**A comparison of wintering duck numbers among European rice production
areas with contrasting flooding regimes**

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ABSTRACT Agricultural lands can provide suitable habitat for birds under some conditions. In particular, waterfowl sometimes rely on ricefields as nocturnal foraging habitat during winter if post-harvest practices make food accessible. To assess whether the winter flooding of ricefields could be a major driver of duck regional abundance in Europe, we relied on a combination of spatial and temporal analyses. In the former, five of the most important western European rice growing regions in Spain, Italy and France were compared in terms of habitat composition over the 2002-2012 period. The relative importance of natural wetlands and ricefields (either dry or flooded) in determining the abundance of wintering ducks was then established. In the second approach, the trends in duck numbers before and after implementation of winter-flooding Agri-Environment Schemes (AES) were compared in two of the study regions. Both approaches highlighted the role of winter ricefield flooding in explaining wintering duck numbers and complementing the natural wetlands; flooding harvested ricