más diversas, en los sitios de nidificación con arrozales dentro de su área de influencia, que en aquellos alejados de estos cultivos (Hafner et al., 1987; Tourenq et al., 2000; Fasola et al., 2010; Fasola et al., 2022). Por lo mismo, la disminución de sus poblaciones en el P. N. L'Albufera, caracterizado principalmente por este tipo de ambiente, podría estar indicando un deterioro en las condiciones del arrozal.

Por otro lado, la Garza imperial fue la primera especie en colonizar los humedales cercanos a L'Albufera (Marjal de Moros, Marjal Xeresa-Xeraco y el P. N. Pego-Oliva), en la década de los 90's, manteniéndose como la segunda especie más abundante en estos dos últimos. De allí la importancia de estas dos últimas áreas protegidas para la conservación de esta especie, la cual se encuentra catalogada como Vulnerable en el Catalogo Valenciano de Especies de Fauna Amenazadas. Posterior a la llegada de la Garza imperial a estas localidades, a partir del año 2000, comenzaron a llegar otras especies de garzas, tales como la Garza real, en primer lugar, seguidas de la Garcilla bueyera y la Gaceta común. El Marjal de Moros fue el último humedal en ser colonizado, con la llegada de estas dos últimas, después del 2010, uniéndose a las poblaciones ya establecidas de Garza imperial y Garza real, coincidiendo con que este humedal también es el más reciente en el sistema de áreas protegidas.

En términos generales, de los humedales catalogados como relevantes dentro de la Comunidad Valenciana, el 24% de los mismos tienen al arrozal como uso del suelo predominante, mientras que la vegetación natural (riparia, palustre, prados, entre otros) es mayoritaria en el 30% de ellos (Generalitat Valenciana, 2002). De los humedales considerados en el estudio, el del Marjal de Moros, Xeresa-Xeraco, Almenara y el P. N. Pego- Oliva se caracterizaron por la presencia o cercanía de cultivos (diferentes al arrozal), vegetación arbustiva o de pastizal, construcciones (urbanismos o industrial), marismas y playas. Por su parte, el P. N. L'Albufera se caracterizó por la presencia del arrozal y por la mayor área total de superficie, mientras que la presencia de salinas y marismas fue lo que distinguió a los parques naturales de El Hondo y Salinas de Santa Pola. En los ambientes caracterizados por marismas o marjales, las precipitaciones juegan un papel importante al intervenir en las condiciones de inundación, lo que determina, de cierta forma, la disponibilidad de área de alimentación en diferentes años (Bancroft et al., 1988; Hafner et al., 1994). De esta manera, las precipitaciones influyen indirectamente en el tamaño de las colonias de reproducción y en el éxito reproductivo, ya que éstas se encuentran relacionadas positivamente al tamaño o superficie de estos ambientes, en donde las garzas obtienen su alimento (Hafner et al., 1987; Hafner et al., 1994; Bennets et al., 2000; Ramo et al., 2013).

Según los resultados del Análisis de correspondencia (AC), la Garza real, Garceta común, Garcilla bueyera y Garcilla cangrejera, mostraron mayor asociación con la presencia de campos de arroz y cuerpos de agua dulce en un radio de 10 km, así como con la superficie total del área protegida. Mientras que la población reproductora de Garza real, según su ubicación relativa en el AC, estuvo más asociada con el arrozal, las demás lo estuvieron con los cuerpos de agua permanentes (Hafner et al., 1987). Por su parte, la Garza imperial y el Morito común se relacionaron mayormente con la presencia de marismas, que se relacionan a su vez con las precipitaciones (Toral et al., 2012), y con la protección del área, lo que es particularmente importante para la Garza imperial, una especie amenazada, que se está recuperando en años recientes.

Con base en lo anterior, se explicaría el hecho que el P. N. L'Albufera sea el humedal que presente la mayor cantidad de parejas reproductoras, especialmente de Garza real, Garceta común, Garcilla bueyera y Garcilla cangrejera, ya que es la localidad con mayor superficie de área total y con mayor superficie de campos de arroz (Pérez-Aranda et al., 2003; Garrido et al., 2012; Generalitat Valenciana, 2013). El arrozal es una fuente importante de alimento para estas aves (Fasola y Ruiz, 1996;Prósper y Hafner, 1996; Generalitat Valenciana, 2002b; Toral et al., 2012), especialmente durante el periodo reproductivo, cuando el tamaño de la colonia de reproducción se ha observado estar relacionada con la presencia de dicho cultivo (Hafner et al., 1987; Lekuona, 2002). Igualmente, el área de los arrozales inundados se ha relacionado con los tamaños poblaciones de garzas, indicando una fuerte asociación entre la disminución poblacional y la reducción del área inundada, que implica una limitación en la disponibilidad de hábitats de alimentación (Fasola et al., 2022). Por otro lado, el estado de protección de la colonia se ha relacionado significativamente con sus tendencias poblacionales (Fasola et al., 2010). Entre los humedales estudiados, algunas especies se establecieron permanentemente algunos años después (2-4 años) de haber sido declarados área protegida. Las iniciativas de conservación y las políticas de protección ha sido un factor importante en el incremento de las poblaciones de garzas dentro de la Comunidad Valenciana, por lo mismo estas medidas deben ser revisadas periódicamente para mantenerse actualizadas, conforme vaya surgiendo nueva información sobre el estado de dichas poblaciones (Generalitat Valenciana, 2013; Martinez-Abraín et al., 2016).

El manejo y la gestión de las marismas de agua dulce y los arrozales puede ser un factor determinante en el éxito de las colonias reproductivas, ya que éste suele ser mayor en las colonias rodeadas por estos tipos de ambientes (Hafner et al., 1987; Delord et al., 2003). Además, según lo obtenido de este estudio, las especies de garzas estudiadas establecen sus colonias de reproducción dentro o en áreas cercanas a estos hábitats. Por lo tanto, una buena gestión del agua es el factor principal a considerar en los planes de manejo de estos espacios, incluyendo el mantenimiento de áreas inundadas, ya sea naturales o artificiales, dentro de la zona de influencia de la colonia, la mayor parte del tiempo, especialmente durante el periodo reproductivo, de manera que no pasen meses con toda el área totalmente seca(y por tanto, en la práctica, sin disponibilidad de hábitat), como sucede en L'Albufera. En el caso específico del arrozal, el drenaje invernal de los campos debería realizarse por lo menos un mes más tarde, y adelantar la inundación para la siembra unas semanas, para favorecer el éxito reproductivo de las colonias. Esta relación se trata con mayor detalle más adelante, en el texto. El manejo del agua, entonces, es vital para la conservación de estas colonias, así como también lo es mantener la red de humedales (Red Natura 2000) con planes de gestión que incorporen medidas como la mencionada anteriormente.

Las colonias reproductoras de la L'Albufera de València, son mixtas, donde los nidos se encuentran muy cercanos unos de otros, tal como lo vienen haciendo desde que se instalaron en el área (Pechuán, 1971; Prósper y Hafner, 1996), a excepción de la Garza imperial que nidifica aparte y con los nidos más dispersos espacialmente (Giménez y Aguirre, 2003; Nedja et al., 2010). Las colonias se ubicaron en la Mata del Fang - la cual ha mantenido poblaciones reproductoras anualmente desde, por lo menos, 1963 (Prósper, 2000), siendo el sitio más importante de nidificación dentro de L'Albufera- y en la Reaplaza de Zacarés, de más reciente colonización (a partir de 1991) (Prósper, 2000), donde, además, se encuentra la principal colonia de la Garza imperial.

El ciclo del cultivo del arroz ha variado a través de los años, retardándose en el inicio de las inundaciones y disminuyendo el tiempo de inundación, lo que ha ocasionado también modificaciones en las fechas de inicio de la puesta de algunas de las especies que nidifican en el área. En los años 70 y 90, la inundación del arrozal comenzaba a mediados de abril y estaban completamente inundados a principios de mayo, cuando se iniciaba la fase de siembra (Prósper, 2000; Oltra et al. 2001). Para este tiempo se ha reportado para l'Albufera, que la construcción de nidos e inicio de la puesta de la Garcilla bueyera, Garceta común, Garcilla cangrejera y Garza imperial, ocurría a finales de abril (Prósper y Hafner, 1996; Prósper, 2000; Dies et al., 2001), de manera similar a como ocurre que en otros sitios de España (Parejo et al., 2001; Belamendia et al., 2003; Galarza, 2020). Sin embargo, en dos de los tres años de nuestro estudio (2015 y 2017), todas las especies comenzaron la nidificación en la primera semana de mayo. Solo en el 2016 el inicio de la puesta comenzó a finales de abril. Actualmente, la inundación de los campos comienza a principios de mayo y la siembra a finales del mismo mes, significando un atraso de dos a tres semanas con respecto a los años 90. De esta manera, los máximos de puesta de huevos están coincidiendo con la inundación de los campos, al igual que ocurrió en el periodo 1988-1990, especialmente en los casos de Garcilla bueyera y Garceta común (Prósper, 2000).

El efecto del ciclo de inundaciones en la fenología de la puesta es más evidente en el caso de la Garza real, la cual comienza a nidificar en enero y realiza puestas escalonadas hasta mayo, con un máximo de puestas en enero-febrero y una segunda en marzo (Prósper y Hafner, 1996;Prósper, 2000). Sin embargo, actualmente no se observa este máximo del mes de marzo si no que se ha desplazado a finales de abril y principios de mayo. El comienzo temprano de la nidificación, en el mes de enero, está asociado a las inundaciones invernales (perelloná) que se realizan en L'Abufera, que permite una mayor disponibilidad de alimento durante este periodo (Prósper, 2000). Actualmente, debido a que el drenaje de los campos comienza a finales de febrero y la inundación para iniciar el cultivo no tiene lugar hasta la segunda semana de mayo, los campos de arroz permanecen secos, al menos, durante dos meses, tiempo durante el cual el hábitat de alimentación se reduce drásticamente, situación que no se presentaba en décadas anteriores ya que las inundaciones comenzaban más temprano (Prósper, 2000; Oltra et al., 2001; Goméz de Barreda, 2009). Esta puede ser la causa que el periodo reproductivo de la Garza real dentro de L'Albufera de València se encuentre dividido en dos estaciones. Ya se ha observado en otras especies de aves, que cambios en los momentos de máxima disponibilidad de alimento pueden inducir, como respuesta, la modificación del inicio del periodo reproductivo (McKinnon et al., 2012; Visser et al., 2012; Funk, 2013).

En cuanto a los parámetros reproductivos, se obtuvo que el número de pollos exitosos por nido fue más bajo que el reportado por varios otros autores para otras regiones de España y Europa (Hafner, 1980;Bartolomé et al., 1997; Parejo et al., 2001; Si Bachir et al., 2008; Dragonetti y Giovanchini, 2009; Jakubas, 2005; Ashoori et al., 2009; Barbraud et al., 2001; Nedja et al., 2010; Boucheker, 2009; Nefla et al., 2012) y en comparación con el estudio previo en L'Albufera (Prósper y Hafner, 1996;Prósper, 2000). Estos bajos números en el éxito de los pollos se ha asociado a la disminución de presas o recursos alimenticios en los campos de arroz, como el cangrejo rojo o americano (*Procambarus clarkii*), y el consecuente uso de otros recursos de menor valor energético (Antón-Tello et al., 2021).

Los análisis realizados (GLMM) muestran que no hay relación significativa entre la superficie de los campos inundados, que generalmente coincide con el momento de la puesta, y el éxito reproductivo. Esto es para la mayoría de las especies estudiadas, salvo para el Morito común, quien si hace uso de estos campos inundados, pocos profundos, a diferencia del resto (Anton-Tello et al., 2021). Por el contrario, el éxito reproductivo se relacionó positivamente con el área de los campos sembrados, que coincide, por lo general, con la eclosión y crecimiento de los pollos, en los casos de la Garcilla bueyera, Garceta común, Garza imperial y Morito común. Esta relación fue negativa en el caso de la Garza real, mientras que para la Garcilla cangrejera no hubo una relación significativa. En el caso de la Garza real, el éxito reproductivo estuvo relacionado positivamente a la presencia de campos con un cierto nivel de agua (fangueados o semi-inundados), pero no inundados completamente.

Al comienzo del ciclo, cuando se drenan los campos, en febrero, para preparar el terreno para la siembra, las presas potenciales, como crustáceos, anfibios y peces, quedan atrapados en los pozos de agua remanente (campos semi-inundados), donde son más accesibles para las garzas (Marques y Vicente, 1999; Mugica et al., 2006). Adicionalmente, las labores de fangueo (remoción o mezcla del fango superficial) produce un incremento en la disponibilidad de presas, principalmente crustáceos, debido al aporte de energía externa al sistema, por lo que en estos campos se ha registrado el mayor consumo (Kg/ha/día) de alimento por parte de varias especies de garzas (Mugica et al., 2006). Por su parte, la superficie sembrada del arrozal tendría un efecto positivo en el éxito reproductivo ya que, la vegetación emergente en esta etapa del cultivo permite que haya una mayor cantidad y diversidad de insectos acuáticos, con mayor biomasa, los cuales constituyen parte importante de la dieta de dichas especies y sus crías (Marques y Vicente, 1999; De Szalay y Resh, 2000; Mugica et al., 2006; Antón-Tello et al., 2021). Sin embargo, a pesar que en los campos sembrados la biomasa y diversidad de las presas incrementa (González-Solís et al., 1996; Marques y Vicente, 1999; Mugica et al., 2006), la cobertura de las plantas dificulta la captura de las mismas para aves de mayor tamaño como lo es la Garza real, por lo que son consumidas a una tasa baja (González-Solís et al., 1996; Mugica et al., 2006; Ibañez et al., 2010; Nam et al., 2015). Es por ello que las garzas de mayor tamaño, como la Garza real, se encuentran más asociadas a los campos semi-inundados o fangueados y muy poco a los campos sembrados, donde la disponibilidad del alimento disminuye por la dificultad de su captura (Nam et al., 2015). De esta manera, el bajo éxito reproductivo de la Garza real, asociado a los campos sembrados, se debería a la baja ingesta de presas resultado del obstáculo que representa la planta de arroz para la captura de las mismas.

Por otro lado, según estos análisis, el éxito reproductivo estaría más relacionado con el tiempo que transcurre entre la puesta de los huevos y el inicio de la inundación, siendo afectado negativamente mientras más días pasen entre ambos eventos. En este estudio, los valores significativamente más bajos de éxito reproductivo se obtuvieron en el 2016, cuando la puesta se inició a finales de abril y la inundación a principios de mayo, mes donde comenzaron las eclosiones. En los otros dos años (2015 y 2017), las puestas comenzaron en mayo, cuando los campos ya estaban inundados, y las eclosiones sucedieron en junio, con los campos sembrados. Se ha reportado que, en los arrozales, la abundancia de invertebrados y la biomasa de las presas incrementa un mes después de la inundación de los campos, cuando la planta de arroz ya está emergiendo (Hafner et al., 1987; Marques y Vicente, 1999). De esta manera, en L'Albufera, la mayor disponibilidad de presas para alimentar a los pollos se encontraría en el mes de junio, un mes después del comienzo de la inundación, en mayo. En el 2016, año donde se registró el valor más bajo del éxito reproductivo, la mayoría de las crías eclosionaron en el momento de la inundación de los campos, cuando las presas que sirven de alimento a los padres todavía no están disponibles en el arrozal. Por lo mismo, una gran parte de las crías no lograron desarrollarse exitosamente debido a la escasez de alimento, lo cual se vio reflejado en el bajo éxito reproductivo registrado en este periodo.

Consideraciones finales

De este trabajo se evidencia la importancia del adecuado manejo del agua en la gestión de los humedales, ya sean naturales o artificiales como los cultivos de arroz, en la reproducción exitosa de las especies de garzas estudiadas y el papel de los arrozales en su conservación a gran escala. Por esta razón, los planes de manejo de estas áreas deben incluir medidas dirigidas al mantenimiento de las zonas inundadas, con cierta cantidad de vegetación emergente para favorecer el desarrollo de las comunidades de insectos acuáticos, macroinvertebrados y vertebrados que sirven de alimento, especialmente durante el periodo reproductivo.

En el caso del P. N. L´Albufera, el manejo del arrozal depende, por un lado, de las presiones del mercado, cada vez más competitivos, que ha producido una baja en la rentabilidad (Girona, 1998; Picazo-Tadeo et al., 2009; Martínez, 2018) y por el otro a las presiones por la competencia en el uso del recurso agua, el cual cada vez tiene más demanda (Picazo-Tadeo et al., 2009). El crecimiento de los usuarios que requieren del recurso (otros cultivos, urbanismos e industrias y la laguna misma) junto con la disminución del mismo en las cabeceras de los ríos que alimentan el área (bajas precipitaciones, cambio climático), han ocasionado que dicho recurso sea cada vez más escaso (Palop, 2015), a pesar de que el caudal ecológico para cubrir los requerimientos biológicos de las especies objetivo de gestión son, de acuerdo a la legislación vigente, un uso restrictivo al sistema. Por otro lado, la tendencia es hacia adoptar nuevas prácticas de cultivo, con siembra en seco o con reducción del tiempo de inundación drenando más temprano los campos (junio-julio), planteándose incluso el riego por goteo, todo en miras de optimizar el consumo de agua, sin considerar que estos cambios pueden afectar negativamente la población de aves acuáticas del área (Lane y Fujioka, 1998; Wood et al., 2010; Sesser et al., 2016; Xie et al., 2018; Fasola et al., 2022). Estos aspectos determinarán la forma y el tiempo en que se realiza la inundación, por lo que el éxito reproductivo de las colonias puede ser afectado dependiendo de las decisiones que se tomen acerca del momento, la cantidad y la duración de la misma.

Considerando que, según los resultados de este estudio, el tiempo que transcurre entre la puesta de los huevos y el inicio de la inundación tiene efecto negativo sobre el éxito reproductivo de la colonia, siendo más bajo mientras más días pasan entre uno y otro acontecimiento, así como también el momento en el que se inicia el drenaje de los campos y el tiempo que permanecen secos, en el caso de la Garza real, se hace evidente que el manejo del agua, los períodos de inundaciones y el mantenimiento de las áreas inundadas deben estar sincronizadas con las necesidades y requerimientos de la colonia si se quiere asegurar la conservación y reproducción exitosa de estas poblaciones. En el caso de la Garza real, es necesario también mantener hábitats alternativos con baja densidad de vegetación, en la época reproductiva, para favorecer el forrajeo de los adultos. Más aún, teniendo en cuenta que la conservación de especies como Garza imperial, Garceta común, Garcilla cangrejera o Morito común es prioritaria en la Unión Europea de acuerdo a la Directiva Aves (Directiva 2009/147/CE del Parlamento Europeo y del Consejo) y sus objetivos de conservación deben ser asumidos en espacios de la Red Natura 2000, como es L'Albufera. Asimismo, estas especies se encuentran amparadas por una u otra normativa de protección, incluyendo convenios internacionales como lo son el Convenio de Berna (BOE núm. 235 del 01/10/86) y el Convenio de Bonn (Decisión 82/461/EEC). Además, a nivel nacional también se las incluye dentro del Catálogo Español de Especies Amenazadas (Garcilla cangrejera) (Real Decreto 139/2011) y a nivel regional, dentro del Catálogo Valenciano de Especies de Fauna Amenazadas (Garcilla cangrejera y Garza imperial) (Decreto 32/2004). Por lo mismo, las autoridades encargadas de la administración y gestión de estas áreas, son responsables de tomar medidas para el mantenimiento y mejora del estado de conservación de estas especies y de su hábitat.

Un aspecto que no se consideró en este estudio, fue el análisis de los factores que podrían activar el inicio de la puesta y cómo esto podría influir en el éxito reproductivo de la colonia. Se ha evidenciado en otros estudios que las condiciones meteorológicas, como las precipitaciones del otoño previo al periodo reproductivo pueden determinar el comienzo y tamaño de las puestas (Hafner et al., 1994; Parejo et al., 2001; Lekuona, 2002), así como la temperatura diaria (Campos y Fernández-Cruz ,1991; Caballero, 1996; Parejo et al., 2001). Por lo mismo, se recomienda incluir, en futuras investigaciones, estudios de las posibles relaciones entre las variables meteorológicas y las condiciones de los campos, previo al periodo reproductivo, con la fenología de la puesta y su vínculo con el éxito reproductivo. Son muchos otros los aspectos que todavía quedan para estudiar en relación a la reproducción de las garzas en L'Albufera, como evaluar la disponibilidad de alimento y recursos energéticos para los pollos en distintas fases de crecimiento, o el efecto en el éxito reproductivo de prácticas de gestión favorables (como alargar la inundación invernal en el caso de la Garza real), o el efecto de pesticidas y plaguicidas en el estado fisiológico de los padres y consecuente efecto en el éxito reproductivo, investigaciones todas que contribuirán a generar acciones de manejo para la conservación de esta importante colonia reproductiva.

En resumen, se ha evidenciado que el manejo y la gestión de las zonas inundadas en los humedales donde nidifican las especies de garzas más resaltantes, dentro de la Comunidad Valenciana, es de vital importancia para la reproducción exitosa de dichas poblaciones. Por otra parte, es sabido que las aves acuáticas, en general, se benefician de la protección legal de sus hábitats y áreas de nidificación, lo que también ocurre con las poblaciones reproductoras de las especies estudiadas (Generalitat Valenciana, 2013; Martinez-Abraín et al., 2016; Fasola et al., 2010; Pavon-Jordan et al., 2022). Aunque no se analizó específicamente, se puede observar una tendencia a colonizar el humedal pocos años después de su declaración como área protegida, tal como se ha reportado en otros humedales protegidos (Ramo et al., 2013). Esto se evidencia en el Marjal de Moros, donde la colonia reproductora de cuatro de las especies en consideración, se estableció más recientemente, en comparación con los otros humedales, luego de su declaración como área protegida, posterior a todo el resto. La mayoría de los humedales evaluados son áreas protegidas, las cuales deben mantenerse bajo esta figura y velar por que cumplan los objetivos y funciones para la que fueron creadas. Sin embargo, la designación por si sola del área protegida no es suficiente, sino que es necesariorealizar una conservación activa de los hábitats y que dichas áreas cuenten con un plan de manejo desde etapas tempranas para que puedan cumplir con su labor de proveer las condiciones adecuadas para mantener y mejorar la riqueza de las especies que albergan (Gaget et al., 2021). Por lo mismo, en aquellas áreas protegidas que aún no cuenten con un plan de manejo, es imperativo su diseño e implementación, tomando en consideración los aspectos planteados, mientras que los planes de manejo que ya se encuentran elaborados deben ser revisados para incorporar, en caso de no tenerlos en consideración, los aspectos y requerimientos de estas poblaciones, especialmente en su periodo reproductivo, en relación al mantenimiento de las zonas inundadas por el tiempo y cantidad que sea necesario para asegurar su éxito reproductivo. Para el caso del P.N. L'Albufera, es imprescindible contar con un Plan de gestión hídrica incluido en el Plan de Gestión del espacio Red Natura 2000, similar al realizado en el P.N. El Hondo, con la participación de los usuarios y administradores del recurso agua, para lograr el consenso entre los participantes en el uso del mismo, específicamente en la dinámica de las inundaciones del arrozal, para incorporar las necesidades de la colonia reproductora en la toma de decisiones sobre los momentos y duración de la inundación y drenaje de los campos de arroz. Esto también puede ampliarse a los humedales donde el recurso agua se reparte entre agricultores y el humedal propiamente dicho. Por otra parte, los cambios en las prácticas de cultivo del arroz que puedan plantearse, en el caso de

L'Albufera, deberían ser evaluadas previamente en función de los posibles efectos que puedan tener sobre la población reproductora y manejar posibles escenarios para compensar dichos efectos en caso de implementarse.

Los planes de manejo y las medidas adoptadas para la protección de las colonias de reproducción, deben estar bajo revisión constante para adecuarlas a los posibles cambios en el comportamiento reproductivo que pueden ocurrir por diversas causas (condiciones climáticas, por ejemplo). Para ello es necesario, continuar con el seguimiento de las poblaciones nidificantes y su hábitat, de manera de mantener la información actualizada e identificar las variaciones que puedan ocurrir en el tiempo con el fin de tomar las decisiones y medidas más acertadas en pro de su conservación.

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Capítulo 7

Conclusiones

L'Albufera
Foto: Mariela Forti

1. Las poblaciones reproductoras de Garza real (*Ardea cinerea*), Garza imperial (*Ardea purpurea*), Garcilla bueyera (*Bubulcus ibis*), Garceta común (*Egretta garzetta*), Garcilla cangrejera (*Ardeola ralloides*) y Morito común (*Plegadis falcinellus*) muestran un incremento durante el periodo de 1984-2015 en la Comunidad Valenciana. Sin embargo, esta tendencia se ha detenido a partir del año 2000, aproximadamente, con excepción de las poblaciones de Garcilla cangrejera y Morito común. Probablemente, este comportamiento de un crecimiento inicial, producto de un periodo de recuperación, y posterior estancamiento (crecimiento logístico), se corresponda a que los ambientes donde nidifican hayan alcanzado su capacidad de carga, debido a sus condiciones actuales. Por su parte, la Garcilla cangrejera y el Morito común, por tratarse de especies de reciente colonización y expansión, todavía se encuentran en una fase de crecimiento exponencial.

2. El P.N. L'Albufera se confirma como el sitio más importante para la reproducción de todas las especies consideradas en el estudio, dentro de la Comunidad Valenciana. Este humedal fue el primero en ser colonizado dentro de la región y en la actualidad alberga, con amplia diferencia, el mayor número de parejas reproductoras de las seis especies estudiadas en la región. Por otro lado, las poblaciones de Garza real, Garza imperial, Garcilla cangrejera y Morito común que nidifican en el Marjal de Moros, Marjal Xeresa-Xeraco, P.N. Pego-Oliva y P.N. Salinas de Santa Pola se correlacionan significativamente con las poblaciones nidificantes en l'Albufera. Este hecho, junto con la compensación observada entre la reciente disminución en el número de parejas nidificantes

en L'Albufera y el aumento en otros humedales como el P.N. El Hondo, evidencia la importancia de L'Albufera como fuente y motor de la dinámica poblacional a escala regional.

3. La figura de protección de los humedales es un factor importante en el establecimiento y mantenimiento de las poblaciones reproductoras de las especies estudiadas. Las colonias de nidificación se establecieron después de la declaración de dichos humedales como áreas protegidas y de la toma de acciones de protección correspondientes. Esto se evidencia mayormente en el caso del Marjal de Moros, el cual fue el último del conjunto de humedales evaluados en ser declarado como área protegida y el último en ser utilizado por estas especies como lugar de nidificación, a pesar de estar cercano a varios humedales con colonias constituidas con mucha anterioridad. La declaración de un área protegida, generalmente, viene acompañada del control de actividades que puedan perjudicar la calidad del área y de gestiones de manejo de hábitat que mejoran las zonas alimentación y reducen la perturbación en las áreas de nidificación que se establecen. Por lo mismo, la figura de área protegida, junto con la implementación de su plan de gestión (al menos parcialmente), beneficia el asentamiento y crecimiento de poblaciones reproductoras de las especies de garzas evaluadas.

4. Las variables del hábitat que caracterizaron al P.N. L'ALbufera fueron las grandes extensiones de cultivo de arroz, con otros cuerpos de agua dulce cercanos en un radio de 10 km, y por ser el área protegida de mayor superficie, mientras que los ambientes del P.N. El Hondo y el P.N. Salinas de Santa Pola se caracterizan por la presencia de marismas y salinas. Por su lado, el hábitat de los humedales costeros (Marjal de Moros, Marjal de Almenara, Marjal Xeresa-Xeraco y P.N. Pego-Oliva) está configurado por la presencia de marismas de agua dulce y playas, y la vecindad de otros cultivos diferentes al arroz, construcciones industriales o urbanismos y de vegetación arbustiva o de pastizal, en sus alrededores. Las precipitaciones tienen mayor peso en los humedales asociados con marismas (Marjal de Moros, Marjal de Almenara, Marjal Xeresa-Xeraco y P.N. Pego-Oliva), ya que éstas determinan, en gran parte, el nivel y disponibilidad de agua en estos ecosistemas.

5. Las variables del hábitat que influyen en el establecimiento de las poblaciones reproductoras de Garza real, Garcilla bueyera, Garceta común y Garcilla cangrejera, son la presencia de cultivos de arroz, la cercanía de cuerpos de agua dulce naturales dentro de los 10 km de radio de donde se establece la colonia y la extensión total del área protegida, las mismas variables que caracterizan al P.N. L'Albufera, lo que explicaría el hecho que este sea el humedal con las colonias de reproducción más numerosas de la región, ya que es el área con mayor superficie total y ocupada casi en su totalidad por arrozales, por lo que tiene capacidad para sustentar gran cantidad de individuos, tanto como hábitat de alimentación como sitio de nidificación. El cultivo de arroz es más determinante en la presencia de las poblaciones de Garza real que para el resto de las especies, las cuales requieren más de la existencia de otros cuerpos de agua dulce, que en el caso de la mencionada garza.

6. Por su parte, el tiempo desde que el humedal fue legalmente protegido es una característica de las localidades que interviene en el establecimiento de las poblaciones reproductoras de Garza imperial y Morito común, al igual que las precipitaciones, por el hecho que éstas son las que van determinar el estado de las marismas, en cuanto al nivel de agua que presentan y, por lo tanto, el área de hábitat de alimentación disponible para estas especies.
7. La fenología de la puesta de las especies estudiadas en L'Albufera de València responde al ciclo de inundaciones de los arrozales. Por un lado, el inicio de la puesta comienza, actualmente, hasta dos semanas más tarde de lo que comenzaba décadas atrás (años 90). Este retraso de la fenología reproductiva es aparentemente una respuesta al retraso que, igualmente, ha ocurrido en el inicio de la inundación de los campos, que comienza a partir de mayo, cuando anteriormente empezaba a finales de abril. En ambas épocas, el máximo de la puesta de los huevos coincide con el comienzo de la inundación.
8. El periodo reproductivo de la Garza real, se encuentra dividido completamente en dos etapas, una de enero hasta principios de marzo y otra a partir de mayo, en respuesta al hecho que, durante todo el mes de abril y parte de marzo, los campos se encuentran completamente secos. Esto no ocurría en décadas anteriores, cuando los campos se drenaban más tarde (marzo) y se inundaban más temprano (finales de abril) permitiendo que permanecieran inundados por más tiempo, con lo que la reproducción iniciaba en enero, pero continuaba con puestas esporádicas hasta mayo, extendiéndose el periodo reproductivo hasta julio.

9. En L'Albufera, el éxito reproductivo de la Garcilla bueyera, Garceta común, Garza imperial y Morito común, está relacionado positivamente con la superficie de los campos sembrados al momento de la eclosión, mientras que, para la Garza real, este éxito se relaciona con el área de los campos fangueados y semi-inundados. En el caso de las primeras cuatro especies, el éxito reproductivo es mayor cuando la eclosión de las crías coincide con la mayor superficie de campos sembrados, cuando la abundancia de presas dentro del arrozal es mayor y va en aumento a medida que el cultivo avanza. El éxito reproductivo de la Garza real,en la temporada de invierno, es mayor cuando la eclosión de los pollos coincide con la etapa de fangueo o semi-inundación de los campos, por la mayor disponibilidad de presas que quedan atrapadas en los remanentes de agua luego del drenaje de los campos. En los campos sembrados, en las etapas avanzadas del cultivo, la Garza real tiene dificultad de capturar el alimento entre las plantas de arroz, por lo que el éxito reproductivo asociado a esta etapa es bajo. El éxito reproductivo de la Garcilla cangrejera no mostró relación con ninguna fase del cultivo.
10. Durante el periodo reproductivo de primavera (mayo-julio), la sincronización entre el inicio de la puesta de los huevos y el comienzo de la inundación de los campos, influye considerablemente en el éxito reproductivo. La cantidad de días que transcurren entre la puesta de los huevos y la posterior inundación del arrozal determina el éxito reproductivo de ese periodo, siendo éste significativamente menor mientras mayor cantidad de días pasan entre la puesta y el inicio de la inundación. Actualmente la inundación se inicia cada vez

más tarde, lo que estaría afectando negativamente el éxito reproductivo de estas especies. Por lo mismo, el cronograma de las inundaciones debe estar sincronizado con el periodo de puestas de los huevos, de tal forma que la eclosión coincida con la germinación de las plantas de arroz, asegurándose que habrá suficiente disponibilidad de alimento en los campos para el levantamiento exitoso de las crías.

11. El éxito reproductivo de la Garza real durante el invierno (enero-marzo), es afectado negativamente por el drenaje temprano de los campos, iniciado a partir del mes de enero y finalizado a principio de marzo. Las crías que eclosionan en febrero lo hacen con una reducida superficie de hábitat de alimentación disponible para los adultos (campos fangueados/semi-inundados), y es casi nula para las crías nacidas en marzo, ocasionando que la mayoría de ellas no logren sobrevivir. Por otro lado, el drenaje de los campos tan temprano en l'Albufera conlleva que todos los arrozales próximos a las colonias estén completamente secos durante casi tres meses en el periodo entre febrero y mayo, afectando la reproducción de esta especie. Por lo mismo, el drenaje de los campos no debería iniciarse hasta, por lo menos, a mediados del mes febrero, para asegurar la presencia de sitios de alimentación disponibles, de manera que los pollos nacidos en dicha temporada logren sobrevivir.

12. El manejo del ciclo de inundaciones del arrozal es vital para la reproducción exitosa de la colonia de garzas que nidifican en el P.N. L'Albufera. El inicio y duración de las inundaciones, así como el comienzo del drenaje de los campos tras el invierno, determina la disponibilidad de hábitats de alimentación para las parejas nidificantes durante el periodo de reproducción y, por lo tanto, la cantidad y calidad de alimento disponible para las crías. Por lo mismo, los cambios en las prácticas de cultivo que impliquen modificaciones en la dinámica de las inundaciones pueden afectar el éxito reproductivo de estas especies, por lo que las reformas que se planteen en este sentido deben ser analizados previamente para prevenir los posibles efectos que puedan tener sobre la reproducción de la colonia.

13. Las colonias reproductoras de las especies evaluadas están establecidas dentro o cercanas a las marismas de agua dulce y arrozales, por lo que la gestión y el manejo de estas zonas inundadas es de suma importancia para la conservación y éxito de dichas colonias. Las acciones de manejo dentro de estos humedales, deben asegurar el mantenimiento de las áreas inundadas como hábitats alternativos que permitan la alimentación de las garzas dentro del área de influencia de la colonia, ya sean naturales o artificiales, como herbazales encharcados o campos fangueados en el caso de la Garza real, durante la mayor parte del año, especialmente durante los periodos reproductivos, evitando que lleguen a secarse por completo al mismo tiempo. De ser necesario, debe invertirse en infraestructura y equipos, además de diseñar planes de manejo del agua, para garantizar el logro de dicho objetivo. Igualmente, es vital mantener la red de humedales (Red Natura 2000) con planes de gestión que incorporen estas medidas.

Resumen ampliado

Los humedales son unos de los ecosistemas más valiosos del planeta por la alta biodiversidad que albergan y sus altos niveles de productividad, además de los numerosos servicios ecosistémicos que prestan (Cannicci y Contini, 2009; Costanza et al., 2014; Convención de la Diversidad Biológica, 2015; Convención de Ramsar sobre los Humedales, 2021). Sin embargo, en las últimas décadas también han sido objeto de preocupación por la rápida y amplia pérdida de superficie a nivel mundial, causado principalmente por su transformación en tierras de cultivo o áreas urbanizadas, estimándose que se ha perdido un 35% de su superficie en todo el mundo,entre los años 1970 y 2015, mientras que, en el Mediterráneo, se calcula esta pérdida en un 48% (Gardner et al., 2015; MedWet, 2016; Convención de Ramsar sobre los Humedales, 2018).

Los arrozales constituyen la mayoría de estos humedales artificiales que han reemplazado a los humedales naturales a nivel mundial (Shine y Klemm, 1999; Elphick, 2000; Czech y Parsons, 2002). A pesar que esta conversión es una amenaza para las especies asociadas a los humedales naturales, son varias las especies de aves acuáticas que se han beneficiado de estos nuevos tipos de ambientes (Fasola y Ruiz, 1996; Elphick, 2000; Czech y Parsons, 2002; Elphick, 2010; Giosa et al., 2018), ya que constituyen sitios importantes de alimentación para numerosos grupos de ellas (limícolas, anátidas, zancudas, entre otras), algunas de las cuales han llegado a establecer una fuerte relación con estos humedales artificiales (Hafner et al., 1987; Fasola y Ruiz, 1996; Fasola et al., 1996; Elphick et al., 2010; Katayama et al., 2015). En las garzas (Ardeidae), se ha evidenciado que las tendencias de las poblaciones reproductoras y el tamaño de las colonias de reproducción están asociadas positivamente a la presencia de arrozales (Hafner et al., 1987; Tourenq et al., 2004; Fasola y Brangi, 2010; Fasola et al., 2010; Ramo et al., 2013), así como también el éxito reproductivo (Cardarelli et al., 2017). No obstante, los cambios en las prácticas de cultivo, virando a técnicas industrializadas o tipos de cultivos "en seco", afectan negativamente a las poblaciones de aves acuáticas que hacen uso de estos ambientes (Lane y Fujioka, 1998; Wood et al., 2010; Sesser et al., 2016; Xie et al., 2018; Fasola et al., 2022).

Entre los humedales más importantes en la región del Mediterráneo occidental, se encuentra L'Albufera de València, la cual fue declarada como "Parc Natural" en 1986, y está incluida dentro de los "Humedales de Importancia Internacional" (sitio RAMSAR) desde 1989, entre otras figuras de protección. El 70% del territorio de esta área protegida, lo constituyen los campos de arroz, de los cuales hacen uso como hábitat de alimentación una comunidad numerosa de aves acuáticas, tanto nidificantes como invernantes. L'Albufera ocupa el tercer lugar más importante de nidificación de garzas dentro de España (Garrido et al., 2012) y alberga el 60% de estas especies que nidifican en la Comunidad Valenciana (Generalitat Valenciana, 2018).

En esta área, el manejo del cultivo de arroz y el ciclo de inundaciones de los campos depende, mayormente, de la disponibilidad y distribución del recurso agua, cada vez más escaso debido a la alta demanda por parte de otros cultivos, industrias y urbanismo de los alrededores (Palop, 2015). Por otro lado, el mercado cada vez más competitivo y la reducción de la rentabilidad, también presiona a los productores a tomar medidas para mantenerse en el mercado (Girona, 1998; Picazo-Tadeo et al., 2009; Martínez, 2018). La modificación en las prácticas de cultivo, buscando una mejor rentabilidad, podría tener efectos negativos sobre la comunidad de garzas nidificantes de L'Albufera si no se tienen en cuenta los requerimientos biológicos de las especies y la compatibilidad con la conservación de sus poblaciones.

Ante este panorama, se planteó, por un lado, actualizar y aportar nuevos datos sobre las tendencias poblacionales de las garzas nidificantes de L'Albufera, y otros humedales de la Comunidad Valenciana, junto con las variables del hábitat con las que se relacionan, así como de la ecología reproductiva de la colonia de garzas de dicho humedal y, por otro lado, analizar los posibles efectos que el manejo y la gestión de los arrozales del área puedan tener sobre el comportamiento reproductivo de las garzas nidificantes de L'Albufera, evaluando para ello, el uso espacio-temporal del arrozal como principal hábitat de alimentación en época reproductiva.Para ello, se buscó evaluar las tendencias poblacionales de las especies de garzas mas representativas dentro de la Comunidad Valenciana en los últimos 30 años y esclarecer las características del hábitat, que, junto con otras variables ambientales, pueden estar determinando el número de parejas reproductoras en las diferentes colonias. Por otra parte, se propuso identificar las colonias reproductoras de garzas en L'Albufera y monitorear los nidos durante el periodo reproductivo, para estimar los distintos parámetros reproductivos por especie, junto con caracterización de los parches de cultivos de arroz del área y el registro de los cambios estructurales en los mismos a lo largo del año, como resultado del manejo agrícola. De esta forma se puede analizar y relacionar el estado de los campos de arroz (fase del cultivo) con los parámetros reproductivos de la colonia.

En el capítulo 3 se presenta el trabajo que abarcó la primera parte del estudio, donde se evaluaron las tendencias poblacionales,dentro de la Comunidad Valenciana,de cinco especies de ardeidas: Garza real (*Ardea cinerea*), Garza imperial (*Ardea purpurea*), Garcilla cangrejera (*Ardeola ralloides*), Garcilla bueyera (*Bubulcus ibis*) y Garceta común (*Egretta garzetta*); y una especie de la familia Threskiornithidae: Morito común (*Plegadis falcinellus*). Para ello se utilizaron los datos de los censos anuales, coordinados por SEO/BirdLife y la Consellería del Medio Ambiente de la Generalitat Valenciana, desde 1984 hasta el 2015, en 11 humedales seleccionados. Se escogieron aquellos humedales con actividad reproductiva durante, por lo menos, tres años consecutivos y con 10 parejas nidificantes como mínimo, resultando elegidos P.N. L'Albufera de Vàlencia, P.N. Salinas de Santa Pola, P.N. El Hondo, P.N. Pego-Oliva, Marjal de Almenara, Marjal dels Moros, Marjal de Xeresa-Xeraco, Marjal Hondo de Amorós, Embalse de Beniarrés, Embalse La Pedrera y Embalse Embarcaderos. Por otro lado, se elaboró una matriz de 42 variables de hábitat y meteorológicas, las cuales se relacionaron con las tendencias poblacionales mediante un Análisis de Correspondencia. Las variables de hábitat incluyeron el tipo de uso del suelo en las cercanías de las colonias, en un radio de 5, 10 y 15 kmde distanca, cuya información se obtuvo a partir de los mapas de CorineLandCover (2012). Tambien se consideró la superficie del marjal o del área inundada del humedal, asi como el área total del mismo (del área protegida o del embalse)y la distancia a L'Albufera y al P.N. El Hondo, por ser los humedales con las colonias de reproducción mas numerosas y que podrían influir en las tendencias poblacionales de los humedales cercanos. Estos datos se estimaron utilizando GoogleEarth® (2016). Los datos meteorológicos de temperatura promedio mensual (previo y durante el periodo reproductivo, de marzo a julio) y de precipitación total en los meses previos al periodo reproductivo (septiembre-abril) fueron suministrados por AEMET. Tambien se consideró como variable la categoría de conservación del área y el tiempo de protección de la misma.

Como resultados de este primer estudio, se obtuvo que todas las especies mostraron tendencias positivas dentro de la comunidad, considerando los 30 años de estudio.Sin embargo, las especies de Garza real, Garza imperial, Garcilla bueyera y Garceta común, detuvieron su crecimiento a mediano y corto plazo (últimos 16 y 8 años). Este comportamiento estaría reflejando un crecimiento del tipo logístico para estas especies, quizás debido a que los humedales donde se localizan, en sus condiciones actuales, han alcanzado su capacidad de carga (Garrido et al., 2012; Martinez-Abraín et al., 2016). Por su parte, la Garcilla cangrejera y el Morito común, especies de reciente colonización y expansión, mantienen su tendencia positiva en todo el periodo de estudio, mostrando un crecimiento del tipo exponencial, propio de especies colonizadoras (Martinez-Abraín et al., 2016).

Los censos históricos mostraron que L'Albufera fue el primer humedal en ser colonizado y es el sitio con mayor abundancia de parejas reproductoras en la Comunidad Valenciana, con números significativamente más altos que el resto de los humedales evaluados, demostrando la importancia de esta localidad como sitio reproductivo de la región. El resto de los humedales considerados fueron todos colonizados posteriormente. Aquellos humedales más cercanos a L'Albufera (Marjal del Moro, Marjal Xeresa-Xeraco y P.N. Pego-Oliva) mostraron tener una correlación significativa entre sus poblaciones de Garza real, Garza imperial, Garcilla cangrejera y Morito común. Por otra parte, se observó una compensación entre las poblaciones de Garcilla bueyera y Garceta común de L'Albufera con las del P.N. El Hondo, entre el 2006 y 2015, donde la disminución del número de parejas en la primera localidad fue compensada por un aumento en la segunda. Estos hechos evidencian el importante papel de L'Albufera como fuente y propulsor de la dinámica poblacional dentro de la región.Por otro lado, las colonias se establecieron primero en aquellos humedales con alguna categoría de protección legal y luego fueron colonizando áreas a medida que eran decretadas como protegidas, con algunos años de diferencia (2-4 años después). El último humedal en ser colonizado fue el Marjal de Moros, el cual a su vez fue el último en ser decretado área protegida, del grupo de humedales considerados.

Con el análisis de correspondencia se obtuvo que las variables de hábitat que están asociadas a L'Albufera fueron la presencia de arrozales y extensión del área, mientras que las variables presencia de marismas y salinas, son las que caracterizaron a los parques naturales El Hondo y Salinas de Santa Pola. Por su parte, los humedales costeros Marjal del Moro, Marjal de Xeresa-Xeraco, Marjal de Almenara y P.N. Pego-

Oliva, se caracterizaron por la presencia de marismas de agua dulce, playas, vegetación arbustiva o de pastizal, adyacencia de cultivos de otra índole diferente al arroz y construcciones, ya sea urbanismos o industrias. Las precipitaciones fueron otra variable que estuvo asociada a estas localidades, las cuales intervienen directamente en el estado de inundación de las marismas naturales y, por lo tanto, en la disponibilidad de hábitat de alimentación para las aves acuáticas (Bancroft et al., 1988; Hafner et al., 1994). A partir del mismo análisis, se encontró, por otro lado, que las poblaciones reproductoras de Garza real, Garcilla cangrejera, Garcilla bueyera y Garceta común están asociadas a áreas que ocupan mayor superficie, a los arrozales y otros cuerpos de agua dulce en las cercanías, mientras que las poblaciones de Garza imperial y Morito común se asocian mayormente a hábitats caracterizados por las precipitaciones, tales como las marismas, y a la protección legal del área. Esto explicaría, en parte, el hecho que L'Albufera sea el sitio con el mayor número de parejas reproductoras de garzas dentro de la comunidad, ya que de todos los humedales estudiados es el de mayor superficie y con grandes extensiones de arrozales.

En este estudio, las colonias reproductoras de las especies estudiadas se han establecido dentro o en zonas adyacentes a marismas de agua dulce o arrozales, por lo que el manejo y gestión adecuada de estos hábitats tiene un papel preponderante en el éxito de las mismas. El mantenimiento de las áreas inundadas dentro del área de influencia de dichas colonias, especialmente en periodos de reproducción, es un factor que debe ser considerado en los planes de manejo de los humedales en cuestión. En este sentido, el P.N El Hondo tiene una experiencia positiva al implementar un Plan de

Gestión Hídrica (Generalitat Valenciana, 2012), en el cual la gestión del agua toma en consideración las necesidades de las aves nidificantes del parque, mejorando la infraestructura para asegurar la buena circulación y la cantidad y calidad necesaria del agua para las mismas. Con estas acciones las poblaciones de Garcilla bueyera y Garceta común incrementaron en número, con lo que el P.N. El Hondo ocupa el segundo lugar en importancia dentro de la región, después de L'Albufera. Por otra parte, la protección legal del área también resultó ser un factor importante en el establecimiento de las colonias reproductoras, especialmente para el Morito común y la Garza imperial, según los resultados del análisis de correspondencia, de las cuales esta última se encuentran como protegida dentro de la región. Por lo mismo, estos humedales deben mantener su figura de área protegida y actualizar sus planes de manejo, en caso de ser necesario, para incluir los requerimientos de zonas inundadas para la reproducción exitosa de sus poblaciones.

Los parámetros reproductivos de las especies estudiadas y su relación con la fenología del cultivo del arroz, en L'Albufera, se abordan en el capítulo 4. En este caso, se estimaron los principales parámetros reproductivos para cada una de las especies ya mencionadas, en los periodos reproductivos de 2015 al 2017. Para ello, se realizaron visitas semanales a las colonias de reproducción ubicadas en dos de las islas de vegetación de la laguna central (Mata del Fang y Replaza de Zacarés) entre los meses de mayo y julio. En cada visita se registró el contenido de cada nido identificado por especie, contabilizando el número de huevos, número de pollos eclosionados y número de pollos que alcanzaron los 20 días de edad, en el caso de la Garza real y Garza imperial, y 15 días para el resto de las especies, los que se consideraron como pollos exitosos (Hafner, 1980; Bartolomé et al., 1997; Hafner et al., 2001; Nedjah et al., 2010; Nefla et al., 2014). Se monitorearon un total de 734 nidos durante el estudio. Con los datos obtenidos se estimaron los parámetros reproductivos de tamaño de la puesta y la nidada, éxito de eclosión, de nidificación y de reproducción, para cada año. La fase del cultivo se evaluó realizando recorridos semanales por las rutas y caminos que cruzan los arrozales y registrando el estado del campo (inundado, semi-inundado, fangueado, seco, sembrado y cosechado) en los puntos preestablecidos de muestreo, siendo un total de 41 puntos que cubrieron 1839 ha del arrozal. Los recorridos se hicieron entre febrero de 2016 hasta junio de 2017. Las relaciones entre los parámetros reproductivos y el estado del arrozal se analizaron utilizando Modelos Lineales Generalizados Mixtos (GLMM).

El periodo reproductivo de estas especies en L'Albufera, inició entre la primera y segunda semana de mayo durante el 2015 y el 2017, mientras que, solo en el 2016, la puesta comenzó en las dos últimas semanas de abril, lo que difiere de la fenología reportada anteriormente, para los años de 1988 a 1990, cuando la puesta se reporta a finales de abril durante todo ese periodo de estudio (Prósper y Hafner, 1996; Prósper, 2000; Dies et al., 2001). Estos cambios coinciden con los cambios que han ocurrido en el régimen de las inundaciones de los campos, previos a la siembra, las cuales actualmente comienzan a mediados mayo, entre dos o tres semanas más tarde de lo que comenzaban en décadas anteriores (entre mediados y finales de abril) (Prósper, 2000; Oltra et al., 2001). En ambos casos, los máximos de puesta coinciden con el inicio de las inundaciones, salvo en el 2016 cuando se adelantó el comienzo de las puestas y resultó ser el año con el menor éxito reproductivo.

En cuanto a los parámetros reproductivos, se obtuvo que todos los parámetros reproductivos fueron más bajos que los reportados en la bibliografía, tanto en el trabajo previo de L'Albufera (Prósper y Hafner, 1996;Prósper, 2000), como en otras localidades de España como de Europa (Hafner, 1980; Bartolomé et al., 1997, Parejo et al., 2001; Si Bachir et al., 2008; Dragonetti y Giovanchini, 2009; Jakubas, 2005; Ashoori et al., 2009; Barbraud et al., 2001; Nedja et al., 2010; Boucheker, 2009; Nefla et al., 2012). Por otro lado, según los resultados del GLMM, el éxito de reproducción mostró estar relacionado significativa y positivamente con el área de campos sembrados, es decir, que el éxito reproductivo es mayor cuando el crecimiento de los pollos coincide con una mayor superficie de campos sembrados. La Garza real, por su parte, mostró una relación negativa con esta variable, es decir, el éxito reproductivo desciende conforme el desarrollo de las plantas de arroz crece en altura y densidad. En el caso de la Garcilla cangrejera no hubo ninguna relación significativa. El éxito reproductivo también estuvo relacionado significativamente con el tiempo que transcurre entre la puesta de los huevos y el inicio de la inundación, que da comienzo al cultivo. A medida que el comienzo de las inundaciones, del mes de mayo, está más distanciada de la puesta de los huevos (mayor número de días transcurridos), el éxito reproductivo es menor. En el 2016, las puestas comenzaron a finales de abril y las inundaciones en mayo, siendo el año con menor éxito reproductivo en relación a los otros dos años de estudio (2015 y 2017), cuando las puestas comenzaron a principios del mes de mayo, muy cerca del inicio de la inundación del arrozal. Estos resultados podrían relacionarse al hecho que el incremento de presas potenciales (macroinvertebrados acuáticos) y biomasa en los arrozales, ocurre transcurrido un mes de haber sido inundado, cuando las plantas de arroz ya están emergiendo (Hafner et al., 1987; Marques y Vicente, 1999) y alcanzan su mayor diversidad y biomasa en los campos sembrados (González-Solís et al., 1996; Marques y Vicente, 1999; Mugica et al., 2006). Por lo mismo, para los pollos que eclosionan con los campos inundados (puestas más tempranas), no hay suficiente disponibilidad de presas en el arrozal para su desarrollo, mientras que aquellos que eclosionan coincidiendo con la siembra de los campos (puestas durante la inundación), obtienen mayor cantidad y disponibilidad de alimento en estos campos sembrados, lo que se traduce en un mayor éxito reproductivo.

Con base en estos resultados, se evidencia la necesidad de planes de manejo en los arrozales y de la gestión del agua, que consideren la sincronización del comienzo y duración de las inundaciones con los requerimientos reproductivos de las especies que nidifican en L'Albufera. El régimen de inundaciones debe tomar en cuenta la fenología de la puesta de las garzas, de manera de asegurar la disponibilidad de alimento en el arrozal durante la fase de levantamiento de los pollos, para mejorar su éxito reproductor y por tanto contribuir a mejorar el estado de conservación de estas poblaciones reproductoras.

Por último, en el capítulo 4 se expone el estudio donde se analizaron los parámetros reproductivos de la Garza real durante todo su periodo de reproducción en l'Albufera, que comprende desde enero hasta julio, estudiando asimismo su relación con la fenología del cultivo de arroz. La toma de datos se realizó de la misma manera que en el caso anterior, pero el periodo de muestreo en la colonia reproductora, que solo se ubicó en Mata del Fang, se realizó en los meses de febrero a abril (estación temprana–invierno) en los años del 2016 al 2018, y durante mayo-julio (estación tardía-primavera) en los años del 2015 al 2017. En este caso, los parámetros reproductivos se estimaron para cada año y para cada estación dentro de cada año. La relación entre dichos parámetros y el estado de los campos se analizó, igualmente, con Modelos Lineales Generalizados Mixtos (GLMM). Por otra parte, se evaluó el uso de los arrozales por parte de la Garza real, registrando el número de individuos en cada punto de muestreo junto con la condición del campo. Estos datos se obtuvieron de los mismos recorridos realizados en el trabajo previo y se utilizó el mismo análisis estadístico para su evaluación. Los parámetros reproductivos obtenidos fueron más bajos en el 2016, coincidiendo con mayor área de campos secos en invierno y bajas precipitaciones en primavera. En relación a la fenología de la puesta, el periodo reproductivo estuvo separado en dos fases, a diferencia del periodo estudiado en décadas anteriores (1988-1990), cuando el mismo comenzaba en enero, con máximos de puesta en enero-febrero, otra en marzo y con puestas esporádicas hasta mayo (Prósper y Hafner, 1996;Prósper, 2000). Actualmente, presenta dos temporadas de puestas claramente diferenciadas, una en enero-febrero y la otra en abril-mayo. Este cambio en la fenología de la puesta podría ser respuesta a los cambios en el régimen de inundaciones, en el cual, actualmente, el drenaje invernal se realiza más temprano (finales de enero) y se comienza la inundación más tarde (en mayo), originando que todos los campos permanezcan completamente secos por casi dos meses (marzo y abril), lo que no ocurría en décadas previas (Prósper, 2000;Oltra et al., 2001). Por otro lado, los resultados del GLMM mostraron que el éxito reproductivo estuvo asociado positivamente a los campos fangueados y semi-inundados (alto coeficiente de regresión positivo), y negativamente a los campos sembrados. El éxito reproductivo es mayor si todavía hay campos con cierto nivel de agua cuando eclosionan los pollos, tal como ocurrió en el mes de marzo de 2017, donde dicho parámetro fue más alto que en el mismo mes del 2016, coincidiendo con mayor proporción de campos fangueados o semi-inundados. De igual manera, en la primavera (estación tardía), los pollos más exitosos fueron aquellos que eclosionaron cuando aún había campos presentes en esta condición. Aquellos pollos que eclosionaron cuando todos los campos estaban sembrados, presentaron menor éxito reproductivo. Al drenar los campos, al finalizar la inundación invernal, las presas potenciales quedan atrapadas en los remanentes de agua, donde son más accesibles a las garzas (Marques y Vicente, 1999; Mugica et al., 2006), por lo que estos ambientes que se crean a medida que se retira el agua, son ambientes idóneos para la alimentación, lo que se traduce en un mayor éxito reproductivo. Por otro lado, en los campos sembrados, aunque la diversidad y biomasa de presas alcanza su punto máximo (González-Solís et al. 1996, Marques y Vicente 1999, Mugica et al., 2006), la vegetación emergente constituye un obstáculo que dificulta la captura del alimento por parte de garzas de mayor tamaño, como es el caso de la Garza real (González-Solís et al., 1996; Mugica et al., 2006; Ibañez et al., 2010; Nam et al., 2015). Esto explicaría el bajo éxito reproductivo de la Garza real, asociado a los campos sembrados.

En cuanto al uso de hábitat, los individuos fueron más abundantes en los campos fangueados en primer lugar, seguido de los campos semi-inundados, por la misma razón explicada anteriormente, de la mayor disponibilidad de alimento en estas condiciones. Durante los meses donde los campos se encuentran totalmente secos, las garzas reales se concentran en las acequias y canales de irrigación. Por otro lado, la mayor abundancia de individuos se encuentra en los campos más cercanos a la colonia, y a la laguna central, dentro un radio de 8,5 km de distancia. Estos campos son los que permanecen con cierto nivel de agua por más tiempo, por la misma cercanía a la laguna y la dinámica de la inundación y drenaje del arrozal. Cuando todos los campos están sembrados algunos individuos se alejan hasta 10 km de la colonia. Estas variables (campos fangueados y semi-inundados, distancia a la colonia) resultaron tener mayor efecto en la presencia y distribución de los individuos, según los resultados del GLMM.

Estos resultados son otra evidencia de la importancia del manejo del régimen del agua en el cultivo del arroz, en donde el momento cuando se realice el drenaje y la inundación de los campos será determinante en el éxito reproductivo de esta especie dentro de L'Albufera. Se recomienda que el drenaje invernal y la inundación en la primavera no se realicen con tantos meses de diferencia, de manera de evitar que los campos permanezcan totalmente secos por tanto tiempo, eliminando por completo la disponibilidad de hábitats de alimentación dentro del área durante ese periodo. Si bien la Garza real no es una especie con problemas de conservación, muy probablemente, otras especies de aves nidificantes en L'Albufera dependan, al igual que ella, de las condiciones y el régimen de inundaciones del arrozal para su éxito reproductivo, por lo que sus requerimientos deben ser considerados al momento de la toma de decisiones sobre el manejo del mismo.

En resumen, estos estudios evidencian la importancia del manejo y la gestión de las zonas inundadas en los humedales de la Comunidad Valenciana, para la reproducción exitosa de las especies de garzas que nidifican en los mismos. Los planes de manejo de dichas áreas deben considerar el mantenimiento de áreas inundadas, en la zona de influencia de las colonias de reproducción, por el tiempo y en los niveles que sean necesarios para satisfacer los requerimientos reproductivos de estas especies. En el caso de los arrozales, las decisiones sobre el comienzo y finalización de la inundación y el drenaje de los campos, deben ser tomadas en consenso con los productores y gestores ambientales, de manera de incorporar las necesidades de la colonia de L'Albufera para asegurar su éxito reproductivo. Ante el planteamiento de posibles cambios en la práctica de cultivo, debe evaluarse previamente las posibles consecuencias que esto podría tener sobre la población reproductora del área y considerar diversos escenarios para poder compensar dichos efectos. Para ello, es necesario continuar con el seguimiento de esta población nidificante y su hábitat para mantener actualizada la información y detectar las variaciones que se puedan presentar en el tiempo, con el fin de tomar las mejores decisiones para su conservación.

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Anexos

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Habitat and weather conditions effects on long-term breeding population dynamics of five species of herons (Ardeidae) and Glossy ibis (Threskiornithidae) in the Valencian Community, Spain

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ABSTRACT

Habitat and weather conditions effects on long-term breeding population dynamics of five species of herons (Ardeidae) and Glossy ibis (Threskiornithidae) in the Valencian Community, Spain

Valencian wetlands include 65 % of the region's priority habitats and most are protected areas. Waterfowl populations are used as indicators of the state of these environments. We calculated the linear population trend by species, per wetland, of five Ardeidae and *Plegadis falcinellus* (Threskiornitidae) species using data from the annual census between 1984-2015 for 11 selected wetlands. We constructed a matrix with 42 habitat and meteorological variables, and evaluated the relation between these variables and population trends by a Correspondence Analysis. We found an increasing trend for most species. The populations of the L'Albufera de Vàlencia Natural Park (NP) differed significantly from the rest. *Ardea cinerea*, *E. garzetta*, *B. ibis* and *A. ralloides* would be associated with large areas, and also with swamps and rice fields, while *A. purpurea* and *P. falcinellus* would be related to environments characterised by rainfall and the level of protection in the area. Rice fields and water management have been important for establishing breeding colonies.

Key words: population trends, breeding populations, Ardeidae, Mediterranean wetlands, protected areas, water birds counts, rice fields, heron populations

RESUMEN

Efectos del hábitat y las condiciones meteorológicas en la dinámica poblacional a largo plazo de cinco especies de garzas (Ardeidae) y el morito común (Threskiornithidae) en la región de Valencia, España

Los humedales valencianos incluyen el 65 % de los hábitats prioritarios de la región y la mayoría son áreas protegidas. Las poblaciones de aves acuáticas se utilizan como indicadores del estado de estos ambientes. Calculamos la tendencia poblacional lineal por especie, por humedal, de cinco especies de Ardeidae y de Plegadis falcinellus *(Threskiornitidae), utilizando datos del censo anual entre 1984-2015, para 11 humedales seleccionados. Además, construimos una matriz con 42 variables de hábitat y meteorológicas y evaluamos la relación entre estas variables y las tendencias poblacionales mediante un Análisis de Correspondencia. Encontramos una tendencia creciente para la mayoría de las especies. Las poblaciones del PN L'Albufera de Vàlencia difieren significativamente del resto.* Ardea cinerea, E. garzetta, B. ibis *y* A. ralloides *estarían asociadas con áreas grandes y con pantanos y arrozales, mientras que* A. purpurea *y* P. falcinellus *estarían relacionados con ambientes caracterizados por las precipitaciones y el nivel de protección del área. Los campos de arroz y la gestión del agua han sido importantes en el establecimiento de colonias de cría.*

Palabras clave: *tendencias poblacionales, poblaciones reproductivas, Ardeidae, humedales mediterráneos, áreas protegidas, conteos de aves acuáticas, arrozales, poblaciones de garzas*

INTRODUCTION

Wetland ecosystems, which provide the population with lots of economic and intangible services, are the most threatened on the planet (Millenium Ecosystem Assessment, 2005; MedWet, 2016). Therefore, initiatives for their conservation are of vital importance (Millenium Ecosystem Assessment, 2005). Water bird trends are considered good indicators of wetlands status (Green & Figuerola, 2003; Gómez-López *et al.*, 2006; Palomino & Molina, 2009). Nevertheless, their effective efficiency depends partly on their scale (Green & Figuerola, 2003). On lower scales, the physical characteristics of wetlands, such as size, form, presence and distribution of emergent vegetation or proximity to other wetlands, influence water bird diversity and abundance (Craig & Beal, 1992; Green & Figuerola, 2003). On a larger scale, landscape heterogeneity is closely related to species richness (Atauri & de Lucio, 2001).

On the Mediterranean coast of the Iberian Peninsula, many lagoons and marshes represent most of the total area of wetlands in this region. Wetlands in the Valencian Community, located east of the Iberian Peninsula, harbour 65 % of the existing priority habitats and provide shelter for 50 % of the rare, endemic and threatened species of their biota (Ferrer-Polo *et al.*, 2006). These figures place these wetlands among the most valuable in the peninsula (Gómez-López *et al.*, 2006), and most are included in the Natura2000 Network (Red Natura, 2000) or the RAMSAR Convention. The majority of these environments are important breeding and wintering sites for waterfowl. The most important for both species richness and abundance are the wetlands of Prat de Cabanes-Torreblanca, L'Albufera de València, Marjal de Pego-Oliva, Salinas de Santa Pola, Lagunas de La Mata-Torrevieja and El Hondo (Martínez-Abrain *et al.*, 2016). Considering only the group of herons, the wetlands in the Valencian Community harbour 9.3 % of the winter population and 11.1 % of the breeding population in Spain, and respectively occupy fourth and fifth place nationally (Garrido *et al.*, 2012). L'Albufera de València is specifically the third most important site for heron reproduction in Spain (Garrido *et al.*, 2012).

The heron species evaluated in this study are *Egretta garzetta* (Little Egret), *Bubulcus ibis* (Cattle Egret), *Ardeola ralloides* (Squacco Heron), *Ardea cinerea* (Grey Heron), *Ardea purpurea* (Purple Heron), and one Threskiornitidae, *Plegadis falcinellus* (Glossy Ibis). Most of these species appear in some national or international protection or conservation category. Internationally, these species are classified as Least Concern on the IUCN Red List (BirdLife International, 2016), and the Purple Heron and the Glossy Ibis are included in Appendix II of the Bonn Convention (Council Decision 82/461/EEC). Therefore, they are subject to regulations and international cooperation to keep their populations safe. Moreover, in the Birds Directive (Directive 2009/147/EC), five of the studied species, except the Cattle Egret and the Grey Heron, are listed as threatened, vulnerable, rare or require special attention (Appendix I). In the Red Book of the Birds of Spain (Madroño *et al.*, 2004), the Squacco Heron is listed as Near Threatened and the Glossy Ibis as Vulnerable according to IUCN criteria. However, 16 years have passed since the last edition of the Red Book of the Birds of Spain, during which time the populations of some species may present changes; e.g., the Glossy Ibis, whose breeding and wintering populations have remarkably increased (Santoro *et al.*, 2013, 2016) which will probably change its conservation status in the next edition. The Squacco Heron is listed as Endangered on the National List of Endangered Species (Real Decreto 139/2011) and in the Valencia Catalogue of Endangered Fauna Species (Decreto 32/2004). On the same list, the Purple Heron is catalogued as Vulnerable. However, the overall breeding population of herons has increased from just over 2500 pairs (in the 1980s) to about 7000 in 2013 (Generalitat Valenciana, 2013), although their numbers have recently diminished by 43 % (Generalitat Valenciana, 2016). Some of these species found in any protection category have significantly increased in the last few decades in Spain, such as Grey Heron, Purple Heron, Squacco Heron and Glossy Ibis (Pérez-Aranda *et al.*, 2003; Figuerola *et al.*, 2003; Garrido *et al.*, 2012; Ramo *et al.*, 2013), and even these last two have reached historic highs in the Valencian Community in 2015 and 2016 (Generalitat Valenciana, 2015; 2016). This increase has been considered a direct consequence of the environmental protection policies carried out in the wetlands of this region in the same time period (Martínez-Abrain *et al.*, 2016).

Our objectives were to evaluate the trends of the breeding populations of the study species in Valencian Community wetlands, and to elucidate which characteristics of this habitat, along with some weather conditions (i.e. temperature and rainfall), contribute or determine the size of these

Figure 1. Location of the study wetlands to the east of the Iberian Peninsula. *Ubicación de los humedales estudiados en el este de la península ibérica.* (Marjal de Almenara: MA, Marjal dels Moro: MM, Marjal Xeresa-Xeraco: MXX, Marjal Hondo de Amorós: MHA, L'Abufera de Valencia NP: LANP, Pego-Oliva NP: PONP, Salinas de Santa Pola NP: SPNP, El Hondo NP: EHNP, La Pedrera Dam: ELP, Beniarrés Dam: EB, Embarcaderos Dam: EE)

species' reproductive colonies. This information will help to manage both the species and habitats they occupy, which are mostly protected areas.

METHODS

Study area

The Valencian Community is located to the east of the Iberian Peninsula (Fig. 1). Thirteen of the 48 sites on the List of Wetlands in this region (Generalitat Valenciana, 2002a) are SPAs (Birds Directive, 2009/147 / CE) included in the Natura 2000 Network. Marshes, lagoons and deltas are the environments with the largest heron colonies, where they nest mostly in marsh vegetation like reeds (*Phragmites* sp.) and bulrushes (*Typha* sp.), and represent 43 % of total breeding populations of these species in this region (Garrido *et al.*, 2012). The habitat surrounding these sites consists of either meadows and grasslands or agricultural areas, and extensive rice fields that are key for the foraging of herons and the Glossy Ibis (Hafner *et al.*, 1987, Fasola & Ruiz, 1996, Garrido *et al.*, 2012).

Of the 48 wetlands defined by the List of Wetlands in the Valencian Community, we selected 11 with active breeding for at least 3 consecutive years (during the 1984-2015 period) and with a minimum of 10 pairs (Fig. 1). These wetlands are L'Albufera de Vàlencia Natural Park (LANP), Salinas de Santa Pola Natural Park (SPNP), El Hondo Natural Park (EHNP), Pego-Oliva Natural Park (PONP), Marjal de Almenara (MA), Marjal dels Moros (MM), Marjal de Xeresa-Xeraco (MXX), Marjal Hondo de Amorós (MHA), Beniarrés Dam (EB), La Pedrera Dam (ELP) and Embarcaderos Dam (EE). Currently, 97 % of the entire breeding population of the Valencian Community nests in these localities (Generalitat Valenciana, 2015; 2018).

Population trends

Since 1984, SEO/BirdLife and the Conselleria de Medio Ambiente of the regional government have periodically conducted annual censuses using the same sampling technique. They derive the number of pairs from the number of nests or adults incubating, except in areas with difficult access, where they were estimated from the number of adult reproducers present (Goméz-Lopéz *et al.*, 2006). In this study, we used the number of nesting pairs in the Valencian Community for the 32 years of consecutive censuses (1984-2015) and six species in all: Grey Heron, Purple Heron, Squacco Heron, Cattle Egret, Little Egret (Ardeidae), Glossy Ibis (Threskiornithidae).

The linear trend was calculated per species in each wetland and in the whole of the Valencian Community to observe breeding population trends in the long (32 years of censuses), mid (last 16 years) and short (last 8 years) terms. An autocorrelation analysis was performed on the number of breeding pairs per species in each wetland to verify that there was no spurious relation between population size and time (Santoro *et al.*, 2010). If data were autocorrelated, we assumed that there was no population trend, unless the significance value of the linear trend was $p < 0.01$ (Hatfield *et al.*, 1996; Santoro *et al.*, 2010).

To evaluate whether there was a preference shown by some species for certain wetlands, and if it was significantly more abundant in some than in others, the non-parametric Kruskal-Wallis test was performed (only the data from two localities were normally-distributed). In this way it was possible to identify which wetlands would be the most important for the conservation of each particular species. The Mann-Whitney *post hoc* test was used and box plots were generated. To determine if the populations of a given species covaried between different wetlands, the population sizes of each species in each wetland were analysed by a Spearman correlation with Bonferonni correction. We ran the analyses with version 3.14 of the Past3 programme (Hammer *et al.*, 2001).

How species composition changed with time and the order of colonisation in the most important wetlands were also evaluated by taking the number of pairs per species in each one at three different times during the census period: at the beginning (1984 for the LANP, 1985 for EHNP and 1988 for the rest), halfway (2000) and for the last census (2015).

Habitat variables

We created a matrix with 42 habitat variables that could be related to the population trends in each wetland (Table 1). As freshwater wetlands and marshes are positively related to heron colonies (Hafner *et al.*, 1987), the area of the marsh or flooded area (with or without vegetation) was included as a variable. This variable and the total area of the protected wetlands were obtained using GoogleEarth® (images from 2016), as was the distance from the wetland to the most important protected areas (L'Albufera de València and El Hondo). These wetlands house the largest heron populations (Garrido *et al.*, 2012; Generalitat Valenciana 2015; 2018) and trends in these large populations can influence the population trends in the closest wetlands. Likewise, we considered the average monthly temperatures during reproduction (March-July), and also the total rainfall during the non-breeding season (September-April) because it may affect success in the following breeding season (Hafner *et al.*, 1994; Lekuona, 2002). We obtained these weather data from the AEMET (Meteorology Statal Agency) database, available either on the web (AEMET OpenData) or provided by the agency. The conservation category and protection time of each locality were also considered as environmental protection policies and the protection status of colonies have an effect on population trends (Fasola *et al.*, 2010; Martínez-Abrain *et al.*, 2016). We also took into account the proportions of land use within radii of 5, 10 and 15 km around nesting colonies, calculated with GVSig (version 2.2.0.2313) from data on the latest available CorineLandCover map (2012). They were chosen because the type habitat surrounding breeding colonies influences their size and population trend, as well as the reproductive and feeding success of herons (Hafner *et al.*, 1987, Fasola *et al.*, 2010, Manikowska-Slepwronska *et al.*, 2016). Distances were selected by bearing in mind that herons feed mostly within a radius of between 5 and 10 km, but some species can move away as far as 15 km from the colony (Hafner *et al.*, 1987; Manikowska-Slepwronska *et al.*, 2019). We were unable to determine the variation in the area occupied by each land use type for the

Table 1. Variables considered in the Correspondence Analysis between the population sizes of heron species and the habitat characteristics of the different wetlands. *Variables consideradas en el Análisis de Correspondencia entre los tamaños poblacionales de las especies de garzas y las características de hábitat de los diferentes humedales.*

Variable	Description	Abbreviation
Wetland/year	Location /year of census	Ejem: MA88
Total area	Total area of the protected area in hectares	TotalArea
Area of marsh	Surface area in hectares occupied by the water body, including lake vegetation	MarshesArea
Distance to L'Albufera NP	Distance in kilometres from the location in question to the L'Albufera de Vàlencia Natural Park	Dist.PNLA
Distance to El Hondo NP	Distance in kilometres from the location in question to the El Hondo Natural Park	Dist. PNEH
Precipitation	Accumulated rainfall between September and April each year, prior to the reproductive period	PPm
Average temperature	Average temperature between March and July each year (reproductive period)	Temp
Category	The locality's protection category (SPA birds, SCI, Natural Park, none)	Category
Protection	Years of protection	Protection
Percentage of water in 5, 10 and 15 km	Percentage of surface area covered by water (rivers, lagoons, estuaries, sea) within the radii of 5, 10 and 15 km around the colony	Water5Km Water10Km Water15Km
Percentage of marshes in 5, 10 and 15 km	Percentage of surface area covered by marshes within the radii of 5, 10 and 15 km around the colony	Marshes5Km Marshes10Km Marshes15Km
Percentage of salt flats in 5, 10 and 15 km	Percentage of surface area covered by salt flats within the radii of 5, 10 and 15 km around the colony	Sal5Km Sal10Km Sal15Km
Percentage of rice fields in 5, 10 and 15 km	Percentage of surface area covered by rice fields within the radii of 5, 10 and 15 km around the colony	Rice5Km Rice10Km Rice15Km
Percentage of other crops in 5, 10 and 15 km	Percentage of surface area covered by different crop types (permanent irrigation, fruit trees, olive trees, mixed) within the radii of 5, 10 and 15 km around the colony	OtherCrops5Km OtherCrops10Km OtherCrops15Km
Percentage of forest in 5, 10 and 15 km	Percentage of surface area covered by forest type vegetation (coniferous, broadleaf, mixed) within the radii of 5, 10 and 15 km around the colony	Forest5Km Forest10Km Forest15Km
Percentage of other vegetation in 5, 10 and 15 km	Percentage of surface area covered by low vegetation (bushes, pastures) within the radii of 5, 10 and 15 km around the colony	OtherVeg5Km OtherVeg10Km OtherVeg15Km
Percentage of urbanism/industry in 5, 10 and 15 km	Percentage of surface area covered by buildings (urbanism, industrial and commercial areas) within the radii of 5, 10 and 15 km around the colony	Urb5Km Urb10Km Urb15Km
Percentage of beaches in 5, 10 and 15 km	Percentage of surface area covered by beaches and dunes within the radii of 5, 10 and 15 km around the colony	Beach5Km Beach10Km Beach15Km
Grey Heron population size	Number of breeding pairs of Grey Heron (*A. cinerea*) for each census year	TpAc
Purple Heron population size	Number of breeding pairs of Purple Heron (*A. purpurea*) for each census year	TpAp
Squacco Heron population size	Number of breeding pairs of Squacco Heron (*A. ralloides*) for each census year	TpAr
Cattle Egret population size	Number of breeding pairs of Cattle Egret (*B. ibis*) for each census year	TpBi
Little Egret population size	Number of breeding pairs of Little Egret (*E. garzetta*) for each census year	TpEg
Glossy Ibis population size	Number of breeding pairs of Glossy Ibis (*P. falcinellus*) for each census year	TpPf

30-year study period because only the 2012 update of maps was available. Nevertheless, as these environments are stable on the surface, we assumed that the difference in the total area occupied by each land use type over the years was not likely to significantly or substantially modify the results. We evaluated the relation between the habitat characteristic and the annual number of breeding pairs in each wetland with a Correspondence Analysis (CA) which, from a graphical point of view, allows the possible relations between a set of variables to be analysed. In this case, wetlands were compared in each census year (rows) with the selected variables and the population size of each species (columns). This analysis was run with version 3.14 of the Past3 programme (Hammer *et al.*, 2001).

RESULTS

Population trends

All the study species showed a growing trend between 1984 and 2015 (Table 2). For no species

Table 2. Trends of the breeding populations of all the species in the studied wetlands in the long (32 years), mid (16 years) and short (8 years) terms, including slope (b), coefficient of determination (r^2) and the *p* values. *Tendencias de las poblaciones reproductivas de todas las especies en los humedales estudiados, considerando largo (32 años), mediano (16 años) y corto plazo (8 años). Se incluye la pendiente (b), el coeficiente de determinación (r^2) y el valor de* p. (MM: Marjal dels Moro, MA: Marjal de Almenara, MXX: Marjal Xeresa-Xeraco, MHA: Marjal Hondo de Amorós, LANP: L'Albufera de Valencia Natural Park, PONP: Pego-Oliva Natural Park, SPNP: Salinas de Santa Pola Natural Park, EHNP: El Hondo Natural Park, EE: Embarcaderos Dam, EB: Beniarrés Dam, ELP: La Pedrera Dam)

Wetland	Years	Heron Species																	
		Grey Heron			Purple Heron			Squacco Heron			Cattle Egret			Little Egret			Glossy Ibis		
		b	r^2	*p*	b	r^2	*p*	b	r^2	*p*	b	r^2	*p*	b	r^2	*p*	b	r^2	*p*
MM	32	3.67	0.64	< 0.01	0.33	0.46	< 0.01				1.02	0.24	0.02	0.72	0.27	0.01	1.5	0.35	< 0.01
	16	12.29	0.89	< 0.01	0.14	0.04	0.43				7.25	0.50	0.03	4.15	0.51	< 0.01	9.08	0.58	0.01
	8	17.01	0.91	< 0.01	0,07	0.003	0.88				11.25	0.60	0.04	7.68	0.66	< 0.01	16.57	0.69	0.04
MA	32				0.44	0.45	< 0.01	0.56	0.53	< 0.01	0.88	0.35	< 0.01	1.77	0.53	< 0.01			
	16				0.54	0.17	0.14	1.22	0.29	0.08	3.11	0.41	0.03	6.22	0.55	0.01			
	8				-0.78	0.10	0.44	0.26	0.009	0.82	4.14	0.33	0.14	6.96	0.35	0.16			
MXX	32	0.31	0.40	< 0.01	0.76	0.58	< 0.01	0.68	0.51	< 0.01	0.72	0.59	< 0.01	0.99	0.50	< 0.01	0.22	0.27	0.02
	16	0.09	0.01	0.68	0.76	0.44	< 0.01	1.90	0.66	< 0.01	1.86	0.60	< 0.01	3.54	0.70	< 0.01	1.42	0.47	0.04
	8	-1.38	0.42	0.08	1.20	0.34	0.13	3.62	0.70	0.01	1.36	0.17	0.31	5.24	0.67	0.01	2.71	0.58	0.08
MHA	8										56.79	0.31	0.19				5.86	0.31	0.25
LANP	32	13.24	0.29	< 0.01	-0.85	0.14	0.03	11.63	0.61	< 0.01	15.32	0.03	0.38	20.55	0.14	0.04	4.00	0.55	< 0.01
	16	-22.76	0.26	0.04	-0.77	0.06	0.37	11.92	0.21	0.07	-137.59	0.54	< 0.01	-23.18	0.08	0.29	21.77	0.85	< 0.01
	8	-36.21	0.27	0.19	5.81	0.82	< 0.01	46.06	0.49	0.05	-310.58	0.70	0.01	-37.11	0.08	0.51	34.43	0.98	< 0.01
PONP	32	0.57	0.29	< 0.01	0.73	0.21	0.01	0.59	0.76	< 0.01	0.72	0.49	< 0.01	2.71	0.53	< 0.01			
	16	0.10	0.002	0.84	-0.67	0.06	0.35	0.89	0.61	< 0.01	1.63	0.20	0.20	8.42	0.49	0.02			
	8	-2.63	0.32	0.14	-3.12	0.27	0.18	0.13	0.007	0.85	0.46	0.01	0.80	7.40	0.22	0.24			
SPNP	32	1.11	0.32	< 0.01	-0.38	0.11	0.11	1.70	0.41	< 0.01	49.85	0.36	< 0.01	-0.76	0.01	0.71	1.33	0.46	< 0.01
	16	-0.66	0.02	0.69	-1.75	0.33	0.05	0.36	0.004	0.85	-52.00	0.09	0.33	-0.61	0.008	0.76	1.48	0.10	0.30
	8	-7.25	0.56	0.05	-0.07	0.007	0.84	-4.06	0.15	0.34	-193.87	0.32	0.14	-5.54	0.31	0.19	-3.23	0.15	0.34
EHNP	32	0.64	0.18	0.06	-0.43	0.12	0.07	3.48	0.54	< 0.01	37.98	0.24	0.02	2.74	0.05	0.33	1.78	0.30	0.01
	16	7.75	0.53	0.06	-0.99	0.10	0.28	19.5	0.63	0.02	328.81	0.48	0.06	55.94	0.70	0.01	14.38	0.60	0.02
	8	7.75	0.53	< 0.01	1.76	0.30	0.16	24.36	0.69	0.02	500	0.74	0.01	69.64	0.77	0.01	17.75	0.64	0.03
EE	8	1.39	0.70	0.01															
EB	32	0.91	0.96	< 0.01															
	16	1.5	0.75	0.33															
	8	1.5	0.75	0.67															
ELP	32							0.31	0.60	< 0.01	3.19	0.66	< 0.01						
	16							-0.14	0.005	0.87	17.79	0.48	0.08						
	8							-1.4	0.56	0.08	10.91	0.28	0.28						
Valencia Region	32	18.53	0.48	< 0.01	1.03	0.13	0.04	17.39	0.73	< 0.01	102.33	0.55	0.01	26.48	0.23	< 0.01	83.42	0.44	< 0.01
	16	-9.90	0.06	0.36	-0.68	0.02	0.62	26.94	0.54	< 0.01	39.10	0.04	0.46	9.8	0.02	0.63	22.35	0.66	< 0.01
	8	-16.62	0.07	0.51	5.39	0.44	0.07	69.46	0.70	0.01	-4.75	0.0004	0.96	48.21	0.16	0.33	53.68	0.87	< 0.01

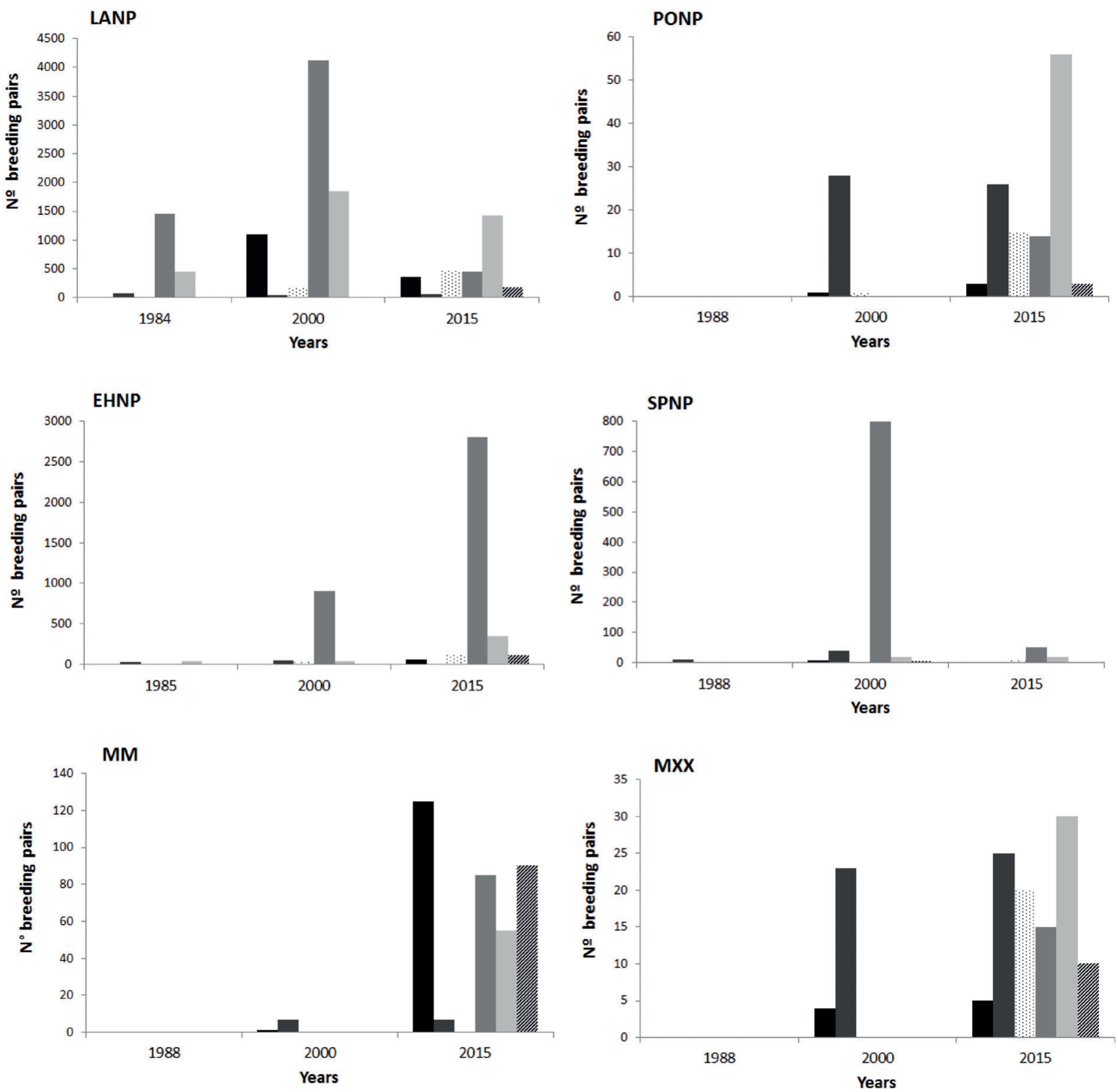

Figure 2. Number of breeding pairs per species at three different times during the 1984-2015 period for six wetlands in the study area. *Número de parejas reproductivas por especie en tres diferentes momentos entre el periodo 1984-2015 para seis humedales del área de estudio.* (■ Grey Heron-Garza Real ■ Cattle Egret-Garcilla bueyera ■ Purple Heron-Garza Imperial ■ Little Egret-Garceta común ░ Squacco Heron-Garcilla cangrejera ▩ Glossy Ibis-Morito común)

was an autocorrelation found between the numbers of nesting pairs in two consecutive years. Indeed, the p of the linear trend was always ≤ 0.01 in those cases for which the coefficient of autocorrelation was > 0.80. Therefore, we considered that there was no autocorrelation.

Locally, the Purple Heron and Little Egret obtained the lowest r^2 values that were, however, significant in the long term (Table 2). For wetlands, all the species in all the localities showed significant positive trends, except for the Purple Heron, which showed a negative trend in SPNP, EHNP and LANP, which was significant only in LANP (Table 2). The Little Egret presented no significant trend in EHNP or SPNP, nor did the Cattle Egret in LANP or MHA (Table 2). When considering the 16- and 8-year periods, throughout the Valencia Community only the Squacco Heron and Glossy Ibis continued to show a significant positive trend (Table 2). By analysing trends for wetlands, in the EHNP all species showed a significant trend in the mid and short terms, except for the Purple Heron (Table 2). The Grey Heron, Cattle Egret, Little Egret and Glossy Ibis showed a significant positive trend for both periods in MM, while the Squacco Heron and Little Egret did so in MXX (Table 2). In LANP, only the Glossy Ibis displayed positive trends in both the mid and short terms, whereas the Cattle Egret showed a significant negative trend during both periods, and the Grey Heron presented a negative trend during the 16-year period (Table 2).

Fluctuations in species composition

During the 30-year census, species richness and abundance has varied in each wetland. At the beginning of the census, breeding colonies were recorded only in LANP, EHNP and SPNP (Fig. 2). In 1984, LANP had colonies of Cattle Egret (most abundant), Little Egret, and Purple Heron (least abundant). Although the Grey heron has nested in the park since 1984, the few pairs (13) are not visible in the graph (Fig. 2). For this initial period, pairs of Purple Heron, Little Egret, Grey Heron, and one pair of Cattle Egret, were recorded in EHNP, and 10 pairs of Purple Heron were present in SPNP (Fig. 2).

Halfway through the period (2000), the Purple Heron had the most breeding pairs in MM, MXX and PONP, and a few Grey Heron pairs also settled in MM and PONP (Fig. 2). In EHNP, Cattle Egret was one of the most abundant species (as in SPNP and LANP), followed by the Purple Heron, Little Egret and Squacco Heron (Fig. 2).

In the last census (2015), all the species were present in all the monitored wetlands, except for the Squacco Heron, which was missing in MM, as was the Glossy Ibis in PONP (Fig. 2). The Little Egret was the dominant species in LANP, PONP an MXX, while it was the Grey heron in MM. The Cattle egret remained the most abundant breeding species in SPNP and EHNP (nearby localities; Fig. 2). The Cattle egret population diminished in LANP and became the third most abundant species after the Squacco Heron (Fig. 2). The Glossy Ibis has colonised the studied wetlands only recently and its biggest breeding population was found in LANP in 2015.

Relations among populations

The breeding populations of all the species present in LANP were significantly larger than the nesting populations of the same species in the other wetlands, except for the Glossy Ibis (Fig. 3), which indicates that it is the most important breeding colony of all those studied. For the Grey Heron, only the LANP population was significantly larger than in any other wetland. Otherwise, the EHNP and SPNP colonies were the second most important ones. The number of breeding pairs of Squacco Heron, Cattle Egret and Little Egret in these wetlands were significantly higher than for the other marshes, but their abundances did not differ from one another (Fig. 3). The Purple Heron showed significant differences among several populations (Fig. 3).

The breeding populations of the Squacco Heron and Grey Heron in the different localities correlated positively and significantly in most cases (Table 3). The breeding populations of the Cattle Egret and Little Egret in LANP showed no relation with any of these populations in other localities, while the other species correlated with the populations of MM, MXX, PONP and SPNP to a greater or lesser extent. The Purple Heron correlated negatively with the MM population (Table 3). All the nesting species in MXX correlated significantly with the species of PONP, except for the Purple Heron and Glossy ibis. Likewise, the population sizes of all the species present in MA significantly correlated with those of PONP and MXX (Table 3).

Habitat variables

In the CA, 82.14 % of total variance was explained on the first three axes (67.18 % on the first two). On the first axis (42.24 %), the variables with a greater weight in positive absolute values (> 1) were Distance to the L'Albufera NP (DistPNLA),

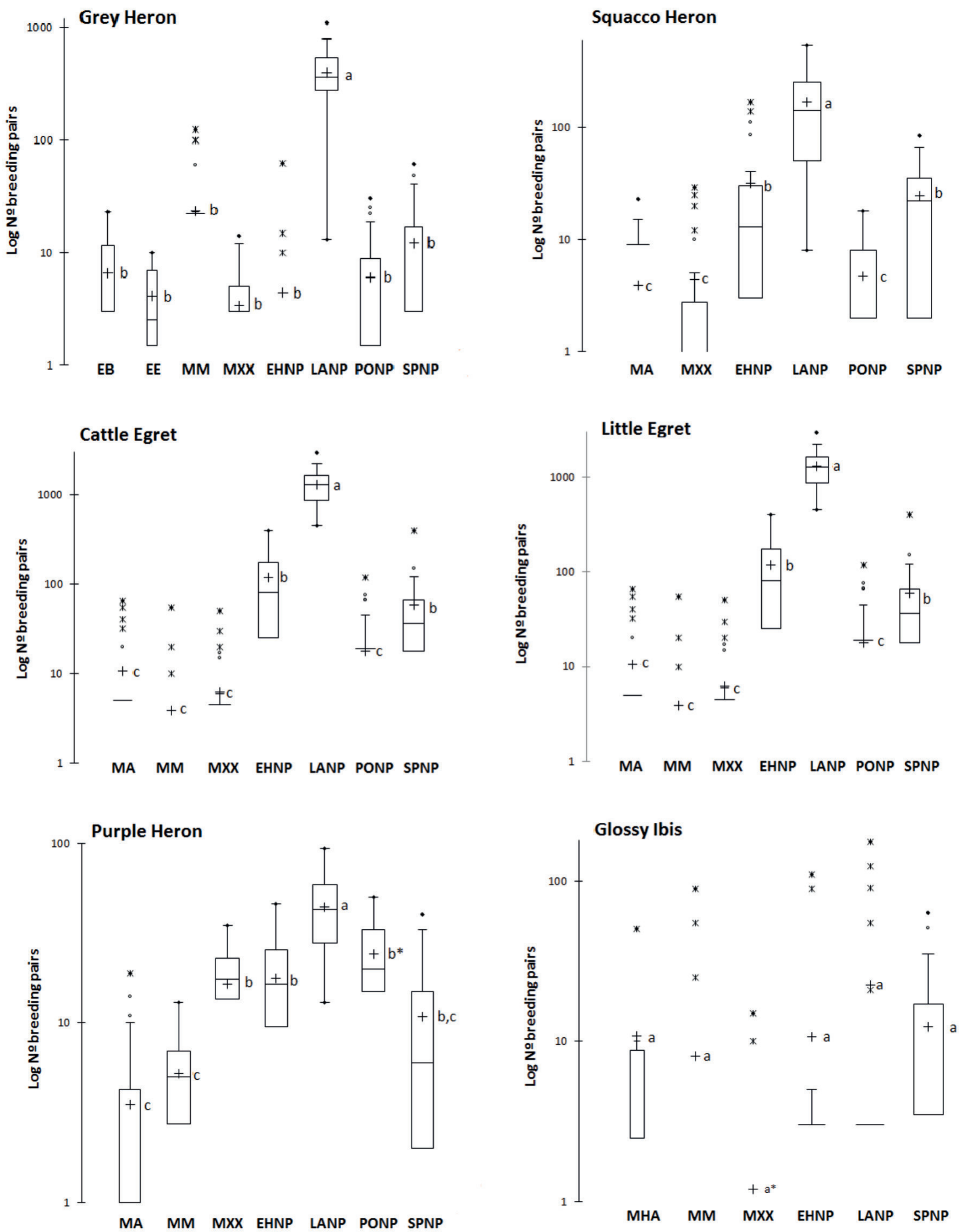

Figure 3. Nesting pairs per species between 1984 and 2015 in each studied wetland (+ mean, ◆ minimum/maximum, — median, ⊤ standard deviation, ○ atypical values ✳ extreme values. Same word: no significant differences, different word: significant differences. a* b* only significantly differs from SPNP). *Parejas nidificantes por especie entre 1984 y 2015 en cada humedal estudiado (+ media, ◆ mínimo/máximo, — mediana, ⊤ desviación estándar, ○ valores atípicos ✳ valores extremos. Letras iguales: no hay diferencias significativas, letras diferentes: hay diferencias significativas. a* b* solo difieren significativamente de SPNP).*

Precipitation (PP), Temperature (Temp), Protection category, Protection, Marshes, Other Vegetation, Other Crops, Beaches and Urbanism. Towards the negative side of the axis, the variables with the greatest weight were Water 10 km and Rice 15 km. However, Total area, Rice 5 km and Water 10 km (the other negative values on the axis) contributed to pull the population size variables of the Grey Heron, Little Egret, Squacco Heron and Cattle Egret towards this sector (Fig. 4). The LANP and EE wetlands were also located slightly towards the negative side of the axis, which were the two wetlands with the largest (total) area of those herein considered (Fig. 4). The population sizes of the Purple Heron and Glossy Ibis were associated with the variables located in the positive sector of axis 1, like marshes (MA, MM, MXX, MHA) and PONP (Fig. 4). The dispersion of points was basically due to the difference in rainfall in several years, and it was one of the variables with a greater weight (positive absolute value) on this axis. Marshes, mainly MM, MXX, MA and PONP, were apparently associated with the presence of Other Crops (not rice), Other Vegetation (non-forest), Urbanism, Marshes and Beaches (Fig. 4).

For axis 2, of the variables with a greater

Table 3. Statistic and *p* values of the Correlation Analysis between the populations of each heron species in the different studied wetlands. *Valor del estadístico y* p *del Análisis de Correlación entre las poblaciones de cada especie de garza en los diferentes humedales estudiados.*

Grey Heron

St\p	PONP	MXX	EB	SPNP	EHNP	LANP	MM	EE
PONP		< 0.0001	0	< 0.001	0.07	< 0.01	< 0.0001	1
MXX	0.86		0	< 0.001	0.19	< 0.001	< 0.01	1
EB	0	0		0	1	0.12	0	1
SPNP	0.83	0.78	0		1	0.28	< 0.01	1
EHNP	0.64	0.58	0.11	0.37		0.25	0.04	1
LANP	0.64	0.74	0.78	0.54	0.57		0.05	1
MM	0.88	0.73	0	0.73	0.66	0.60		1
EE	0	0	0.86	0	0.25	0.69	0	

Purple Heron

St\p	MM	MXX	PONP	SPNP	MA	EHNP	LANP
MM		0.27	1	1	0.05	1	0.04
MXX	0.46		0.18	1	0.03	1	0.78
PONP	0.19	0.49		1	< 0.0001	1	1
SPNP	-0.07	-0.27	-0.22		1	1	1
MA	0.59	0.62	0.86	-0.39		1	1
EHNP	-0.15	-0.30	-0.13	0.15	-0.18		1
LANP	-0.56	-0.40	-0.07	-0.20	-0.21	-0.28	

Squacco Heron

St\p	PONP	MXX	MA	SPONP	EHNP	LANP	ELP
PONP		< 0.0001	< 0.0001	1	< 0.001	< 0.01	0.35
MXX	0.91		< 0.0001	1	< 0.001	0.02	1
MA	0.91	0.97		0.04	0.02	0.12	1
SPONP	0.38	0.33	0.64		1	< 0.01	0.3
EHNP	0.75	0.76	0.67	0.03		1	1
LANP	0.69	0.62	0.58	0.68	0.38		1
ELP	0.57	0.43	0.43	0.58	0.17	0.37	

Cattle Egret

St\p	MM	MXX	PONP	SPNP	MA	EHNP	LANP	ELP	MHA
MM		0.06	0.24	1	0.77	0.16	1	0	1
MXX	0.63		< 0.0001	1	< 0.0001	1	0.49	1	1
PONP	0.56	0.94		1	< 0.0001	1	0.16	1	1
SPNP	0.07	0.37	0.38		0.04	1	0.05	0.07	1
MA	0.50	0.85	0.86	0.66		1	0.16	0.87	1
EHNP	0.58	0.09	0.05	0.05	0.14		1	1	1
LANP	0.25	0.49	0.57	0.63	0.60	-0.03		0.87	1
ELP	0	0.50	0.50	0.70	0.54	0.19	0.54		1
MHA	0	0	0	0.67	0	0.67	-0.52	0	

Little Egret

St\p	MM	MXX	PONP	SPNP	MA	EHNP	LANP
MM		< 0.01	0.03	1	1	1	1
MXX	0.72		< 0.0001	1	< 0.0001	1	0.54
PONP	0.64	0.91		1	< 0.0001	1	0.38
SPNP	0.11	-0.04	0.06		1	1	1
MA	0.29	0.97	0.86	0.13		0.35	1
EHNP	0.42	0.06	-0.01	0.09	-0.53		1
LANP	0.32	0.45	0.49	0.26	0.16	0.26	

Glossy Ibis

St\p	MM	MXX	MHA	SPNP	EHNP	LANP
MM		< 0.0001	1	0.03	0.04	< 0.01
MXX	0.79		1	0.21	0.57	0.09
MHA	0.00	0		1	1	1
SPNP	0.63	0.53	0		< 0.01	< 0.01
EHNP	0.64	0.47	0	0.77		0.06
LANP	0.69	0.58	0.42	0.69	0.62	

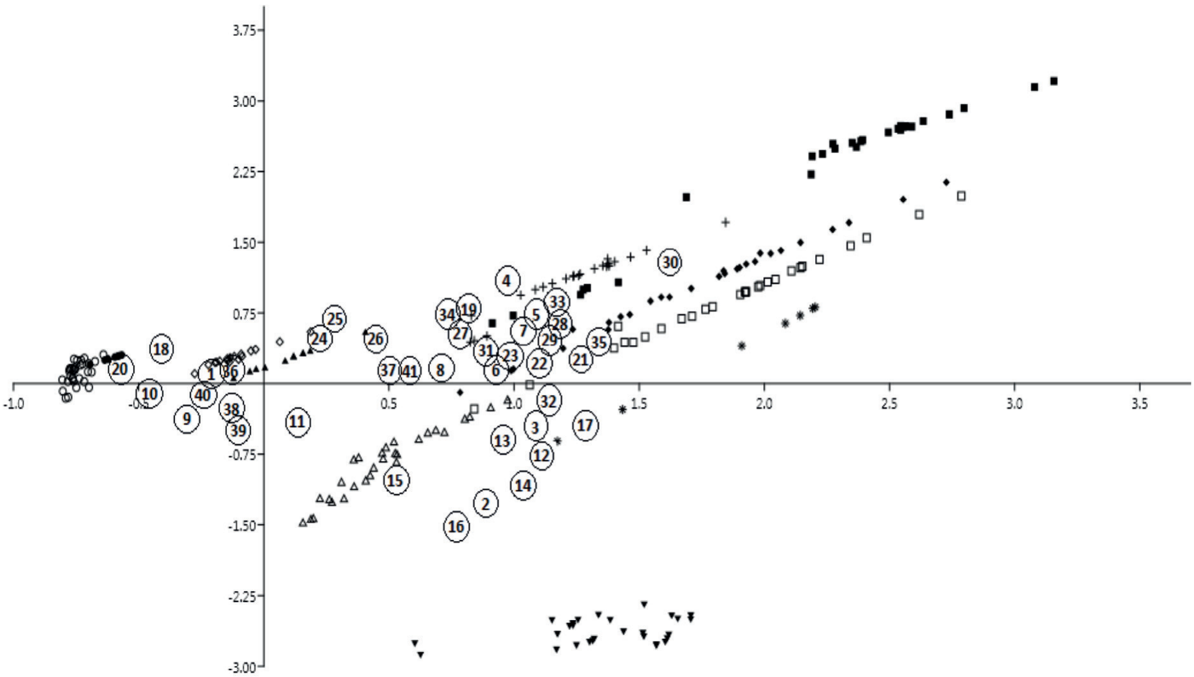

Figure 4. Correspondence analysis showing the relations between the studied wetlands and variables. *Análisis de correspondencia mostrando la relación entre los humedales y entre las variables estudiadas.* Wetlands- Humedales: ■ MM □ MXX + MA ✳ MHA ◆ PONP ○ LANP △ SPNP ▼ EHNP ● EE ▲ EB ◇ ELP / Variables: 1 TotalArea, 2 MarshesArea, 3 Dist.PNLA, 4 Dist. PNEH, 5 PPm, 6 Temp, 7 Category, 8 Protection, 9 Water5Km, 10 Water10Km, 11 Water15Km, 12 Marshes5Km, 13 Marshes10Km, 14 Marshes15Km, 15 Sal5Km, 16 Sal10Km, 17 Sal15Km, 18 Rice5Km, 19 Rice10Km, 20 Rice15Km, 21 OtherCrops5Km, 22 OtherCrops10Km, 23 OtherCrops15Km, 24 Forest5Km, 25 Forest10Km, 26 Forest15Km, 27 OtherVeg5Km, 28 OtherVeg10Km, 29 OtherVeg15Km, 30 Urb5Km, 31 Urb10Km, 32 Urb15Km, 33 Beach5Km, 34 Beach10Km, 35 Beach15Km, 36 TpAc, 37 TpAp, 38 TpAr, 39 TpBi, 40 TpEg, 41 TpPf.

negative weight, which seemed to characterise environments, we found Saltpans and Marshes, which led SPNP and EHNP to be located towards this sector of the axis (Fig. 4).

DISCUSSION

The results of this study confirm that the reproductive populations of the six considered species have increased in the last three decades. However, this increase appears to have stopped in the last half of the period, except for the Squacco Heron and Glossy Ibis. Moreover, the Grey Heron, Cattle Egret, Little Egret and Squacco Heron species seem to be associated with the environments characterised by having a bigger area, nearby freshwater bodies and the presence of rice fields. The Purple Heron and Glossy Ibis species would be associated with environments influenced mostly by rainfall and with some form of protection. Of all these variables, management of water bodies and rice fields, and administration of protected areas, would be those to consider when devising conservation plans for these species.

Between 1984 and 2014, 80 % of the reproductive water bird species in the Valencian Community, such as ducks, grebes and seagulls, have increased, of which 21 % are herons (Martinez-Abraín *et al.*, 2016; Garrido *et al.*, 2012). All our heron species have displayed an increasing breeding population trend in the last 30 years, which has also been observed in Doñana (SW Spain) over the 1984-2010 period (Ramo *et al.*, 2013) The populations of these species have increased in western Mediterranean wetlands since the 1970s (Galewski *et al.*, 2011). The breeding populations of the Purple Heron, Grey Heron, Cattle Egret and Little Egret have displayed a significant positive trend, but not in the last 16 and 8 study years. Garrido *et al.* (2012) mentioned that in the Valencian Community, the Little Egret population seems to have stabilised in the last 10 years prior to their study (between 2000 and 2010) following a growth phase in the 1990s. A coherent trend has also been observed in the populations of the Grey Heron and Little Egret in NW Italy (Fasola *et al.*, 2010). Martinez-Abraín *et al.* (2016) found that the population trends of the Cattle Egret and Little Egret in the Valencian Community fit the logistic growth curve, which would be consistent with the fact that they have stopped showing a positive trend in the last 16 years. According to the same author, this would suggest that these species have recovered after the critical situation they were in at the beginning of the study, which was caused by the poor conditions of wetlands, and would have reached their carrying capacity. Their work also mentions that the Squacco Heron and Glossy Ibis are going through an exponential growth phase as they are the most recent colonisation (Martinez-Abraín *et al.*, 2016). This would coincide with the fact that these species displayed significant increasing trends in all the considered wetlands throughout our study period. In 2016, both species had more than 700 pairs distributed in eight different localities, which denotes their extended local distribution (Generalitat Valenciana, 2016).

Although the Cattle Egret has maintained a significant growing trend in the Valencian Community, when considering the whole period, it has displayed a decreasing trend in recent years in LANP. However, it has increased in other wetlands, especially in EHNP, which compensates local declines thanks to their increasing numbers in nearby areas (Garrido *et al.*, 2012).

The breeding populations of all the studied species in LANP were significantly more numerous than those in the other wetlands, and were the first colonies to be established in the region, which confirms the importance of this wetland for the reproduction of this species group. The Purple Heron was the first species to colonise the wetlands closest to LANP from the 1990s to a decade later, when other species began to arrive. The colony being established could be conditioned by the state of vegetation, which would offer adequate coverage and density (Santoro *et al.*, 2010), along with the presence of a small population to attract other individuals of the same species or of others (Pechuan, 1971; Prosper, 2000; Delord *et al.*, 2003; Santoro *et al.*, 2010). The last in this group of wetlands to be colonised was MM. In the wetlands of MXX and PONP, which are close to one another, the Purple Heron is the second most abundant species. Therefore, these protected areas play an important role in this species' conservation, considered to be Vulnerable in the Valencia Catalogue of Endangered Fauna Species.

Between 2006 and 2016, the most numerous nesting populations in LANP have dropped by 43 % due to the declining number of pairs of the Grey Heron, Little Egret and Cattle Egret (Generalitat Valenciana, 2016). However, populations have considerably increased in EHNP and, together with SPNP, could be concentrating part of the breeding population of the Cattle Egret and Little Egret of LANP. (Generalitat Valenciana, 2016). The number of both the Cattle Egret nests and Little Egret colonies is positively associated with the area occupied by rice fields (Tourenq *et al.*, 2000), and they depend on water conditions and variations in water quality (Hafner *et al.*, 1987; Bartolomé *et al.*, 1997; Garrido *et al.*, 2012). Therefore, the decline in the Cattle Egret and Little Egret populations in LANP could be indicative of a deterioration in rice field conditions as this variable characterises this wetland. In contrast, both species are present in larger numbers in EHNP, which may be a response to better water management (Generalitat Valenciana, 2016). The EHNP from 2011-2012 made improvements to the hydraulic infrastructure and changes in water management, which have favoured the increased quantity and quality of the water bodies in the park (Generalitat Valenciana, 2012). These species have benefited from this management as they find more water resources (marshes, ponds, irrigation canals), where they can further use as feeding areas. These water bodies have been shown an important association with size of colonies and these species' reproductive success (Hafner *et al.*, 1987; Bartolome *et al.*, 1997; Parejo *et al.*, 2001; Garrido *et al.*, 2012).

Most wetlands are characterised by the presence or proximity of other types of crops, shrub and grassland type vegetation (non-forests), urbanism and industry, marshes and beaches, especially coastal wetlands like MM, MXX, MA and PONP. Rainfall seems to considerably influence the environment of marshes as this variable causes different flood conditions, which would determine the availability of feeding areas in different years (Bancroft *et al.*, 1988; Hafner *et al.*, 1994). Colony size and reproductive success are positively related to the freshwater habitat area, which constitutes their feeding habitat and this, in turn, is affected by rainfall (Hafner *et al.*, 1987; Hafner *et al.*, 1994, Bennets *et al.*, 2000, Ramo *et al.*, 2013).

Spring rains would potentially have a stronger effect on these natural wetlands than on artificial ones (rice fields) like LANP (Sánchez-Guzmán *et al.*, 2007; Fasola *et al.*, 2010).

Four of the studied species (Grey Heron, Little Egret, Cattle Egret, Squacco Heron) were associated with the presence of rice fields and freshwater bodies, and with the total site area. This species may prefer similar environments to nests, where these three variables are the most important. Of these, the Grey Heron seems to be more associated with rice fields than the other three species, whereas the remaining three appear to be slightly more associated with permanent marshes (Hafner *et al.*, 1987). Rice fields are an important source of food for many waterfowl species, including herons and ibises (Fasola & Ruiz, 1996; Prosper & Hafner, 1996; Generalitat Valenciana, 2002b; Toral *et al.*, 2012), especially during the reproductive period when paddies relate positively to the size of breeding colonies (Hafner *et al.*, 1987; Lekuona, 2002). LANP, in addition to rice fields, is also characterised as the most extensive total area of the considered wetlands. This would explain why LANP is the site with the most breeding pairs (Pérez-Aranda *et al.*, 2003; Garrido *et al.*, 2012; Generalitat Valenciana, 2013). However, certain factors like reducing the flooding period or winter drainage intensification for soil preparation can negatively affect these species' populations (Prosper & Hafner, 1996; Ibañez *et al.*, 2010).

The Purple Heron and Glossy Ibis are more associated with marshes, which are, in turn, associated with rainfall (Toral *et al.*, 2012). These species seem to have a closer relation with protecting nesting areas. This relation is particularly important for the endangered Purple Heron, which has been able to recover only in recent years. In NW Italy, the protection status of breeding colonies was significantly related to population trends, as were feeding habitats (Fasola *et al.*, 2010). In our case, some species had permanently established in some wetlands 2-4 years after being declared protected areas.

The increase in heron populations, including threatened or vulnerable species, highlights the importance and effectiveness of conservation initiatives and protection policies, which are more critical locally during the reproductive season (Generalitat Valenciana, 2013; Martinez-Abraín *et al.*, 2016).

Reproductive success is typically higher in the colonies surrounded by rice fields and freshwater marshes (Hafner *et al.*, 1987; Delord *et al.*, 2003). Therefore, how paddies are managed will be a determining factor to maintain positive environmental externalities, such as the feeding, nesting and productivity of different bird species, including herons (Picazo-Tadeo *et al.*, 2009). This is especially true for LANP, whose production is adapting to more competitive markets and an increasingly strong pressure on water resources distribution (Picazo-Tadeo *et al.*, 2009). We also highlight the importance of conserving the wetland network (Red Natura, 2000) with management plans that incorporate measures for these nesting bird populations. Water management is a major aspect to consider in any management plan for these areas. Maintaining sufficiently flooded areas, which may be either artificial like rice fields or reservoirs, or natural like ponds and marshes, in breeding colonies' area of influence is vital for their conservation. The management plans of these protected areas should be reviewed to evaluate this aspect, and to invest, if necessary, in infrastructure and research to ensure good water resources management. These populations should always be considered a priority within the regional framework, and continuing with the typical metapopulations and source-sink dynamics processes that might occur must be ensured.

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Effects of rice field phenology on breeding parameters of heron colonies in the east of the Iberian Peninsula

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Forti M., Monrós J.S. & Vera P. 2021. Effect of rice field phenology on breeding parameters of heron colonies in the east of the Iberian Peninsula.
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Rice fields have traditionally been considered key feeding grounds for many waterbird species, including herons. Studies show that field management and flooding cycles influence the reproductive parameters of these birds. L'Albufera de València, on the east coast of the Iberian Peninsula, has large areas of rice fields and is home to the third largest breeding colony of herons in Spain. Changes in water and rice field management that have occurred since the colony was last assessed (1990) may have affected the colony's reproductive performance. Clutch and brood size, and hatching, nesting and breeding success were estimated for Grey Heron *Ardea cinerea*, Purple Heron *Ardea purpurea*, Cattle Egret *Bubulcus ibis*, Little Egret *Egretta garzetta*, Squacco Heron *Ardeola ralloides* (Ardeidae) and Glossy Ibis *Plegadis falcinellus* (Threskiornithidae) in 2015–2017. The extent of flooding and cultivation of rice fields was assessed from February 2016 to June 2017. Reproductive parameters were related to the state of the rice fields. All reproductive output parameters were lower than those reported in the literature. In 2016, laying started earlier (at the end of April), when the fields were still dry and hatching started from May, after flooding. In 2017, peak hatching occurred in June, when the fields were sown. A significant relationship was found between breeding success and the area of sown fields, except for the Squacco Heron. We found that birds that initiated egg laying closer to the date of flooding had a relatively higher breeding success for the Little Egret, Glossy Ibis, Cattle Egret and Purple Heron. The success of nesting populations in this type of artificial wetland requires water management plans that synchronize flooding regimes and maintenance of flooded areas with the biological requirements of these species.

Key words: Ardeidae, breeding parameters, Mediterranean wetlands, rice fields, reproductive population, heron colonies, artificial wetlands

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Wetlands are ecosystems that provide important services to the human population, both economic and ecological, but during the last century many wetlands have been transformed for cultivation (Zedler & Kercher 2005). Therefore, wetlands have been a focus of conservation initiatives as they are considered to be one of the most threatened ecosystems on the planet (Millennium Ecosystem Assessment 2005, MedWet 2016). In many countries natural wetlands have largely been replaced by rice paddies (Shine & Klemm 1999, Czech & Parsons 2002), these are considered to be artificial wetlands (Elphick 2000). Rice fields have traditionally been viewed as key feeding sites for many waterbird species (Fasola & Ruiz 1996, Czech & Parsons 2002, Kloskowsky *et al.* 2009), with obvious conservation implications (Sánchez-Guzmán *et al.* 2007, Toral & Figuerola 2010, Katayama *et al.* 2014, Sebastián-González & Green 2015, Sesser *et al.* 2016, Cardarelli *et al.* 2017). Herons and egrets (Ardeidae) are one of the groups of waterfowl that have established a stronger link with these artificial habitats (Hafner *et al.* 1987, Fasola *et al.* 1996, Tourenq *et al.* 2004, Mugica *et al.*

2006, Kazantzidis & Goutner 2008, Fasola & Brangi 2010, Fasola *et al.* 2010, Fujioka *et al.* 2010, Cardarelli *et al.* 2017). The reproductive success, nest survival and nestling body condition of these birds are affected by the quality of their foraging habitat (Hafner *et al.* 1987, 2001, Delord *et al.* 2003), so their reproductive parameters, together with their population trends, can be good indicators of wetland conditions.

There are many studies on the breeding biology of herons and egrets in different parts of Europe. Perhaps the largest amount of information has been generated in Camargue (France; e.g. Hafner 1980, Hafner *et al.* 1994, 2001, Thomas *et al.* 1999, Bennets *et al.* 2000, Barbraud *et al.* 2001, Tourenq *et al.* 2001, Delord *et al.* 2003). More recent are studies on Grey Herons *Ardea cinerea* in Central Europe (Manikowska-Slepowronska *et al.* 2015, 2016) and North Africa (Nefla *et al.* 2012, 2014, Nedjah *et al.* 2010, 2014). The reproduction of herons has also been studied in Spain, such as the studies conducted in Extremadura (Bartolomé *et al.* 1997), in Duero region (Campos 1984, Campos & Fernandez-Cruz 1991) and in Cantabria and Navarra (Lekuona 2002, Navedo *et al.* 2004), in addition to those carried out by Prósper in the Albufera de València (Prósper & Hafner 1996, Prósper 2000), among others.

L'Albufera de València is a European Union Natura 2000 site and one of the main wetlands of the Iberian Peninsula, as well as being one of the most important wetlands in the western Mediterranean, both for its size (21,120 ha) and for its valuable biodiversity of conservation interest (Generalitat Valenciana 2002). This wetland is the third most important breeding site for herons in Spain (Garrido *et al.* 2012). Seven species of herons are considered regular breeders in this area, with a total population of up to 5000 pairs (Generalitat Valenciana 2015, 2016). On a regional scale, this wetland hosts more than 50% of the breeding pairs of five species out of the seven that breed in the region (Generalitat Valenciana 2016). Pechuán (1965, 1971) carried out the first studies on the breeding biology of herons in the wetland. Subsequently, Prósper & Hafner (1996) and Prósper (2000) studied the biology of nesting species, including the breeding success of Grey Heron, Cattle Egret and Little Egret between 1988 and 1990. Thereafter, no further studies on their breeding biology have been carried out. In view of the increase in the breeding population observed in recent years, according to the annual census carried out by SEO/BirdLife and the Conselleria de Medio Ambiente of regional government, a new review of these parameters at the colonies is desired. There is no information on whether the increase in the number of breeding pairs has affected the breeding success of the colony. However, there is evidence that nest density or the increase in nesting pairs is inversely related to clutch size or reproductive success in several heron species (Hafner 1980, Bennets *et al.* 2000, Hafner *et al.* 2001). Therefore, we expect that reproductive success will be lower than in previous years when the population was smaller.

The high density of breeding pairs in this wetland is favoured by the extension of rice fields that occupy almost 70% of the protected area. These rice fields constitute an important feeding habitat for waterfowl during breeding, specifically for herons (Hafner *et al.* 1987, Fasola & Ruiz 1996, Fasola *et al.* 1996, Toral *et al.* 2012). The management of the rice fields consists of two annual flooding periods (summer and winter), which leads to large flooded areas during most of the year, which favours the availability of food for the herons (Prósper & Hafner 1996, Martínez-Abraín 1998, Prósper 2000, Generalitat Valenciana 2002). Several reproductive aspects of the herons are related to the timing of flooding. Prósper & Hafner (1996) report that the laying phenology of most heron species in L'Albufera, is related to the dates of flooding and the condition of these crops. Likewise, the number of nests, colony size and breeding success were associated with the presence of rice fields (Hafner *et al.* 1987, Tourenq *et al.* 2001, Lekuona 2002, Delord *et al.* 2003). Competition with international markets and changes in the subsidy mechanisms used by the Common Agricultural Policy (CAP) have increased pressure on water allocation for rice cultivation in search of higher profitability (Girona 1998, Picazo-Tadeo *et al.* 2009, Martínez 2018). How these changes in the management of flooding and rice cultivation cycles may affect the reproductive parameters of the colony has not been assessed.

In this study, two mixed colonies of Grey Heron, Cattle Egret, Little Egret, Purple Heron, Squacco Heron *Ardeola ralloides* and Glossy Ibis *Plegadis falcinellus* (Threskiornithidae) were monitored for three years. The results obtained for the main reproductive parameters during the breeding periods of 2015, 2016 and 2017 are reported. The main objective of this study is to analyse the effects of the state of the rice fields (phase of the crop cycle) surrounding the colonies on reproductive parameters of the herons. If the phenology of the rice fields changes between years, this may affect reproductive success, affecting colony productivity, which is a major issue for the management of this site and of other breeding areas directly related to the rice fields.

METHODS

Study area

L' Albufera de València is located in the Valencian Community, in the east of the Iberian Peninsula on the Mediterranean side (39°20'N, 00°20'W; Figure 1). It is an important European area for birdlife, regularly hosting some 240 species throughout the year, 90 of which are common breeders and 75 of which are waterfowl. For this reason, L' Albufera has been included in the 'Wetlands of International Importance' (RAMSAR) since 1989 and has also been recognized as a 'Special Protection Area for Birds' (SPA) since 1991. The protected area has a total surface area of 21,120 ha, of which 2837 ha is made up of a coastal lagoon and 14,500 ha of surrounding rice fields. The maintenance of the rice fields involves the management of the waters of the rivers Júcar and Turia, which in turn feed the lagoon through canals used for agricultural purposes. The rice fields follow a flooding regime, which takes place twice a year (May–September and October–February), while in the months of March–April the fields are dry to prepare the land, as well as in September–October when the harvest takes place.

The lagoon has several islands or vegetation formations ('matas') covering some 290 ha, which are used

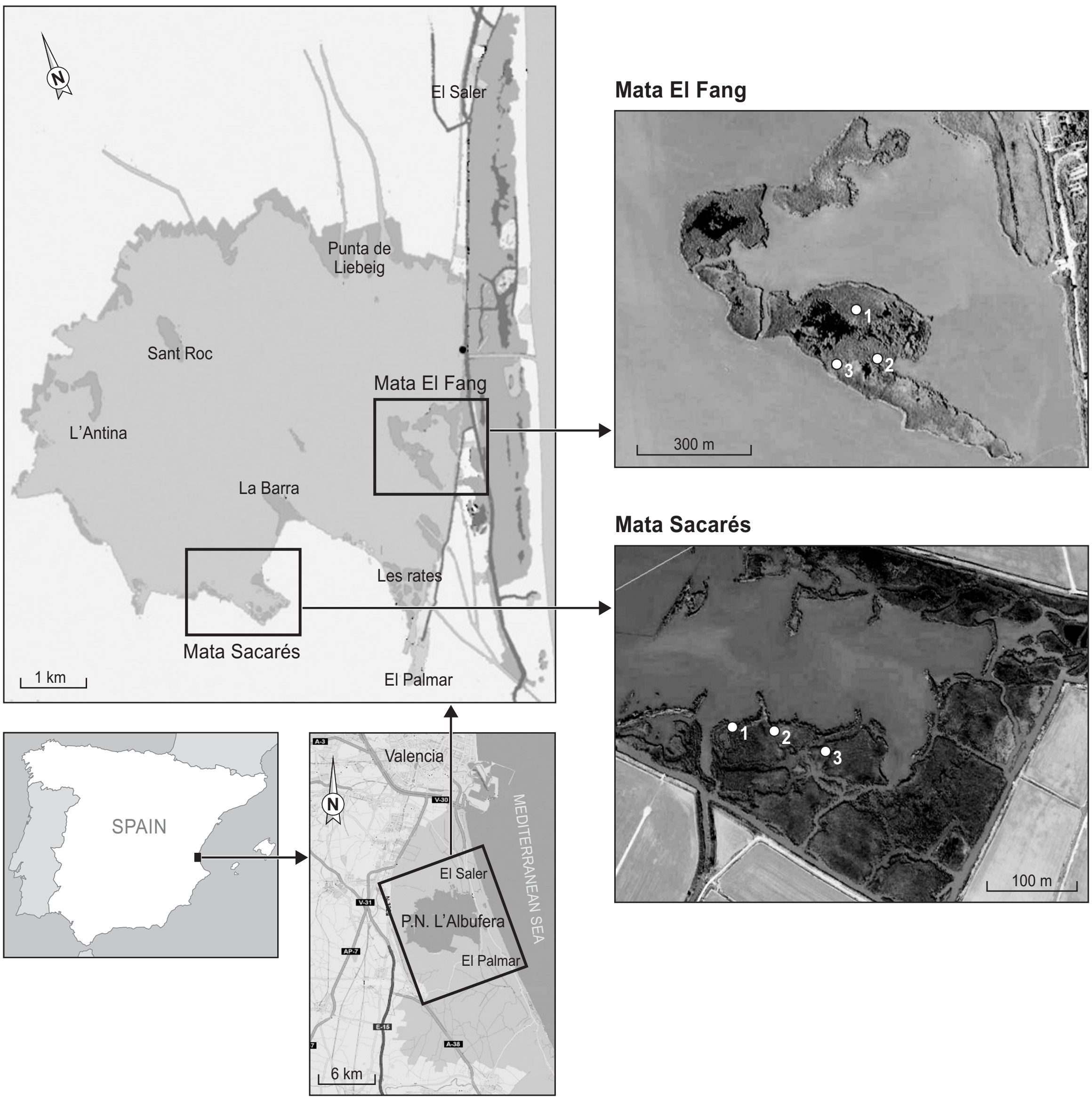

Figure 1. Location of nesting colonies in 'matas' El Fang and Sacarés in L'Albufera de València.

by herons and other birds to establish their nesting colonies. The colonies studied are located at Mata El Fang (hereafter MEF) and Replaza de Sacarés (hereafter RS; Figure 1). MEF is a reserve area located on the eastern shore of the lake and is the largest (c. 30 ha), while RS is located on the southern shore of the lake and has an area of c. 11 ha. The predominant vegetation in these 'matas' are Common Reed *Phragmites australis*, Cat-tails *Thypha domingensis*, Seashore Mallow *Kosteletzkia pentacarpos* and Swamp Sawgrass *Cladium mariscus*. On this vegetation, the herons establish their heterospecific colonies, except in the case of the Purple Heron, which forms single-species colonies.

Since the beginning of May of each year, field-observations were conducted from the surroundings of the 'matas' to determine the location of the colonies, looking for adults flying and resting. Subsequently, aerial photographs were taken from an ultralight (25/06/2015, 19/07/2016 and 23/06/2017) that allowed the determination of locations of other small colonies, and to confirm that no relevant colony had been missed out. Several nesting clusters were recorded within each reed bed. Some of these clusters were very difficult to access, so they were not included in the monitoring. In total, three colonies were surveyed at MEF and three at RS. Some of them varied in location, at the same island, from year to year.

Breeding parameters

Visits to the different nesting colonies were made every 7–10 days during the breeding period (May–July) 2015, 2016 and 2017. Most nests in the main colonies were marked with numbered tape and geo-referenced. As many nests as possible were followed up. Each nest was identified by species and its contents (eggs, shells, unhatched eggs, nestlings, dead nestlings and nestling condition) were recorded at each visit. Colonies were visited after they were established, to avoid interfering with the nesting process (Prósper & Hafner 1996, Caballero 1996). Clutch size was established as the largest number of eggs observed in the nest that remained unchanged on subsequent visits. If the nest contained only newly hatched or few-day-old chicks, clutch size was assumed to be equal to the number of chicks. The onset of egg laying was estimated by counting back the days of incubation from the hatching date of the chicks, considering 25 days for Grey Heron (Hankock & Kushlan 1984), 26 days for Purple Heron (Tomlinson 1975), 23 days for Cattle Egret and Glossy Ibis (Blaker 1969, del Hoyo *et al.* 1992) and 22 days for Little Egret and Squacco Heron (Sterbetz 1962, Hafner 1980).

Brood size was recorded as the number of nestlings still alive at 15 days of age (Hafner 1980, Bartolomé *et al.* 1997, Hafner *et al.* 2001, Nedjah *et al.* 2010, Nefla *et al.* 2014). After this time, nestlings may move along branches or jump to the ground, making them difficult to observe and making it impossible to identify the nest to which they belong. In the case of the Grey Heron, chicks stay longer in the nest, so chicks up to 20 days old were also counted (Jakubas 2005, Ashoori *et al.* 2009). Chicks found dead after this time were recorded as unsuccessful.

Hatching success (number of hatched eggs/total number of eggs), nesting success (number of successful chicks/number of hatched chicks) and breeding success (number of successful chicks/total number of eggs) per nest and for each species were estimated.

Rice fields status

To assess the influence of the flooding cycle and cultivation phase on the colony's reproductive parameters, rice fields were surveyed every two weeks. The northern and southern areas of the lagoon were visited between February 2016 and June 2017. Twenty-six observation points were selected along a 22 km route in the southern zone and 15 points along a 9 km route in the northern zone, established on roads crossing the rice fields. A total area of 1839 ha of the rice fields was covered. The selection of points and routes depended on the accessibility during the hunting season, when several roads and fields are closed to the general public. During the surveys, the condition of a rice field was recorded by classifying it as dry, muddy/wet, semi-flooded, flooded, sown or harvested (Table 1).

The proportion (by area) of each category in each month was calculated. The number of individuals of each species of interest was also recorded for each survey. For the analyses, records from February to June (before and during the breeding season) were used.

Statistical analysis

Reproductive parameters for each species were compared using a Kruskal-Wallis test to determine if there were significant differences between years. Past3 v. 3.14 was used for statistical analyses. Reproductive parameters of nests were compared between before and after flooding and between before and after sowing, in the years in which the rice fields were followed (2016 and 2017), using Kruskal-Wallis tests. For the analysis of brood size and breeding success, nestlings hatched in May (flooded fields from the second week) and in June (sown fields) were excluded because all nestlings hatched at or after flooding.

To assess whether the condition of the rice fields has an effect on the breeding success of the colony, we fitted Generalized Linear Mixed Models (GLMMs) with a Binomial distribution. The condition of rice fields was defined by two continuous variables: percentage of number of sown fields and percentage of number of flooded fields. The response variable was the breeding success (proportion), and the predictors were the percentage of number sown fields, percentage of number flooded fields (rescaled as the arcsine of the square root of the proportion) and the species of heron. We compared seven models with different combinations of predictors and the study year as a random effect. We selected the best explanatory model using the Akaike Information Criterion corrected for small sample size (AIC_c; Burnham & Anderson 2004). Models within delta $AIC_c < 2$ were considered equally plausible, however, after model selection none of the other considered models fell within this range (Table S2, S3; Harrison *et al.* 2018).

In the same way, a GLMM was run to assess the effect of timing between egg laying and flooding, and between hatching and seeding. The timing was defined by 'days to flooding' (days elapsed between egg laying and onset of flooding) and 'days to sowing' (days elapsed between hatching and onset of sowing). These variables together with the heron species were the predictors and the breeding success (proportion) was the response variable. Squacco Heron was not included in this analysis since in all cases egg laying and hatching occurred after flooding and sowing, respectively. Six models were compared with different combination of predictors and the study year included as a random effect. Again, the AIC_c was used to select the best model as described above. All the analyses were performed using R (R Core Team 2020).

Table 1. Categorization of the state of rice fields in L'Albufera de València.

Category	Description
Dry	Totally dry field, presence of cracks, ploughed or not.
Muddy/wet	Field with wet earth, mud, with small spatially dispersed pools of water, worked with machines or not. There are no dry areas.
Semi-flooded	Field with some areas covered with water, very shallow, but the water does not cover the total extent of the field.
Flooded	Field with the entire area flooded, resembling a lagoon, without visible vegetation.
Sown	Field with water cover but with rice plants, in all stages (freshly planted up to > 70 cm).
Harvest	Field with remnants of the crop, fallow, burned or not.

RESULTS

All colonies surveyed were mixed, except for one Grey Heron colony at MEF observed in 2015 and the Purple Heron colony. The Purple Herons settled only at RS, while the Grey Herons established their entire nesting population at MEF.

Phenology of egg laying and hatching

A total of 734 nests were monitored during the study. The onset of egg-laying began in late April and continued through May. During the three years of the study, most heron species had the highest number of nests with eggs in the third and fourth week of May. In 2016, egg laying in Grey Heron, Cattle Egret, Purple Heron and Glossy Ibis started from the third week of April, whereas in 2015 and 2017 it started in May (Figure 2). Despite observing this earlier egg laying in 2016, for these four species, only the Grey Heron significantly advanced egg laying (Kruskal-Wallis test: $H = 5.4$, $P = 0.02$). Squacco Heron was the exception, maintaining the onset of laying in the second week of May and extending it until the first week of June during the three years of the study, without significant changes. In terms of peak laying, Grey Heron, Cattle Egret and Purple Heron peaked in the last week of April during 2016, while peak laying in the other years was in May and June (Figure 2).

All species had hatching peaks in June during the three study years. However, in 2016, Grey Herons and Purple Herons had the highest hatching peaks in the last week of May, while Cattle Egrets had a second peak at this time. In 2016, due to the earlier onset of egg laying, the first hatching occurred from the second week of May in the Grey Heron, Cattle Egret, Purple Heron and Glossy Ibis, and from the third week of May in the Little Egret. In 2015 and 2017 hatching was concentrated in June. No significant differences were found in the number of hatched eggs per month between years (Table S1).

Clutch and brood size

The mean clutch size was between 2 and 4 eggs, depending on the species. Squacco Heron had the largest mean clutch size (4.16 eggs; Table 2). This species also had the highest mean number of successful

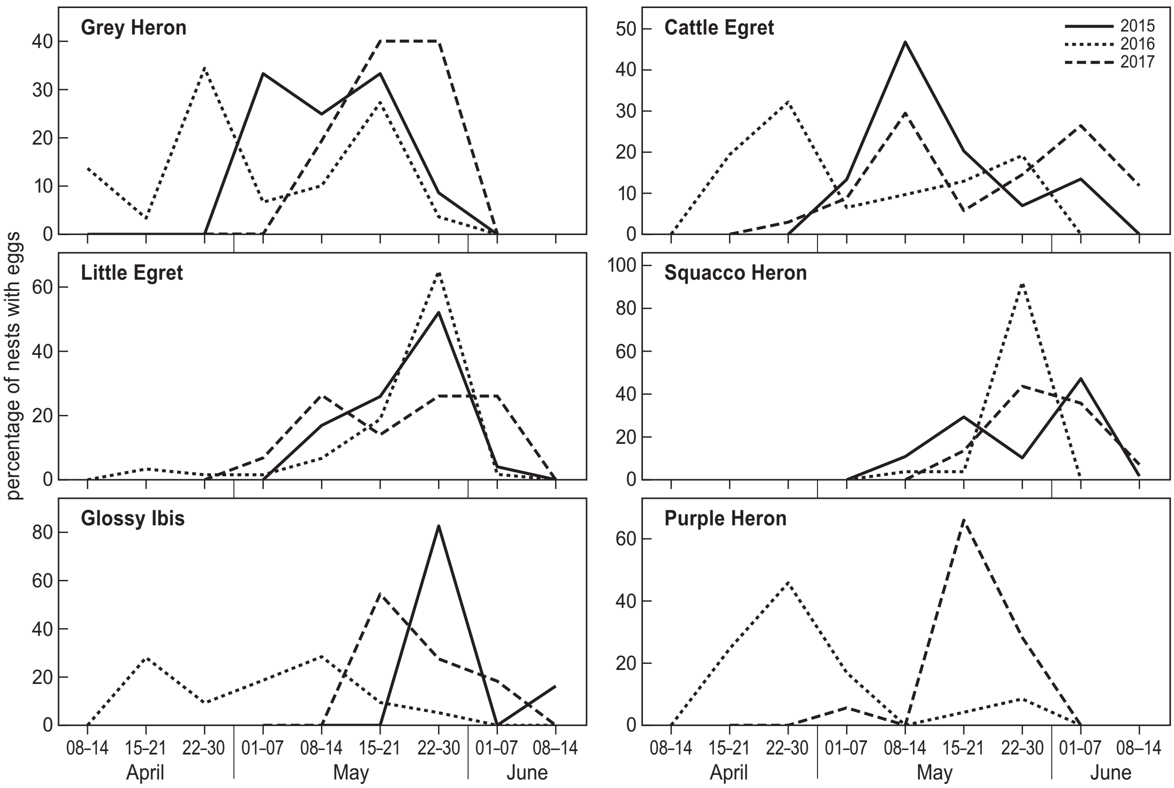

Figure 2. Phenology of egg laying of six species of herons and Glossy Ibis during three years of study (2015–2017), within L'Albufera de València.

Table 2. Mean clutch size, number of hatchlings and brood size (successful nestlings) per nest for each species, in the 2015–2017 breeding period, within L'Albufera de València and results of the Kruskal-Wallis test. *significant differences.

	Grey Heron	Purple Heron	Squacco Heron	Little Egret	Cattle Egret	Glossy Ibis
Clutch size						
2015	2.56 ± 0.73	–	4.21 ± 0.84	3.85 ± 0.66	3.44 ± 0.89	3.57 ± 1.27
2016	2.82 ± 0.77	2.89 ± 0.79	4.16 ± 0.67	3.64 ± 0.80	2.86 ± 0.68	3.00 ± 0.77
2017	3.00 ± 0.71	2.64 ± 0.92	4.12 ± 0.81	3.63 ± 0.80	2.83 ± 0.77	3.20 ± 0.77
Total	2.78 ± 0.76	2.76 ± 0.82	4.16 ± 0.80	3.67 ± 0.78	2.96 ± 0.79	3.13 ± 0.86
H (*P*)	1.99 (0.27)	0.64 (0.39)	0.59 (0.71)	1.85 (0.33)	5.46 (0.04)*	3.37 (0.14)
Number of hatchlings						
2015	2.00 ± 0.93	–	3.42 ± 0.83	2.85 ± 0.72	2.88 ± 0.50	2.57 ± 1.27
2016	1.31 ± 1.28	2.20 ± 1.21	3.28 ± 1.29	2.75 ± 1.19	2.64 ± 0.87	2.00 ± 1.37
2017	2.40 ± 0.55	2.45 ± 1.13	2.27 ± 1.15	2.96 ± 0.96	2.52 ± 0.80	1.94 ± 0.94
Total	1.50 ± 1.22	2.44 ± 1.10	3.10 ± 1.26	2.86 ± 1.00	2.61 ± 0.76	1.96 ± 1.28
H (*P*)	7.76 (0.02)*	0.03 (0.8)	15.55 (< 0.01)*	0.50 (0.76)	2.15 (0.28)	2.15 (0.32)
Brood size						
2015	1.47 ± 0.99	–	2.35 ± 1.23	2.04 ± 1.14	1.87 ± 0.83	2.17 ± 1.33
2016	0.41 ± 0.91	1.06 ± 1.16	2.64 ± 1.73	0.82 ± 1.31	0.38 ± 0.74	0.89 ± 0.93
2017	1.33 ± 0.58	1.80 ± 0.84	1.67 ± 1.11	4.71 ± 0.97	2.29 ± 1.11	2.10 ± 0.88
Total	0.72 ± 1.02	1.04 ± 1.12	2.33 ± 1.40	1.45 ± 1.38	1.32 ± 1.17	1.74 ± 1.20
H (*P*)	16.99 (< 0.01)*	1.90 (0.62)	3.84 (0.06)	17.58 (< 0.01)*	17.62 (< 0.01)*	7.57 (< 0.01)*

chicks per nest (2.33 chicks/nest), while the Grey Heron had the lowest number (0.72 chicks/nest). Only the Cattle Egret showed significant differences in clutch size between years, being larger in 2015. In terms of the mean number of eggs hatched, only two species showed significant differences between years: Squacco Heron had the lowest mean clutch size in 2017 and the Grey Heron in 2016 (Table 2). In relation to brood size, most species showed significant differences between years, with the smallest in 2016, with the exception of Purple Heron and Squacco Heron (Table 2).

Hatching, nesting and breeding success

During the study period, Grey Heron showed the lowest values for hatching, nesting and breeding success (Table 3). Cattle Egret showed the highest hatching success, but was one of the species with the lowest nesting and breeding success. In contrast, Squacco Heron and Glossy Ibis had the highest nesting and breeding success (Table 3).

In terms of hatching success, only Grey Heron and Squacco Heron showed significant differences between years, being lower in 2016 for Grey Heron, and in 2017 for Squacco Heron (Table 3). Both nesting and breeding success showed significant differences between years for most species. During 2016, the lowest values for these parameters were recorded in all cases. The exception was the Purple Heron, which did not show significant differences in any case. In the case of Squacco Heron, the lowest value for breeding success was recorded in 2017, while the lowest value for nesting success was recorded in 2015, but was not statistically significant (Table 3).

Rice fields status

In February and March 2016 (before the start of the breeding period) the proportion of dry fields was higher than in 2017 (Figure 3). In March there were no longer any totally flooded fields, only some with mud or small puddles, representing 18% of the rice fields surveyed in 2017 and 4% in 2016. During April (when egg laying started in 2016), all rice fields (100%) were dry in both 2016 and 2017. In these two years, the fields were flooded again in May and by June most of them were already sown. Flooding started from the second week of May in both years (Figure 3). However, in 2016 the proportion of flooded fields by that date was higher than in 2017 (51% versus 31% respectively). On the other hand, fields that started to be flooded (muddy or semi-flooded) were also found in a higher proportion in 2016 (36%) than in 2017 (14%). Sowing of the fields started in the last week of May and, in 2016, 27% of the fields were sown (Figure 3). There is no data on the start of sowing for 2017, as for

Table 3. Mean hatching, nesting and breeding success per nest for each species, in the 2015–2017 breeding period, within L'Albufera de València and the results of the Kruskal-Wallis test. *significant differences.

	Grey Heron	Purple Heron	Squacco Heron	Little Egret	Cattle Egret	Glossy Ibis
Hatching success						
2015	0.81 ± 0.32	–	0.82 ± 0.16	0.75 ± 0.18	0.87 ± 0.18	0.65 ± 0.32
2016	0.46 ± 0.43	0.76 ± 0.38	0.73 ± 0.34	0.76 ± 0.29	0.91 ± 0.17	0.65 ± 0.40
2017	0.82 ± 0.17	0.91 ± 0.20	0.54 ± 0.25	0.82 ± 0.21	0.83 ± 0.32	0.77 ± 0.31
Total	0.58 ± 0.43	0.81 ± 0.35	0.75 ± 0.31	0.78 ± 0.25	0.87 ± 0.24	0.64 ± 0.35
H (*P*)	8.78 (< 0.01)*	0.51 (0.36)	10.82 (< 0.01)*	2.92 (0.2)	0.23 (0.84)	1.75 (0.38)
Nesting success						
2015	0.66 ± 0.42	–	0.67 ± 0.32	0.69 ± 0.35	0.67 ± 0.31	0.75 ± 0.42
2016	0.19 ± 0.38	0.39 ± 0.42	0.71 ± 0.44	0.30 ± 0.44	0.18 ± 0.35	0.50 ± 0.49
2017	0.50 ± 0.17	0.38 ± 0.39	0.79 ± 0.37	0.73 ± 0.67	0.38 ± 0.46	0.95 ± 0.12
Total	0.32 ± 0.43	0.39 ± 040	0.71 ± 0.37	0.52 ± 0.52	0.40 ± 0.41	0.67 ± 0.45
H (*P*)	13.67 (< 0.01)*	0.02 (0.89)	2.93 (0.18)	10.44 (< 0.01)*	11.93 (< 0.01)*	4.96 (0.04)*
Breeding success						
2015	0.63 ± 0.41	–	0.56 ± 0.24	0.53 ± 0.31	0,57 ± 0.28	0.58 ± 0.38
2016	0.14 ± 0.45	0.35 ± 0.37	0.63 ± 0.41	0.20 ± 0.35	0,15 ± 0.30	0.34 ± 0.35
2017	0.39 ± 0.10	0.38 ± 0.39	0.39 ± 0.24	0.47 ± 0.35	0,35 ± 0.43	0.92 ± 0.14
Total	0.28 ± 0.39	0.36 ± 0.37	0.55 ± 0.34	0.36 ± 0.37	0,34 ± 0.36	0.56 ± 0.40
H (*P*)	16.08 (< 0.01)*	0.02 (0.87)	5.93 (0.048)*	12.3 (< 0.01)*	11.3 (< 0.01)*	20.11 (< 0.01)*

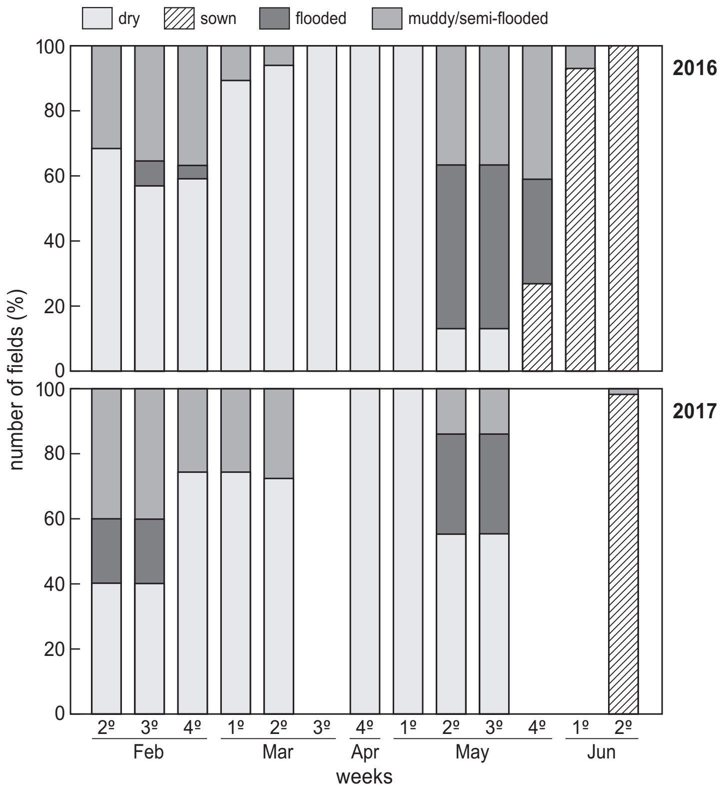

Figure 3. Changes in the state of the monitored rice fields over the breeding period of the studied heron species and the Glossy Ibis (2016–2017) in L'Albufera de València.

Table 4. Mean clutch size before and after the flooding of the fields (April and May), mean brood size (successful nestlings) and breeding success before and after sowing (May and June), for each species in the 2016–2017 breeding period, within L'Albufera de València and the results of the Kruskal-Wallis test. *significant differences.

	Grey Heron	Purple Heron	Little Egret	Cattle Egret	Glossy Ibis
Clutch size					
April 2016	2.50 ± 1.00	2.50 ± 1.00	3.33 ± 0.58	2.80 ± 0.42	2.80 ± 0.42
May 2016	2.84 ± 0.76	2.75 ± 0.74	3.66 ± 0.81	2.88 ± 0.77	3.12 ± 0.67
H (*P*)	0.32 (0.5)	1.22 (0.22)	0.58 (0.41)	0.12 (0.68)	2.03 (0.1)
April 2017	–	2.80 ± 1.10	2.89 ± 0.78	3.13 ± 1.13	–
May 2017	–	2.50 ± 0.84	2.75 ± 0.65	3.73 ± 0.76	–
H (*P*)	–	0.13 (0.67)	6.68 (< 0.01)*	0.52 (0.43)	–
Brood size					
May 2016	1.50 ± 1.29	0.95 ± 1.13	0.17 ± 0.41	0.16 ± 0.5	0.84 ± 0.90
June 2016	0.27 ± 0.67	0.80 ± 1.01	0.48 ± 1.04	0.38 ± 0.89	1.10 ± 1.12
H (*P*)	0.61 (0.27)	0.06 (0.79)	0.06 (0.72)	0.20 (0.46)	0.40 (0.50)
May 2017	–	0.80 ± 1.30	0	3.33 ± 0.58	–
June 2017	–	1.25 ± 0.96	2.5 ± 0.97	2.5 ± 0.97	–
H (*P*)	–	0.18 (0.65)	16.62 (< 0.001)*	3.86 (0.04)	–
Breeding success					
May 2016	0.50 ± 0.43	0.44 ± 0.39	0.06 ± 0.14	0.08 ± 0.20	0.29 ± 0.29
June 2016	0.09 ± 0.23	0.39 ± 0.42	0.15 ± 0.31	0.15 ± 0.32	0.32 ± 0.32
H (*P*)	0.83 (0.19)	0.58 (0.43)	0.13 (0.62)	0.13 (0.6)	0.04 (0.83)
May 2017	–	0.63 ± 0.18	0	0.78 ± 0.20	–
June 2017	–	0.72 ± 0.25	0.62 ± 0.26	0.62 ± 0.26	–
H (*P*)	–	0.08 (0.76)	16.62 (< 0.01)*	3.86 (0.05)	–

logistical reasons observations could not be made during this period. By the first week of June, 93% of the fields were already sown in 2016 and 98% by the second week of June in 2017. Although in 2017 the sampling ended in June, based on the results of 2016 and the already known dynamics and management of the rice fields, it can be stated that during July and August (last months of the reproductive period), 100% of the fields were sown.

The number of individuals of the monitored heron species present in the rice fields was highest in May and June, coinciding with the hatching and rearing of chicks.

Effect of rice field status on breeding parameters

In 2016, egg laying for four of the six species studied started at the end of April, when the rice fields were completely dry. In 2017, they started in May, when the fields started to flood (Figure 2 and 3). Hatching started from the second week of May in 2016 (except for Little Egret and Grey Heron), when there were still 13% dry fields. In 2017, hatching occurred in the last week of May, when fields were flooded or sown. Hatching peaks were entirely concentrated in the month of June during 2017, when all fields were already sown, whereas in 2016 there were hatching peaks in the last week of May (Figure 4). Nesting and breeding success was significantly lower in 2016 (Table 3), when the first hatchings occurred when fields were flooding or just starting to be sown. In 2017, when nesting and breeding success was higher, hatching occurred mostly when all fields were already sown.

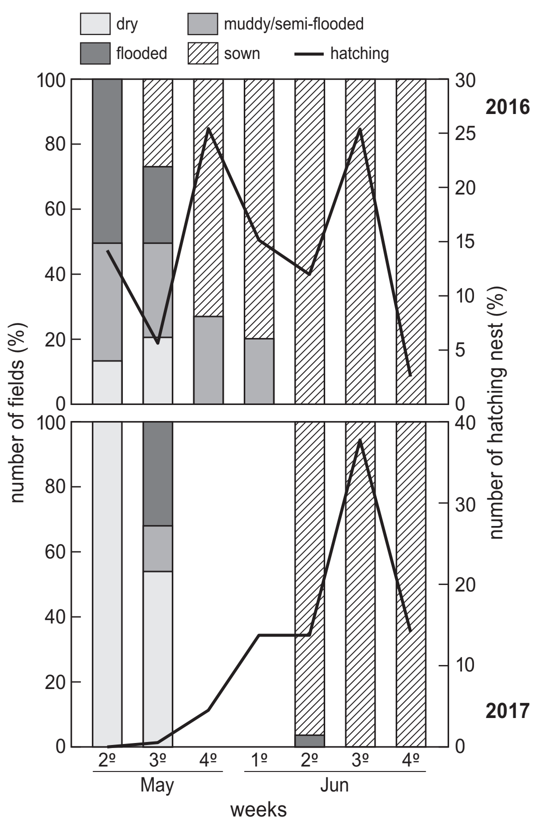

Figure 4. The mean hatching percentage of the studied species (dark solid lines) in relation to the state of the rice fields (bar graphs) in L'Albufera de València during the reproductive period of the years 2016 and 2017.

There were no significant differences in clutch size between nests established before and after the flooding of the fields (second week of May). In all cases, although some nests were established before the flooding of the fields, all eggs hatched after the flooding. There were also no significant differences in clutch size and breeding success between chicks hatched in May and June for any of the monitored species (Table 4). Only Little Egrets showed significant differences in all parameters, due to the zero survival (dead chicks) or loss (empty nest) of the few chicks hatched in May 2017 (Table 4).

We found a significant relationship between breeding success and the proportion of sown rice fields in all species except the Squacco Heron, and with the proportion of flooded rice fields only in the case of the Glossy Ibis (Table 5). Breeding success increased with an increasing area of sown fields, in the case of the Purple Heron, Cattle Egret, Little Egret and Glossy Ibis. The opposite was true for Grey Herons (Table 5). For the Glossy Ibis, reproductive success decreased with an increasing area of flooded fields (Table 5). The best explanatory model (Model 5) included the percentage of sown fields together with species and the interaction between both variables ($AlC_c = 623.6$; Table S2). Nevertheless, we also examined the model that considers the effect of the percentage of flooded fields and heron species and the interaction between both variables (Model 6), as this allowed us to show the effect of flooded fields on the breeding success of each heron species. This model was the second-best explanatory model ($AlC_c = 641.8$; Table S2). The two variables (percentages of sown fields and flooded fields) were not included in a single model as they turned out to be collinear ($r = 0.70$).

Considering the effect of timing of egg laying relative to the date of rice field flooding on breeding success, there was a negative effect on breeding success in all species, except Grey Heron (Table 6). The negative effect of timing (more days between egg laying and flooding) was significant for Cattle Egret, Little Egret

Table 5. Model estimates of two selected GLMM models in which the effect (β coefficients) of the percentage of sown rice fields (Model 5) and the percentage of flooded rice fields (Model 6) on the breeding success of the different heron species was tested. See Table S2 for all tested candidate models.

Species	Sown fields (Model 5) Random effect year (θ) = 0.641			Flooded fields (Model 6) Random effect year (θ) = 0.652		
	β	SE	95% Confidence Interval	β	SE	95% Confidence Interval
Grey Heron	–2.256	0.634	–3.657 – –1.122*	0.490	0.668	–1.347 – 2.411
Purple Heron	1.585	0.739	0.215 – 3.153*	1.184	1.217	–1.235 – 3.567
Squacco Heron	0.616	1.330	–2.056 – 3.237	1.157	1.5039	–1.794 – 4.163
Cattle Egret	1.981	0.763	0.563 – 3.595*	–0.777	1.308	–3.407 – 1.756
Little Egret	3.198	0.982	1.461 – 5.378*	–1.349	1.310	–4.053 – 1.134
Glossy Ibis	3.911	0.851	2.352 – 5.722*	–3.370	1.386	–6.204 – –0.728*

*significant effect: confidence interval does not include 0

Table 6. GLMM model estimates of the effect (β coefficients) of the number of days between first egg laying and flooding of the rice field on breeding success of the different heron species. See Table S3 for all tested candidate models.

Species	Days to flooding (Model 5) Random effect year (θ) = 0.961		
	β	SE	95% Confidence Interval
Grey Heron	0.117	0.027	–4.490 – 0.384
Purple Heron	–0.060	0.036	–0.133 – 0.009*
Cattle Egret	–0.068	0.039	0.147 – 0.006*
Little Egret	–0.420	0.129	–0.821 – –0.235*
Glossy Ibis	–0.179	0.038	–0.258 – –0.107*

*significant effect: confidence interval does not include 0

and Glossy Ibis. In the case of the Purple Heron, the effect was not significant (95% confidence interval include 0), although the upper limit of the interval exceeds 0 only by 0.009 (Table 6). The selected explanatory model included the predictor variables 'days to flooding', species and the interaction between both variables (AIC_c = 520.5; Table S3).

DISCUSSION

Changes in breeding pairs and colony numbers

In L'Albufera de València, we found that the heron species we studied have, in line with earlier work, continued to nest in mixed colonies with the nests very close together (Pechuán 1971, Prósper & Hafner 1996). The only exception was the Purple Heron which establishes its own colonies with spatially more dispersed nests (Giménez & Aguirre 2003, Nedja *et al.* 2010). The Fang area (MEF) remains an important nesting site and since at least 1963 has maintained breeding populations every year (Prósper 2000). On the other hand, the Sacarés area (RS) began to be used annually as a breeding site in 1991 (Prósper 2000) and currently hosts a considerable number of breeding pairs, including a Purple Heron colony. Previously, colonies had been recorded in other reedbeds in the lagoon, some of which were important in terms of the number of colonies during the 1990s (Prósper 2000). However, these colonies were not established during the years of our study.

Changes in reproductive timing of herons in relation to rice field management

In recent years, the start of the flooding of the rice fields has been delayed, starting up to three weeks later compared with when they were flooded in the 1990s. This coincides with the delay also observed in the start of egg laying of the nesting herons in L'Albufera de València relative to previous periods (Prósper & Hafner 1996, Prósper 2000, Dies *et al.* 2001) and with what has been reported in other wetlands (Parejo *et al.* 2001, Belamendia *et al.* 2003, Galarza 2020). In L'Albufera, nest building and egg laying of the Cattle Egret, Little Egret, Squacco Heron and Purple Heron has been reported to start at the end of April (Prósper & Hafner 1996, Prósper 2000, Dies *et al.* 2001) as in other areas of Spain (Parejo *et al.* 2001, Belamendia *et al.* 2003, Galarza 2020). In our study, the onset of egg laying coincides with the third week of April in 2016, although in 2015 and 2017 all species started nesting from the first week of May. These results are different from those reported for the period 1988–1990, in the case of the Squacco Heron and Cattle Egret. In those years they had two egg laying peaks, one in April–May and one in June–July (Prósper & Hafner 1996). During our study period (2015–2017), the peak egg-laying period for the Cattle Egret was in the second week of May and the first week of June, while the Squacco Heron only had a peak in the last week of May, as did the Little Egret. This difference may be related to changes in the onset of flooding, as flooding currently occurs later. Prósper (2000) mentions that the fields were flooded between April and May and the start of sowing took place at the beginning of May, coinciding with the first peak of egg laying in the period 1988–1990. On the other hand, Oltra *et al.* (2001) mention that in the 1970s and 1990s the flooding of the rice fields to start cultivation began in mid-April and that the fields were completely flooded at the beginning of May. Currently, the fields begin to flood in early May and sowing starts at the end of the month, two to three weeks later than in the 1990s. It was observed in both studies that the flooding of the fields coincides with the egg laying peaks of most species, especially the Cattle Egret and Little Egret (Prósper 2000).

The Squacco Heron always started egg laying in May, while there was greater variability in start date in the period 1988–1990, probably attributed to high variation in temperature and rainfall in the autumns preceding the breeding season (Prósper 2000). The Squacco Heron was the last to initiate breeding in the colony in our study, starting egg-laying about a week later than the other species, as has been described in other colonies (Pechuán 1971, Hafner 1980, Prósper 2000, Delord *et al.* 2003). This species possibly requires prior settlement of the other species that establish the core and create the right conditions in the colony (Pechuán 1971, Prósper 2000). The first species to establish modify the vegetation in the core of the colony, while the Squacco Heron establish on the periphery of the colonies where the vegetation is denser (Pechuán 1971, Hafner 1980). Moreover, although the core may offer better conditions, competition is likely to be greater here than on the periphery, where the Squacco Heron nests are located (Hafner 1980).

On the other hand, the Grey Herons started nesting in January and carried out staggered egg laying until May (Prósper & Hafner, 1996, Belamendia *et al.* 2003). In our study we only considered breeding in the spring-summer period (May–July), so the Grey Heron clutches observed in our study correspond to the last sporadic clutches of the breeding period (Prósper & Hafner 1996). In 2017, breeding must have ended earlier as by June almost no Grey Heron nests were found; whereas in previous years nests with newly hatched chicks could still be found in June.

There is no information on the breeding phenology of Glossy Ibises in Spain, but studies carried out in North Africa mention that laying would start from mid-April or early May (Boucheker *et al.* 2009, Nefla *et al.* 2012), which approximately coincides with what was observed during our study.

Changes in reproductive parameters and possible explanations

Regarding reproductive parameters, the number of successful chicks per nest recorded in our current study was lower than that reported by several other authors. For L'Albufera, for example, clutch size values reported for the period 1988–1990 were, on average, higher for the Cattle Egret (2.83 chicks/nest), Little Egret (3.46) and Grey Heron (3.48; Prósper & Hafner 1996). In other colonies, both in Spain and elsewhere in Europe, values higher than 2 chicks/nest and in some cases higher than 3 chicks/nest are recorded for Cattle Egret (Hafner 1980, Bartolomé *et al.* 1997, Parejo *et al.* 2001, Si Bachir *et al.* 2008, Dragonetti & Giovanchini 2009), Little Egret (Hafner 1980, Bartolomé *et al.* 1997), Grey Heron (Jakubas 2005, Ashoori *et al.* 2009), Purple Heron (Barbraud *et al.* 2001, Nedja *et al.* 2010) and Glossy Ibis (Boucheker 2009, Nefla *et al.* 2012), while in our study these values were between 0.7 and 1.7 chicks/nest. Only in the Squacco Heron were values higher than 2 chicks/nest, but other authors cite values higher than 3 chicks/nest (Hafner 1980, Nefla *et al.* 2014). This low breeding success, seen mainly in those species most dependent on rice fields, such as Grey Herons, Cattle Egret and Little Egret, has been related to the decline of food resources in rice fields, such as the Red Swamp Crayfish *Procambarus clarkii*, and the increase in the use of other resources to feed chicks, such as dragonfly (Anisoptera) larvae, that may not satisfy the energy requirements of breeding herons and their chicks (Antón-Tello *et al.* 2021).

The low values of breeding success for the whole period of 2015–2017 were mainly determined by the low values obtained during 2016. Low brood sizes translate into low values for nesting and breeding success in general, in all cases lower than those reported in the literature (Hafner 1980, Barbraud 2001, Delord *et al.* 2003, Si Bachir *et al.* 2008, Ashoori *et al.* 2009, Nefla *et al.* 2012, 2014). Values related to egg survival, such as the average number of hatched eggs or hatching success, did not show significant differences between the three years, except in the Grey

Heron and Squacco Heron. From these results it is clear that the critical phase in the breeding period was chick rearing. In the case of Grey Heron, it can be said that both egg viability and chick raising were affected in 2016. The same can be said for the Squacco Heron in 2017, when hatching peaked one to two weeks earlier than in the other two years (second week of June). In this year, in the Little Egret chicks which hatched in May, none reached the age to be considered successful. It is not certain whether this was due to high mortality in the nest or to the loss of chicks from nests (by jumping or falling out), as only empty nests were found. Predation in the colony is anecdotal and only on one occasion was a nest observed where the nestlings were covered with ants, which eventually led to their death (pers. obs.).

In 2016, although the fields were flooded from May onwards, as in 2015 and 2017, June and July were extremely dry (AEMET). Although flooding levels in rice fields could be considered stable during the year, the low and almost zero rainfall in 2016 may have influenced flooding conditions in surrounding areas and irrigation systems, which contribute to macroinvertebrate diversity in rice fields (Lupi *et al.* 2013, Marques Pires *et al.* 2015). Such decreases in food availability can directly affect reproductive performance (Owen 1960, Hafner *et al.* 1987, 1994). In contrast, in 2015, rainfall in the breeding months (May–July) was the highest of the three years (AEMET). It was also the year with the highest breeding success for all species except Glossy Ibis and Squacco Heron. In 2017, rainfall was not abundant but not as low as in 2016, with July being the driest month with very low values. Other studies have found that reproductive success is positively related to rainfall (Hafner *et al.* 1994, Si Bachir *et al.* 2008, Nefla *et al.* 2012).

According to the GLMM analyses, the area of flooded fields had no effect on the breeding success of most of the species studied, except in the Glossy Ibis where the area of sown fields had an effect. In areas with emergent vegetation cover or mature rice fields there is a greater abundance of aquatic insects, such as Odonata and Diptera larvae, which constitute an important part of the diet of these heron species and their chicks (Marques & Vicente 1999, De Szalay & Resh 2000, Mugica *et al.* 2006, Antón-Tello *et al.* 2021).

Breeding success for most species did seem to be associated with the time elapsed between egg laying and the onset of flooding. According to our GLMM results, the number of days between egg laying and the onset of flooding negatively affected the breeding success of all species, with the exception of the Grey Heron, which starts its reproductive period in January. A significantly lower breeding success was obtained in 2016, when egg laying started before flooding, in the last two weeks of April, and hatching started in the second week of May, when fields begin to flood. In general, the peak of egg laying was between the second and third week of May, when the rice fields were already flooded, and the hatching peaks occurred mainly when they were already sown, from the second week of June. The fact that colony settlement and the onset of egg-laying occurred earlier in 2016, despite the fact that rice fields conditions were the same, may suggest that the start of egg laying is more related to weather conditions than to the flooding regime of the paddy fields (Hafner *et al.* 1994, Caballero, 1996, Prósper 2000, Parejo *et al.* 2001).

The rice fields are progressively flooded throughout the wetland, resulting in a time lag between the different fields, which produces a contagious distribution, in groups, of herons feeding on the rice fields (Martínez-Abraín 1998). The number of individuals in the rice fields is highest in May and June, coinciding with the hatching and rearing of chicks. Several authors have already reported the importance of this type of habitat as a source of food in the breeding stage of herons (Hafner *et al.* 1987, Fasola & Ruiz 1996, Fasola *et al.* 1996, Longoni 2010, Pierluissi 2010, Fasola & Brangi 2010), especially in years of very low rainfall, when natural marshes dry up (Tourenq *et al.* 2001). According to Hafner *et al.* (1987), there is usually an invertebrate explosion one month after the flooding of rice fields and there would be an abundance of small prey for chicks. Also, prey biomass generally increases one month after flooding when the rice has already emerged (Marques & Vicente 1999). Likewise, small prey are more abundant and increase their biomass from the early stages of flooding until they reach their maximum in fields with mature rice (Mugica *et al.* 2006). Similarly, the highest fish biomass values were recorded in these fields, while crustacean biomass was found to be highest in muddy/wet fields (Mugica *et al.* 2006). On the other hand, macroinvertebrate diversity has been positively related to the time of flooding of rice fields and to the emergent vegetation cover in seasonal wetlands (De Szalay & Resh 2000, Lupi *et al.* 2013). Thus, the highest prey availability in L'Albufera would have been in June in both study years, as the flooding of the fields started in May and rice plants emerge and grow during this month. However, in 2016, most of the chicks hatched during the flooding of the fields, so the rearing of these chicks could have been affected by the lack of available food in the rice fields, which may explain the lower nesting and breeding success that year.

Conclusion

Our results show that L' Albufera de València is still a very important breeding site for herons, due to the large number of breeding pairs nesting in the wetland. However, the breeding success of some of the species recorded in this study was low, especially in 2016 and 2017. Squacco Heron and Glossy Ibis are the species that seem to be doing best in this respect. A decline in the Cattle Egret population had already been reported for L' Albufera (Generalitat Valenciana 2016). Its population decline in the area may be due to the dispersal of a fraction of the breeding population to other colonies due to their experienced low breeding success (Serrano *et al.* 2001, Santoro *et al.* 2013).

Herons depend on the presence and condition of rice fields to feed their chicks, as well as other freshwater bodies (Hafner *et al.* 1987, Delord *et al.* 2003). The way rice cultivation is managed and the flooding regime, as well as extreme weather conditions such as droughts, could affect the breeding populations and reproductive success of heron species nesting in L' Albufera (Prósper & Hafner 1996, Lekuona 2002, Generalitat Valenciana 2002, Garrido *et al.* 2012, Cardarelli *et al.* 2017). Rice cultivation in L' Albufera has had to adapt to competition from international markets, which has affected its profitability (Girona 1998, Picazo-Tadeo *et al.* 2009, Martínez 2018), leading to increasing pressure on the distribution of water resources (Picazo-Tadeo *et al.* 2009). The demand on the irrigation system is growing, due to the reduction of available resources in the basin and the changes in use in recent decades (Palop 2015). At times when the profitability of rice cultivation is sought, competition for the resources among irrigators (other crops, housing developments, industry, the lagoon itself), together with the cost of pumping the fields empty in the lower areas and flooding in the upper areas, will determine when and how the rice fields will be flooded. Therefore, the reproductive success of the colonies will be affected in one way or another, depending on the decisions that are made in the timing, amount and duration of flooding.

The biological needs of species of conservation concern, such as those in our study, must be taken into account when drawing up management plans and agri-environmental plans for this type of artificial wetlands (rice paddies). Based on our results, such as those obtained on the effect of the time between egg laying and the start of flooding on breeding success, we conclude that water management, flooding schedules and maintenance of flooded areas must be synchronized with the needs of the colonies to ensure the conservation and success of these breeding populations.

To this end, it is also necessary to keep information on the reproduction of these species up to date, as changes in cultivation techniques and in the flooding regime, as well as changes in the rainfall regime caused by climate change, could affect the reproductive performance of the colonies studied.

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SAMENVATTING

Van oudsher worden rijstvelden als belangrijke voedselgronden voor reigers en andere watervogels aangemerkt. De wijze waarop de rijstvelden worden bewerkt en de timing van het onder water zetten van de velden zijn van grote invloed op het voortplantingssucces van deze vogels. In het aan de Spaanse oostkust gelegen L'Albufera de València liggen grote gebieden met rijstvelden. In het gebied ligt de op twee na grootste reigerkolonie van Spanje. De broedbiologie van de reigers in deze kolonie is voor het laatst in 1990 onderzocht. Sindsdien is het beheer van de rijstvelden veranderd. In 2015–17 is onderzocht of deze veranderingen van invloed zijn geweest op broedbiologische parameters als legselgrootte, broedselgrootte, uitkomstsucces, nestsucces en het uiteindelijke broedsucces bij Blauwe Reiger *Ardea cinerea*, Purperreiger *Ardea purpurea*, Koereiger *Bubulcus ibis*, Kleine Zilverreiger *Egretta garzetta*, Ralreiger *Ardeola ralloides* en Zwarte Ibis *Plegadis falcinellus*. Van februari 2016 tot juni 2017 is het waterniveau op de rijstvelden gemeten en de correlatie met de reproductieparameters van de reigers en ibissen bepaald. De waarden van alle reproductieparameters lagen lager dan bekend is uit de literatuur. In 2016 begon het broedseizoen eind april toen de rijstvelden nog droog waren. De eieren kwamen vanaf mei uit (nadat de velden onder water waren gezet). In 2017 viel de uitkomstpiek van de eieren in juni, toen de velden werden ingezaaid. Alleen bij de Blauwe Reiger en de Zwarte Ibis werd een correlatie gevonden tussen het broedsucces en het areaal ondergelopen of ingezaaide velden. Bij Kleine Zilverreiger, Zwarte Ibis, Koereiger en Purperreiger werd een negatief verband gevonden tussen zowel de legdatum als het moment waarop de velden onder water waren gezet en het broedsucces. Uit ons onderzoek blijkt dat in kunstmatige wetlands als rijstvelden bij het waterbeheer rekening moet worden gehouden met de biologische behoeften van de watervogels die gebruikmaken van deze wetlands.

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SUPPLEMENTARY MATERIAL

Table S1. Average of hatching per nests in May and June 2016 and 2017 and results of the Kruskal-Wallis test.

	Grey Heron	Purple Heron	Squacco Heron	Little Egret	Cattle Egret	Glossy Ibis
May 2016	1.55 ± 1.10	2.44 ± 1.04	–	3.00 ± 0.63	2.48 ± 0.68	2.32 ± 1.25
May 2017	–	–	–	2.56 ± 0.73	2.67 ± 0.71	2.00
H (*P*)	–	–	–	1.39 (0.20)	0.15 (0.67)	0.12 (0.72)
June 2016	1.78 ± 1.17	2.07 ± 1.27	3.25 ± 1.40	2.74 ± 1.18	2.68 ± 0.89	1.75 ± 1.48
June 2017	2.40 ± 0.55	2.45 ± 1.13	2.27 ± 1.15	3.05 ± 0.96	2.45 ± 0.86	1.94 ± 0.97
H (*P*)	1.25 (0.24)	2.23 (0.12)	11.56 (0.0004)*	1.33 (0.23)	0.44 (0.48)	0.13 (0.71)

*significant differences

Table S2. Multi-model selection based on the Akaike Information Criterion of Maximum Likelihood. The response variable was breeding success, the predictors were the percentage of sown fields, percentage of flooded fields and the species of heron. All models include the Year as random effect. –LogLik = log Likelihood function, AIC_c = Akaike Information Criterion with correction for large models, ΔAIC_c = AIC_c of each model – AIC_c of the best model.

Model	Predictors	–LogLik	AIC_c	*df*	ΔAIC_c
Model 5	Percentage sown fields + Species (with interactions)	–298.0	623.6	13	0
Model 6	Percentage flooded fields + Species (with interactions)	–307.1	641.8	13	18.2
Model 3	Percentage sown fields + Species (without interactions)	–315.7	648.0	8	24.4
Model 4	Percentage flooded fields + Species (without interactions)	–316.4	649.5	8	25.9
Model 7	Null effect	–342.3	688.7	2	65.1
Model 1	Percentage sown fields	–341.8	689.6	3	66.0
Model 2	Percentage flooded fields	–342.3	690.7	3	67.1

Table S3. Multi-model selection based on the Akaike Information Criterion of Maximum Likelihood. The response variable was breeding success, the predictors were 'days to flooding' and 'days to sowing' and heron species. All models include the Year as random effect. –LogLik = log Likelihood function, AIC_c = Akaike Information Criterion with correction for large models, ΔAIC_c = AIC_c of each model – AIC_c of the best model.

Model	Predictors	–LogLik	AIC_c	*df*	ΔAIC_c
Model 5	Days to flooding + Species (with interactions)	–248.6	520.5	11	0
Model 6	Days to sowing + Species (with interactions)	–250.4	523.9	11	3.5
Model 4	Days to sowing + Species (without interactions)	–274.7	564.0	7	43.5
Model 3	Days to flooding + Species (without interactions)	–275.6	565.8	7	45.3
Model 2	Days to sowing	–295.3	596.7	3	76.2
Model 1	Days to flooding	–296.2	598.5	3	78.0
Model 0	Null effect	–298.6	601.2	2	80.7

Effects of Rice Field Water Cycles on the Breeding Biology of Grey Heron (*Ardea cinerea*) and Conservation Implications

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Abstract.—Wetlands are among the most threatened ecosystems on the planet, largely due to their conversion to agricultural or dry land. L'Albufera de Vàlencia is characterized by a large expanse of rice fields (c. 14,000 ha), which hosts the most important colony of Grey Heron *Ardea cinerea* on the Mediterranean coast of Spain. The colony was visited every 10 days during February-April of 2016 to 2018 and during May-July of 2015 to 2017. The reproductive parameters were estimated for each year and season. We also monitored the available habitat and habitat use of the species in the rice fields from February 2016 to June 2017. The condition of the rice field was related to reproductive parameters. The breeding period was divided into two stages per year. In 2016 all reproductive parameters were lower values, coinciding with a larger area of dry fields in winter and low rainfall in summer. Breeding success was found to be positively associated with the muddy/semi-flooded fields and negatively associated with the sown fields. Like Grey Heron, other waterbirds species nesting in L'Albufera de Valencia could depend on the condition of the rice fields for breeding success. Their reproductive requirements should be considered in rice cultivation management. *Received 22 Apr 2022, accepted 17 Jan 2023.*

Key words.—Ardeidae, breeding parameters, habitat use, Mediterranean wetlands, rice fields.

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Wetlands are among the most valuable ecosystems in the socio-economic, ecological and biodiversity sense, but they are also the most threatened ecosystems on the Meditarrean Region (The Millennium Ecosystem Assessment 2005; MedWet 2016). Globally, large areas of these environments have been converted to agricultural systems, mainly rice paddies (Czech and Parsons 2002). In 2018, approximately 167 million hectares of land worldwide were used for rice cultivation, of which 625,000 ha were in Europe (FAOSTAT 2020). This decline in natural wetlands results in a threat to the conservation of a wide diversity of species associated with this type of habitat, including waterbirds (MedWet 2016).

The development of rice fields, which could be considered artificial wetlands since they have replaced the natural ones, have benefitted some waterbird species, but others have been negatively affected (Fasola and Ruiz 1996, Elphick 2000, Czech and Parsons 2002, Elphick 2010, Giosa et al. 2018). Many of the species that have benefited, mainly waders, shorebirds and ducks, obtain a substantial fraction of their food in these types of agroecosystems, especially during the breeding season (Hafner et al. 1987, Fasola and Ruiz 1996, Fasola et al. 1996, Elphick el al. 2010). Similarly, the presence and extent of rice paddies has been related to population trends, colony size and reproductive success (Hafner et al. 1987, Tourenq et al. 2000, Fasola et al. 2010, Fasola and Brangi 2010, Fujioka et al. 2010, Ramo et al. 2013, Forti et al. 2021a, Fasola et al. 2022). However, these aspects of waterbird biology are associated with the rice cultivation practices and rice flooding regime (Ibañez et al. 2010, Cardarelli et al. 2017, Forti et al. 2021b). Substitution of rice fields by another crops or the change to practices where the months of flooding or the depth of the water sheet are reduced, may have negative effects on the populations of some species and their reproduction (Toral et al. 2012, Cardarelli et al. 2017, Fasola et al. 2022).

In the Mediterranean, the loss of natural wetlands has been estimated at 48% between

1970 and 2013 (Ramsar 2018), partly due to their conversion to rice paddies (Longoni 2010, MedWet 2016). Rice cultivation has increased its area by more than 30% globally since 1960 (Ramsar 2018). Rice fields in Doñana, L'Albufera de València and the Ebro Delta in Spain, La Camargue in France and the Po basin in Italy are important breeding and feeding areas for several waterbird species, as well as wintering and resting sites for migratory species (Fasola and Ruiz 1996, Hafner and Fasola 1997, Rendón et al. 2008, Ramo et al. 2013).The dynamics of rice cultivation throughout the area are basically the same, in most cases starting in April with the flooding of the land, followed immediately by sowing and ending in September-October with harvesting, after the fields have dried out (Longoni 2010). Water levels during cultivation can vary depending on specific agricultural management, i.e. administration of pesticides and fertilizers (Longoni 2010). Rice cultivation faces several challenges, such as changes in the mechanisms established in the Common Agricultural Policy (CAP), pressures on water distribution, dependence on international market prices and public support to the farmer, which could change cultivation practices or decrease rice production (Picazo-Tadeo et al. 2009, Martinez 2018).

L'Albufera de València is one of the main wetlands in the east of the Iberian Peninsula. Due to its vast extension (21,120 ha) and high biodiversity, it is considered one of the most important wetlands in the western Mediterranean. The large extension of the rice field in L'Albufera has favored the establishment of 20,000-30,000 breeding pairs of different species of waterbirds, among which herons can be highlighted. L'Albufera de València is the third most important heron breeding site in Spain (Garrido et al. 2012) and hosts 61% of the egrets and herons nesting in the whole Valencia Region, including the Grey Heron as the third most numerous species (Generalitat Valenciana 2018, Forti et al. 2021a). This Grey Heron breeding colony, established in 1984 (Gómez-Lopéz et al. 1985, Prósper 2000) has been the most important colony on the Spanish Mediterranean coast for the last 20 years (Campos et al. 2001, Prieta and Campos 2003, Garrido et al. 2012) and represents 48% of the nesting Grey herons in the Valencia Region (Generalitat Valenciana 2021) and 11% in Spain, according to the last published national census (Garrido et al. 2012).The breeding population of L'Albufera had been experiencing a significant increase until 2013, reaching 1095 breeding pairs in 2000 (GeneralitatValenciana 2013). However, in recent years its nesting numbers decreased, with only 215 pairs found in the last local census in 2021 (Generalitat Valenciana 2021).

The breeding population of L'Albufera was formerly studied from 1988 to 1990 (Prosper and Hafner 1996, Prosper 2000), where it was established that the species starts nesting in January, with peak clutches at the end of the month when the rice fields are still flooded. However, in recent decades, rice field management has varied in terms of the start and duration of flooding periods during the annual period and in agronomic practices during the growing season, with flooding starting later and for shorter periods, among others. These changes have affected negatively both the quality of the feeding habitat for herons and other birds, as well as the reproductive success of some species such as the Little Egret (*Egretta garzetta*) or Cattle Egret (*Bulbucus ibis*) (Antón-Tello et al. 2021, Forti et al. 2021b). According to these studies, it is to be expected that the reproductive biology of the Grey Heron in L'Abufera de Vàlencia could have been affected, both in phenology and reproductive success, due to the effect of new practices in rice cultivation, which could also be related to the population declines that have been reported for the area (Generalitat Valenciana 2021, Forti et al. 2021a). Over the last 30 years no further studies have been carried out on this breeding colony and how changes in the management of the rice field have influenced its breeding parameters, so a new assessment is needed. Therefore, the aim of this study is to analyze the effects of current rice field management practices and their inter-annual variations on the breeding parameters of the Grey Heron. Although the

Grey Heron does not present conservation problems, since it is a widely distributed and easily adapted species, there are other heron species that nest in the study area that are in some conservation category, such as the Purple Heron, the Squacco Heron and the Glossy Ibis (Real Decreto 139/2011, Decreto 32/2004, Madroño et al 2004). Probably, the condition of the rice fields is also related to the reproduction of these and other species of waterbirds nesting in L'Albufera. With this information, rice field management measures can be proposed to maintaining healthy breeding populations of waterbirds within this important nesting area.

METHODS

Study Area

L'Albufera de València is a Mediterranean coastal wetland, located between the mouths of the Júcar and Turia rivers, in the Gulf of València (39°17′ N, 0°20′ O; Fig. 1). Since 1989 l'Albufera has been included in the "Wetlands of International Importance" (RAMSAR site), and since 1992 it has formed part of the Natura 2000 Network, having been declared a "Special Area for the Protection of Birds" (SPA) and "Site of Community Importance" (SCI). L'Albufera de València covers an area of 21,120 ha, of which 2,800 ha correspond to a shallow lagoon and 290 ha of marshland vegetation, which is fed by crop returns and water from the fluvial systems of the Júcar and Turia rivers. The rice fields cover 14,000 ha and represent an important habitat for the waterfowl community, both resident and migratory, especially during the breeding season, as they are the main feeding area for the latter (Fasola and Ruiz 1996, Fasola et al. 1996, Dies and Dies 1998, Prosper 2000, Toral and Figuerola 2010, Antón-Tello et al. 2021, Forti et al. 2021b). The hydrological dynamics of the paddy fields depend on the amount of water that enters the system twice a year. At the beginning of May, the paddy fields are flooded for rice cultivation, which lasts until the end of September or early October. This is followed by a draining period for rice harvesting. In November, as an environmental measure and to create places for waterfowl hunting, the rice fields on the perimeter of

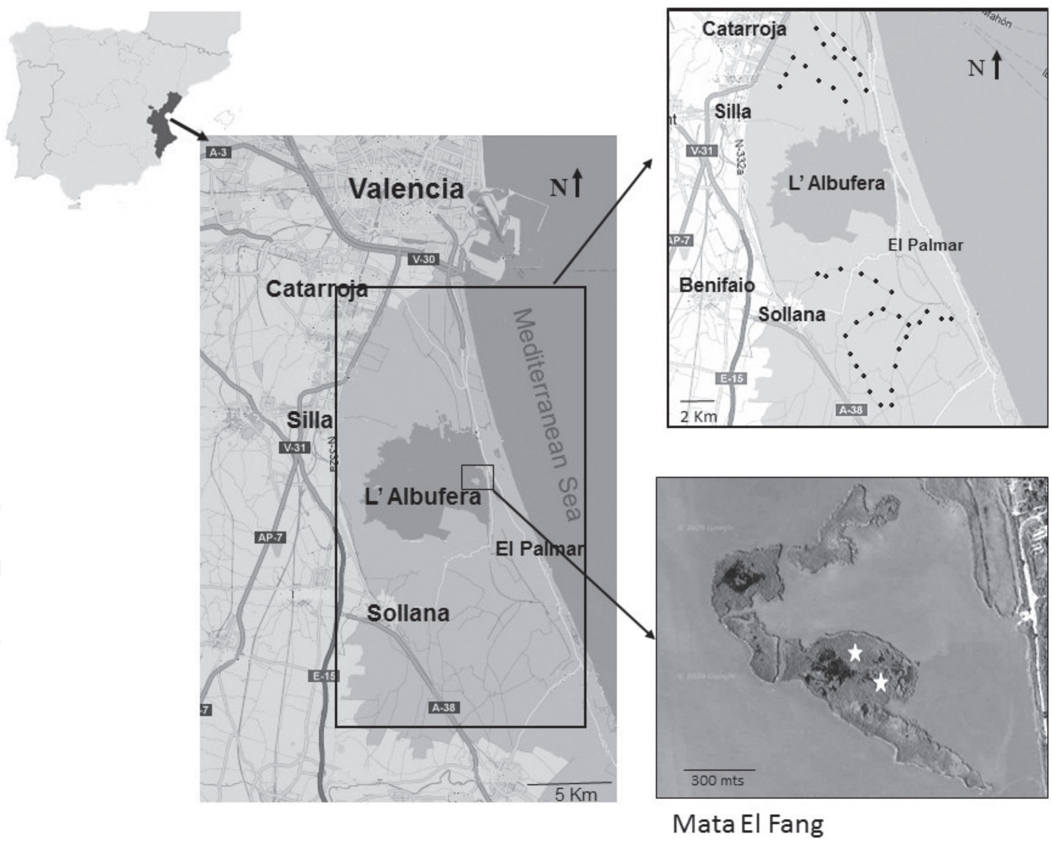

Figure 1. Location of Grey Heron breeding colony in the "mata" of El Fang and census points in the rice fields of L'Albufera de València.

the lagoon are flooded again, remaining with different levels of water until the end of the hunting period, at the end of January. From then on, the rice fields are progressively dried, in accordance with current agronomic practices, to prepare the land for sowing (Prosper 2000, Oltra et al. 2001).

The marsh vegetation consists mainly of Common Reed (*Phragmites australis*), Cat-tails (*Typha domingensis*), Swamp Sawgrass (*Cladium mariscus*), and Bulrush (*Scirpus lacustris*, S. *tabernamontani*, *S. holoschoenus*), which group together to form islands known locally as "matas" and which constitute refuges for birds and a nesting substrate for herons. Grey Heron colony are located in the Mata El Fang, located on the eastern shore of the lake (Fig. 1).

Breeding Parameters

Grey Heron colonial cores were visited every 10 days between February and April in the years 2016–2018 (hereafter referred to as early breeding season) and between May and July 2015–2017 (referred to as late breeding season). Sampling was conducted on these dates because these are the nesting periods reported for this species in the locality (Prosper and Hafner 1996, Prosper 2000). All nests found were marked with numbered tape and geo-referenced. On each visit, the number of eggs, number of hatched chicks and age of each chick in the nest were recorded. The clutch size was set as the maximum number of eggs observed, which did not vary on subsequent visits. Clutch size was assumed to be equal to the number of chicks when the nest contained newly hatched or 2–3 day-old chicks. Egg laying date was estimated by counting backwards 25 days of incubation from the hatching of the first chicks in the nest (Hankock and Kushlan 1984). Brood size was taken as the number of successful chicks per nest. Successful chicks were defined as those that survived until 20 days after hatching (Jakubas 2005, Ashoori et al. 2009). Nests that produced at least one successful chick were considered successful nests.

With the data obtained, hatching success (number of hatched eggs/total number of eggs), nesting success (number of successful chicks/number of hatched chicks) and breeding success (number of successful chicks/total number of eggs) were estimated per nest.

Habitat Availability and Use

The rice fields were visited fortnightly, making routes in both the northern and southern areas of the lagoon, between February 2016–June 2017. Sampling routes were established along the roads that run through the rice fields, where observation points were selected approximately 500 m apart, resulting in 26 sampling points in the southern zone and 15 points in the northern zone (Fig. 1). The field condition was established by categorizing each observed field according to its status, as dry (totally dry field, ploughed or not), muddy/wet (field with wet soil, mud, with small scattered puddles of water, worked with machines or not), semi-flooded (field with some areas covered with water, very shallow, but not covering the whole area), flooded (field with the whole area flooded, resembling a lagoon), sown (field with water cover but with rice plants, in all stages), and harvested (field with remnants of the crop, fallow, burned or not). For each month, the percentage of fields in each of the categories was calculated. In this case, the months of the reproductive period (January–June) were considered. July was not included as no data were available for this month in 2017.

The number of Grey Herons present at each observation point was also recorded during the same surveys. The total number of individuals observed on each date and for each field condition (dry, mud/wet, semi-flooded, flooded and sown) was quantified, as well as those observed in irrigation ditches and canals. Because the number of surveys was not equal in the two years, the data were standardized by dividing the number of individuals observed, in each field condition, by date, by the number of surveys conducted during the year, in order to make comparisons.

Data Analysis

To compare reproductive parameters between years and between seasons within years, generalized linear models of the Binomial family were used for breeding success, hatching and nesting success, and Poisson for egg numbers. As predictors we used the interaction between Year and Season (Buckley 2015). Because these are categorical predictors, we calculate the marginal means of the parameters from the regression coefficients to facilitate the interpretation of the interaction between predictors (Searle et al. 1980).

Reproductive parameters were estimated for each breeding period (early and late), and within each season, corresponding to egg laying peaks and hatching maxima. These parameters were estimated separately for broods hatched in February and March (winter) and in May and June (spring). Due to the small sample size for each grouping (Year:Season:Month) we used the non-parametric method of Bootstrapping simulation with 10,000 randomizations to calculate means and 95% confidence intervals for these parameters for comparisons within seasons.

To assess the association between field condition and distance to the colony with the number of individuals at observation points, as well as the relationship between field condition and breeding success, generalized linear mixed models (GLMM) of the Poisson family were used for the number of individuals, and Binomial for reproductive success (Bolker 2015). For the Poisson model, we used year and the location of the observation point with respect to the colony (north, south) as random effect variables, while for the Binomial model we used year and season. Due to the high collinearity between field-related variables (dry/sown, $r = -0.83$; flooded/semi-flooded, $r = 0.76$), a reduction of variables was performed through a Principal Component Analysis with orthogonal rotation, which maximizes the variance explained by the components (Vejmelka et al. 2015).

Variable and model selection was achieved through the maximum likelihood approach based on AICc (Burnham and Anderson 2004). This analysis was performed in the bbmle R-package (B. M. Bolker, bbmle: Tools for general maximum likelihood estimation, https://cran.r-project.org/web/packages/bbmle/index.html). The effect of each predictor was estimated from the standardized regression coefficients and the maximum likelihood confidence interval was calculated for each coefficient (Harrison et al. 2018). Coefficients whose confidence interval is different from zero are considered significant.

Statistical analyses were performed in GNU R 4.1.1. (R Core team 2021).

RESULTS

Breeding parameters

Laying and hatching phenology. In general, Grey Herons presented two differential egg laying periods, which are not necessarily the same individuals nesting in both periods (not a second clutch). The first period occurs in January–February and the second in April–May (Fig. 2a). In turn, in the early months of the year (early season), clutches were concentrated mainly in the third week of January and in the second and last week of February. In the late season, the highest proportion of clutches was found mainly in the third week of May (Fig. 2a).

Hatching occurred in greater proportion during the second week of February and the first and third weeks of March in the early season, while in the late season the dates with the highest percentage of hatchings were the last week of May and the second week of June (Fig. 2b).

Hatching, nesting and breeding success. Values for both clutch size and brood size were higher in 2017 than in 2016 (Table 1). Marginal means of GLMs showed significant differences in clutch size between late season 2016 and 2017, and for brood size between the 2016 and 2017 early season (Fig. 3a and b). Within each year there were only significant differences in clutch size between early and late season 2017 (Fig. 3a).

Concerning hatching success, the values within each season were higher in 2017 for both, early and late (Table 1). During the early season, significant differences were found between the 2017 and 2018 marginal means, but there were no differences in the late season (Fig. 3c).

Within the early season, 2018 had the highest nesting success, while for the late season the highest values were in 2015 (Table 1). Significant differences were found between the late season in 2015 and 2016, being lower in 2016, while in the early season there was no difference (Fig. 3d).

The highest values of breeding success for the early season were found in 2015, and in 2017 for the early season (Table 1). Between years, there were only significant differences in the late season between 2015 and 2016, with the lowest breeding success found in the latter (Fig. 3e). No significant differences in hatching, nesting and breeding success were found between seasons (early and late) within each year (Fig. 3c, 3d and 3e).

In the early season of 2016 and 2017, hatching, nesting and breeding successes were significantly higher in February than in March (Fig. 4). There were no significant differences between the late season months (May and June) (Fig. 4). In 2017 all chicks hatched in June. Hatchings were not analyzed separately before and after the flooding of the fields, as all hatchings occurred from May onwards (post-flooding).

Habitat Availability and Use of Rice Paddies

Overall, during the first breeding season of the year (February and March), the proportion of fields that were still waterlogged (muddy and semi-flooded) was higher in 2017 than in 2016 (Fig. 5a). In 2016, the proportion of these fields decreased from 43% in the third week of February to 6% in the second week of March, while in 2017, muddy and semi-flooded fields occupied 60% of the area by the same week of February and only dropped to 4% in the fourth week of March. In 2016 the fields were completely dry from the third week of March (Fig. 5a).

In the late season (May-June), there was a higher proportion of muddy and flooded fields in May 2016 (22% and 24% respectively) than in 2017 (6% and 13% respectively) (Fig. 5b). Specifically, in 2016 the flooding of fields started in the second week of May, while in 2017 it started in the third week (Fig. 5b). The sowing of fields also started

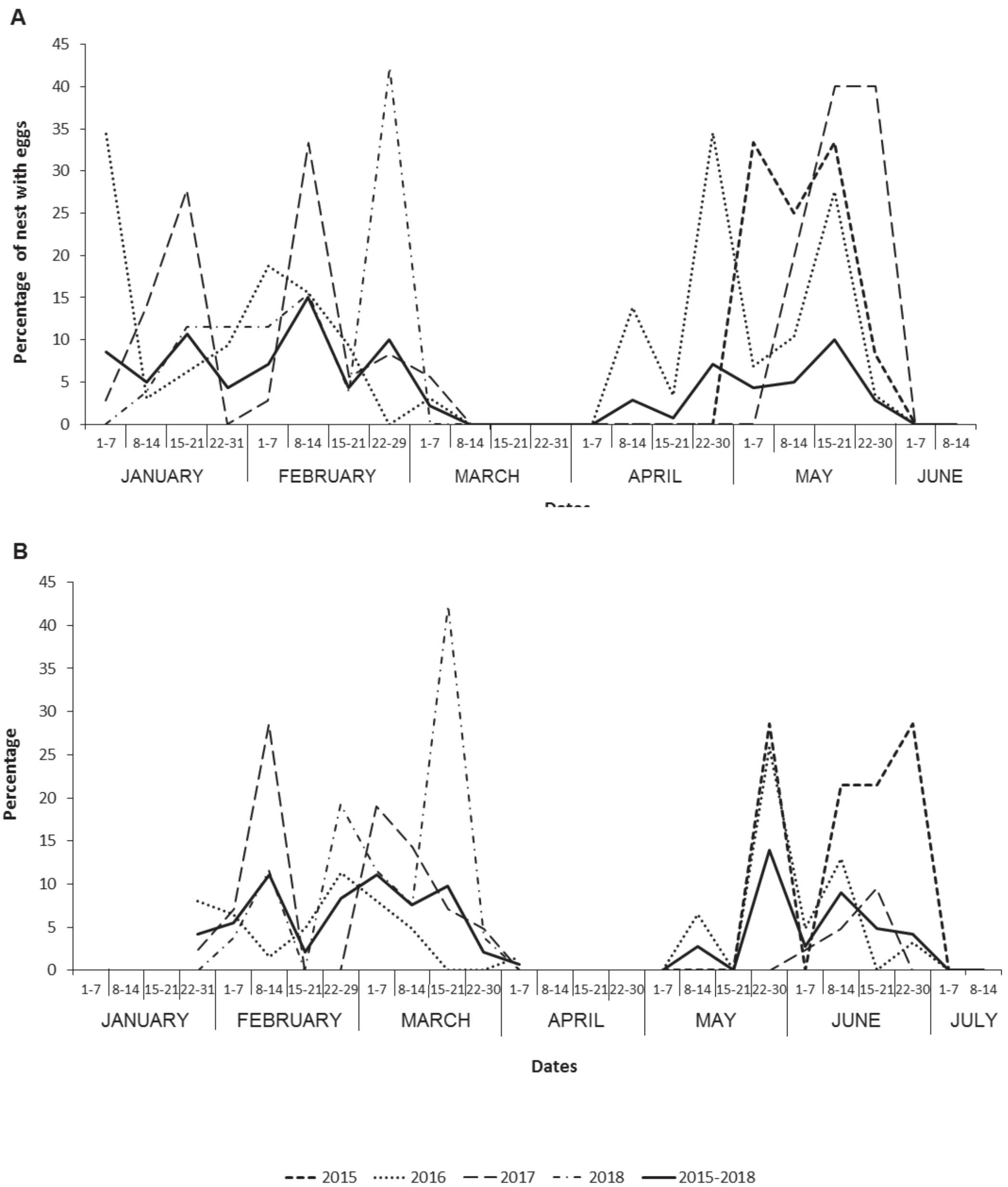

Figure 2. Grey Heron egg laying and hatching phenology during the period 2015–2018 in L'Albufera de València (A: egg laying phenology, B: hatching phenology).

later in 2017, as by the third week of May the proportion of fields sown in 2016 was 20% while in 2017 it is 0%. The 100% of fields sown is reached in the second week of June in 2016 and one week later in 2017 (Fig. 5b).

The highest number of individuals was recorded in February, coinciding with the highest percentage of muddy/semi-flooded fields, while the lowest number of herons was recorded in April, when 100% of the fields were dry. At this stage, the number of individuals using the irrigation ditches increased.

Statistical analyses support this observation. The best model explaining the abundance of individuals included the variables of muddy/semi-flooded, flooded and dry fields, and the interactions between them (model 4,

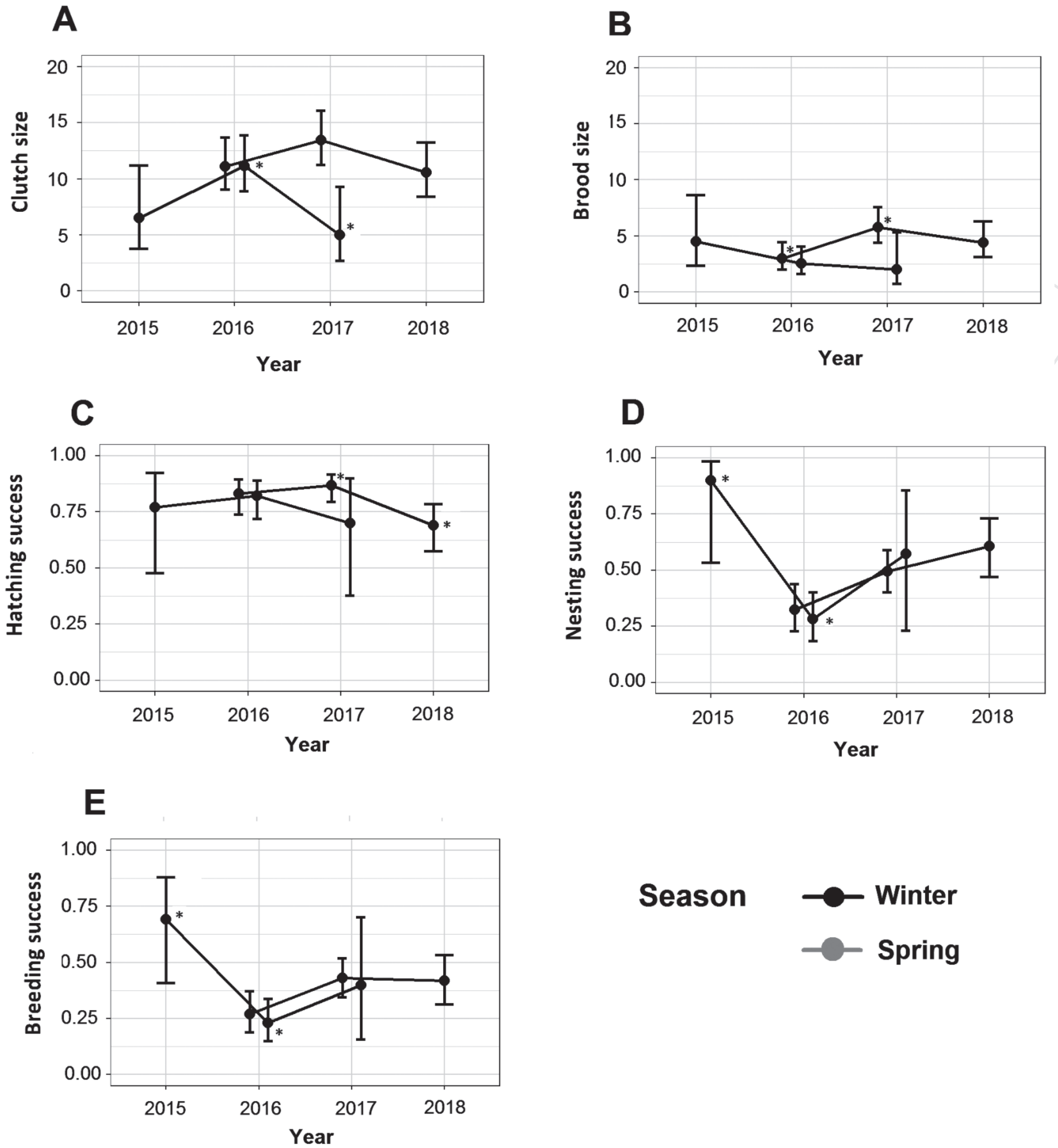

Figure 3. Marginal means of Grey Heron breeding parameters in the 2015–2018 breeding period in L'Albufera de València, obtained from the generalized linear models (* significant differences).

Table 2). In the GLMM coefficient analysis, muddy fields had a high positive effect (highest regression coefficient) on the presence of individuals, followed by flooded fields, while dry fields were shown to have a negative effect on heron abundance (Fig. 6a).

Distance to the colony was also a variable that is related to the number of individuals present (model 4, Table 2), having a strong negative effect (high negative regression coefficient) on the presence of individuals (Fig. 6a). The highest concentration of herons occurred in the fields closest to the colony, within a radius of 8.5 km from the colony, while in the fields furthest from the colony the presence of the birds was lower (Fig. 7). In late season, when all fields were equally flooded (May) or sown (June), herons extended their range to about 11 km from the colony, although the number of individuals using these fields remained low in relation to those using the fields closer to the colony (Fig. 7).

Table 1. Reproductive parameters for the Grey Heron in the period 2015–2018 within L'Albufera de València.

	nest n	n successful nests	Clutch size	n hatched eggs	Brood size	Hatching success	Nesting success	Breeding success
2016	97	26 (27%)	2.88 ± 0.78	1.55 ± 1.30	0.46 ± 0.84	0.55 ± 0.43	0.22 ± 0.36	0.16 ± 0.29
2017	51	31 (61%)	3.19 ± 0.61	2.21 ± 1.33	1.13 ± 1.19	0.70 ± 0.39	0.37 ± 0.36	0.34 ± 0.34
Winter								
2016	43	15 (34%)	2.95 ± 0.79	1.95 ± 1.28	0.59 ± 0.89	0.66 ± 0.40	0.23 ± 0.35	0.21 ± 0.32
2017	46	28 (60%)	3.19 ± 0.61	2.21 ± 1.33	1.15 ± 1.22	0.69 ± 0.40	0.38 ± 0.39	0.36 ± 0.37
2018	40	18 (45%)	3.00 ± 0.64	1.29 ± 1.20	0.82 ± 1.01	0.42 ± 0.38	0.55 ± 0.46	0.26 ± 0.35
Spring								
2015	16	13(81%)	2.56 ± 0.73	2.00 ± 0.93	1.47 ± 0.99	0.81 ± 0.32	0.66 ± 0.42	0.63 ± 0.41
2016	54	11 (20%)	2.82 ± 077	1.25 ± 1.25	0.41 ± 0.91	0.46 ± 0.43	0.19 ± 0.38	0.14 ± 0.45
2017	5	3 (60%)	3.00 ± 0.71	2.40 ± 0.55	1.33 ± 0.58	0.82 ± 0.17	0.5 ± 0.17	0.39 ± 0.10
total	204	88 (43%)	2.95 ± 0.73	1.72 ± 1.29	0.77 ± 1.01	0.59 ± 0.42	0.35 ± 0.40	0.26 ± 0.35

Rice Field Condition and Reproductive Parameters

The model that best explains the relationship of field condition with breeding success was the one that includes the variables of sown fields and muddy/semi-flooded fields and their interactions (model 9, Table 3). Although model 10 had the same explanatory weight, model 9 was selected, following the principle of parsimony, as it had fewer variables. According to the coefficient analysis of the GLMMs, muddy/semi-flooded fields had a positive effect on reproductive success (high positive regression coefficient), while sown fields had a negative effect (Fig. 6b). A higher number of hatchlings, of those born in February, in both 2016 and 2017, reached the age to fledge the nest (higher reproductive success, assigned to hatching date) coinciding with a higher percentage of muddy/semi-flooded fields (Fig. 8). For chicks hatched in March, reproductive success was lower compared to that of hatchlings born in February. However, between years, reproductive success for March 2017 was higher than in 2016, as was the proportion of muddy/semi-flooded field. In the first two weeks of March 2017, muddy/semi-flooded fields occupied 27% of the paddy area, while in 2016 such fields occupy only 9% (Fig. 8). Similarly, during the late season, chicks that hatched when there were still muddy/semi-flooded fields were more likely to fledge successfully. This was the case for hatchlings born in the second week of May in 2016 and in the second week of June in 2017 (Fig. 8). Likewise, breeding success decreased in those cases when chicks were hatched at the time when most of the fields were sown (Fig. 8). For these cases the reproductive success is assigned to the hatching date of each nest.

Discussion

Reproductive Phenology

Two laying seasons were observed during the study period, the first between January and February, and the second between April and May. The same pattern was observed in the 1988–1990 breeding season, although on that occasion there was a peak egg laying season in March, followed by sporadic clutches in April and May (Prosper and Hafner 1996). This pattern has also been observed in the Duero River Basin, though the onset of egg laying does not begin until early March (Campos and Fernández-Cruz 1991). These authors attribute the second peak of clutches, which occurs in this locality in late April and early May, to the late arrival of breeding pairs and the second (replacement) clutches of couples that failed to lay their first clutch. In other regions of northern Spain, although the breeding season begins in January with nest building, egg laying is staggered from February to May (Belamendia et al. 2003). In the case of L'Albufera, the earliest onset has been attributed to the availability of food during the winter

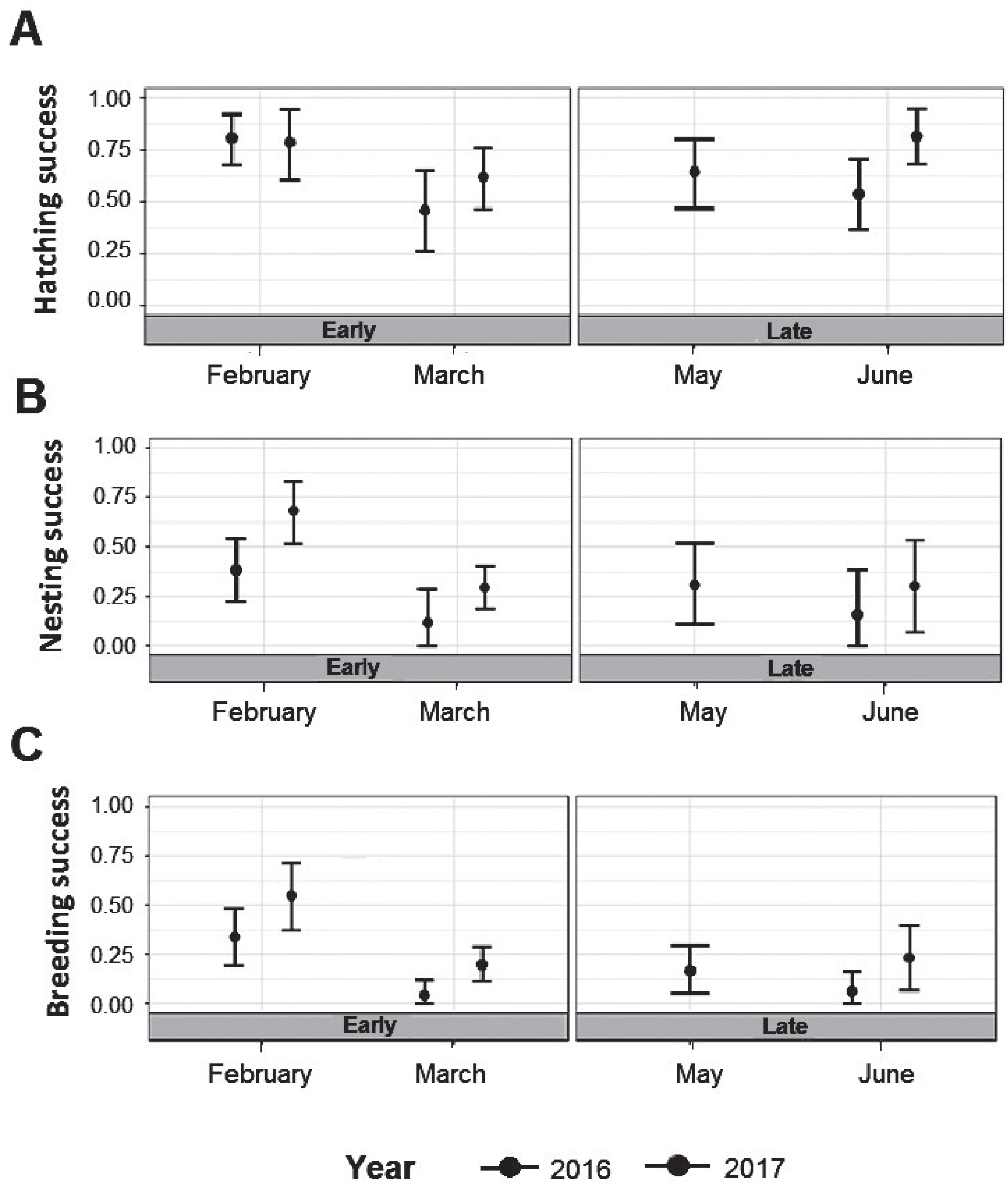

Figure 4. Mean and 95% confidence interval by Bootstrapping of hatching, nesting and breeding successes within the early (February–March) and late (May–June) breeding seasons of Grey Heron in the 2016–2017 breeding period in L'Albufera de Vàlencia.

months due to the agro-environmental practices of flooding of the surrounding rice fields (Prosper 2000) and to the less critical winter temperatures compared to other areas in Spain and Europe (Campos and Fernández-Cruz 1991, Caballero 1996, Prosper 2000). On the other hand, the fact that in L'Albufera the reproductive period is divided into two separate seasons may be due to the management of the rice paddies, which keeps the fields completely dry for about a month and a half, which was not the case in previous decades. Previously, in the 1980s and 1990s, flooding of rice fields in L'Albufera began in April, while planting began in early May (Prosper 2000,

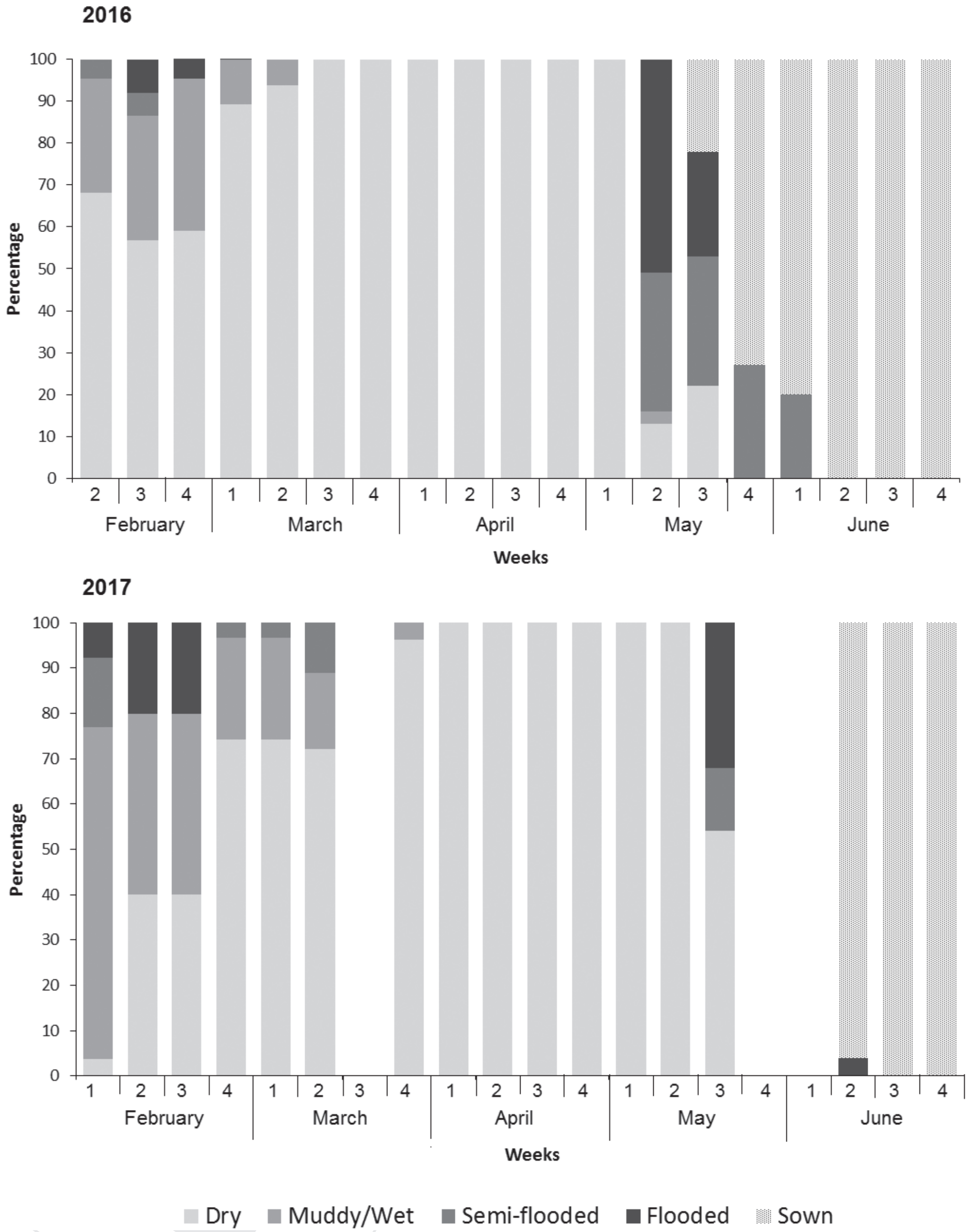

Figure 5. Status of rice fields in 2016 and 2017 in L'Albufera de València (gaps are weeks without data).

Oltra et al. 2001, Goméz de Barreda 2009), whereas during the study period, flooding did not begin until early May and planting at the end of the month. The interruption of the flooding regime during the month of April (and part of March) could be the reason why the breeding period is divided. Like other bird species, herons may have modified the onset of reproduction in response to the change in the timing of peak food abundance (McKinnon et al. 2012, Visser et al. 2012, Funk 2013).

Table 2. Multi-model selection (GLMMs) for Grey Heron abundance in the rice field, using different combinations of fixed predictors (standardized field conditions and distance to the colony) and year and location of the fields (north or south) as random effect. Selection based on the Maximum Likelihood Approach. In bold the selected model is indicated (- LogLik = log Likelihood function, AICc = Akaike Information Criterion with correction for large models, ΔAICc = AICc of each model - AICc of the best model).

Model	Fixed effects	LogLik	AICc	ΔAIC	d.f
Model 4	Distance + Muddy/Wet + Flooded/semi-flooded + Dry	-4886.4	9786.9	0.0	7
Model 3	Distance + Muddy/Wet + Flooded/semi-flooded +	-5051.4	10115.0	328.1	6
Model 2	Distance + Muddy/Wet	-5070.6	10151.2	364.4	5
Model 1	Distance	-5721.2	11450.4	1663.5	4
Model 0	Null	-6192.6	12391.2	2604.3	3

Distance: normalized score of distance; PC1 scores: dry; PC2 scores: flooded/semi-flooded; PC3 scores: muddy/wet

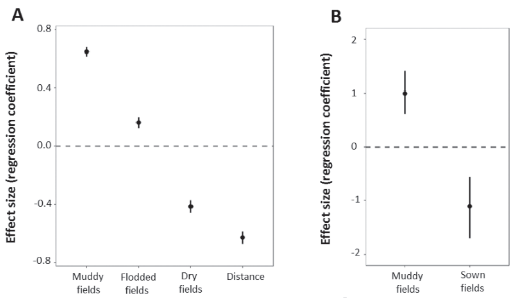

Figure 6. Effect (regression coefficient) of field condition and distance on number of individuals (A) and of field condition on breeding success (B).

Reproductive Success and Rice Field Management

Paddies and irrigation canals are important foraging habitats for breeding herons and egrets (Hafner et al. 1987, Fasola and Ruiz 1996, Fasola et al. 1996, Delord et al. 2003, Elphick et al. 2010) and more so, when marshes and natural freshwater bodies dry up (Tourenq et al. 2001). Although rice fields are flooded independently of rainfall, the flooding regime for rice field management may affect the availability of flooded feeding areas and consequently breeding success (Prosper and Hafner 1996, Lekuona 2002, Cardarelli et al. 2017). In L'Albufera, reproductive parameters were higher in February than in March (in both years), when most of the fields still had some water level due to the flooding and drying schedule of the rice field, despite the lower rainfall in that month (AEMET). However, in the spring, the lowest reproductive success was obtained in 2016, when rainfall was lower, reaching zero in the month of June, and the highest was achieved in 2015 when rainfall was the highest of the three study years (AEMET). Although the effect of rainfall on reproductive success was not directly assessed in this study, other studies have found that rainfall is associated with a higher value of this parameter (Hafner et al. 1994, Bennets et al. 2000, Si Bachir et al. 2008, Nefla et al. 2012), which could partly explain the results obtained during the late season (spring).

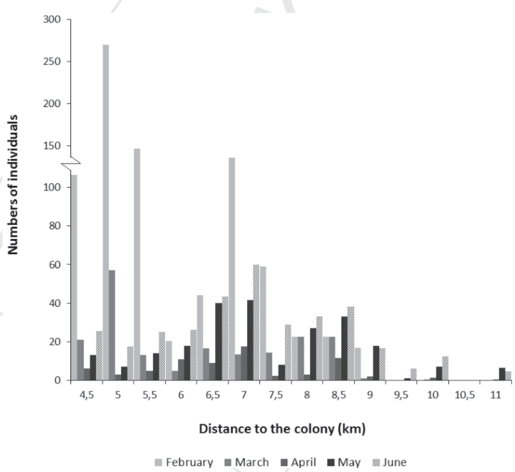

Figure 7. Average number of Grey Heron individuals recorded at different distances from the colony in L'Albufera de Vàlencia during the breeding period 2016–2017 (mainland starts from 4 km from the colony).

The total surface area of flooded fields has been linked to food availability and this in turn to reproductive success (Owen 1960, Hafner et al. 1987, Hafner et al. 1994, Manikowska-Slepwronska et al. 2016). Similarly, this influences the number of visits to the nest by parents to feed chicks or the quantity/quality of food offered at each visit (Owen

Table 3. Multi-model selection (GLMMs) for Grey Heron breeding success using different combinations of fixed predictors (standardized field conditions) and year and season as random effect. Selection based on the Maximum Likelihood Approach. In bold the selected model is indicated (- LogLik = log Likelihood function, AICc = Akaike Information Criterion with correction for large models, ∆AICc = AICc of each model - AICc of the best model).

Model	Fixed effects	LogLik	AICc	∆AIC	d.f
Model 10	sown + muddy/wet + flooded/semi-flooded	-37.4	92.8	0.0	6
Model 9	sown + muddy/wet	-39.7	93.5	0.7	5
Model 8	muddy/wet + flooded/semi-flooded	-40.7	95.4	2.6	5
Model 6	flooded/semi-flooded	-44.7	99.8	7.0	4
Model 7	flooded/semi-flooded + sown	-44.4	102.8	10.1	5
Model 5	null	-54.0	115.4	22.6	3

PC1 scores = flooded and semi-flooded fields; PC2 scores = sown fields; PC3 scores = muddy/wetfields

1955), which is directly related to mortality of larger chicks and fledglings (Jakubas 2005). In this study, reproductive success was positively associated with the presence of fields with a certain level of water (muddy and semi-flooded). On the one hand, when the fields begin to drain in February and March, potential prey, such as crustaceans, amphibians and fish, were concentrated in the remaining water (semi-flooded fields), which made them more accessible to herons and thus provided a high feeding opportunity (Marques and Vicente 1999, Mugica et al. 2006). Before all the water is removed, the muddy fields are ploughed blending the mud in surface, which also allows the entry of external energy, which also produces an increase in the availability of prey, mainly crustaceans, which are more abundant at this stage of the crop (Mugica et al. 2006). This type of field (muddy ploughs) is where the highest prey consumption (Kg/ha/day) has been recorded throughout the year in the rice fields of Cuba (Mugica et al. 2006). By March most of the fields were already dry. Thus, chicks hatched in the last week of February (in 2016) and the first weeks of March (in 2017) find the rice fields mostly dry. As March and April progressed, the availability of fields with a certain level of water decreased, reducing the availability of foraging areas where parents obtain food for their offspring. This translates into the low survival rate found in the chicks born at this stage. The suitable and abundant food habitat found at the beginning of the reproductive cycle disappears completely with the drying of the fields.

In relation to the late season, breeding success was also higher in the months with a higher proportion of muddy/semi-flooded fields, as was the case in 2016, when hatchings occurred at the beginning of the floods, in the month of May. In 2017 all the chicks hatched in June so they found with most of the fields sown. However, those hatched at the beginning of the month still had some area of muddy/semi-flooded fields available. In May, the fields began to be flooded to prepare the land for cultivation by means of new mud-ploughing operations. Due to the increase in weight and size of the organisms, the biomass of prey increases as the crop progresses, reaching its maximum in mature rice fields, where there are also a greater number and diversity of prey (Gonzalez-Solís et al. 1996, Marques and Vicente 1999, Mugica et al. 2006). The highest fish biomass is found at this stage of the crop (Mugica et al. 2006), and the cover of emergent plants can also favor the colonization of macroinvertebrates, as has been observed in seasonal wetlands (De Szalay and Resh 2000). However, the high cover of rice plants at this stage makes it difficult to capture prey, so they are consumed at a low rate (Gonzalez-Solís et al. 1996, Mugica et al. 2006, Ibañez et al. 2010, Nam et al. 2015). Thus, great herons, such as Grey Heron, are rarely found in dense paddy fields and are more associated with flooded fields after mud-ploughing (Nam et al. 2015). Decreasing prey availability in sown fields as cultivation progresses could be the cause of the low reproductive success associated with this rice field condition. For this reason, it would be advisable, as agricultural

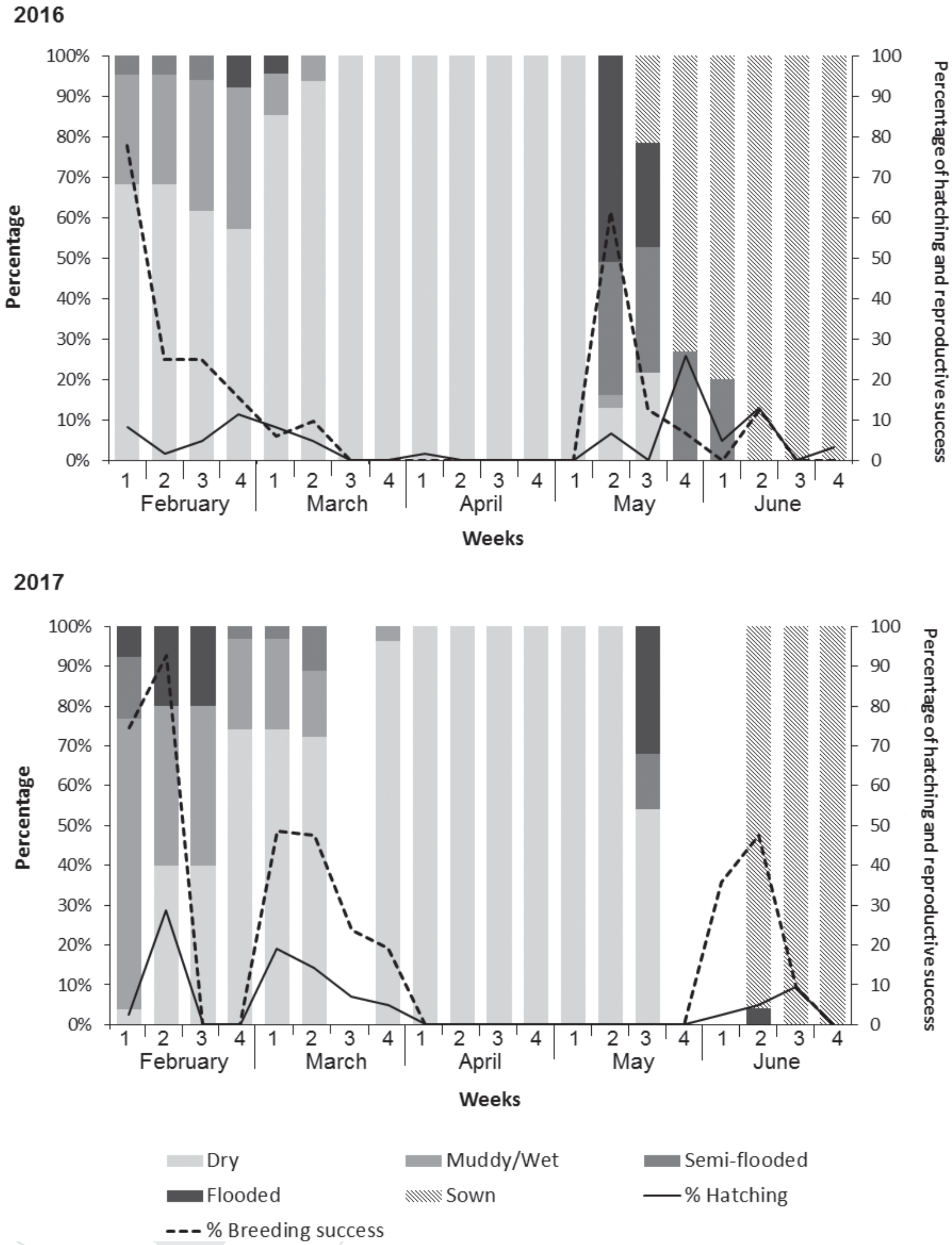

Figure 8. Percentage of hatching and breeding success of Grey Heron and condition of the rice field in L'Albufera de València during the breeding period of 2016 and 2017 (gaps are weeks without data)

management, to leave spaces on the edges or margins of the fields with lower sowing density in order to encourage the feeding of this and other species.

Because prey availability varies seasonally and is related to the flooding regime and cultivation practices (Ibañez et al. 2010, Cardarelli et al. 2017), changes in water management and the flooding cycle of the rice field, such as reducing the flooding period or intensifying winter drainage for soil preparation, may negatively affect the reproductive performance of this species (Prosper and Hafner 1996, Generalitat Valenciana 2002, Ibañez et al. 2010). In L'Albufera de Vàlencia, the management of winter flooding, both in extent and duration, acquires a relevant importance in the reproductive success of the Grey Heron. However, in recent decades, the area flooded in this period has been decreasing, as well as the volume of flood water by approximately 6% (Soria et al. 2015). On the other hand, rice field management is currently facing increasing pressure on the distribution of water resources, which is a determining factor in the maintenance of feeding and nesting of different bird species (Picazo-Tadeo et al. 2009). The development of agricultural activities other than rice cultivation, in areas surrounding the rice field, increases the demand on irrigation systems that depend entirely on the Jucar and Turia rivers, as well as the lagoon itself (Palop 2015). This is combined with the effects of climate change, which is causing a decrease in water supplies due to the reduction of the resource at the basin level as a result of reduced rainfall (Palop 2015). Given this situation, the way in which water management planning and rice field management, including flooding regimes, is undertaken takes on greater importance, particularly at this time when production is adjusting to more competitive markets and is facing declining profitability (Girona 1998, Picazo-Tadeo et al. 2009, Martinez 2018).

Conclusions

L'Albufera de València is the most important Grey Heron colony in eastern Spain (Campos et al. 2001, Prieta and Campos2003, Garrido et al. 2012). The reproductive success of the Grey Heron in L'Albufera de València is related to the fact that the rice fields maintain a certain level of water so that they serve as a food source for the young. The early drainage of the fields in winter and the prolonged time that the fields remain dry, results in high mortality of chicks, which translates into low reproductive success. Hence the importance of proper management of winter flooding, in terms of extent, water volume and duration. On the other hand, reproductive success in spring is favored when the crop cycle is synchronized with the reproductive cycle of the species, so that the start of summer flooding and rice sowing should coincide with the hatching and rearing of the young.

The Grey Heron is a widely distributed species and adapted to different types of habitat, so there are no real conservation problems. However, there are numerous species of aquatic birds that also nest in the area, including species with some conservation category. These species, which also feed in the rice field during their reproductive season, could also be affected by rice field management, as has been observed in other heron species in the area (Forti et al. 2021b). Therefore, the success of the breeding populations in L'Albufera de València requires planning and management of the protected area that considers the biological and reproductive requirements of the species. In this case, based on the results of this study, water management, the timing and duration of floods must be synchronized with the needs of the colony to ensure reproductive success. It is also important to maintain certain areas with low plant density to allow for adult foraging success.

On the other hand, it is also necessary to keep information on this colony up to date to show the effects that changes in cultivation techniques and water management, as well as the effects of climate change (changes in rainfall patterns), could have on the reproductive performance of this population.

Acknowledgments

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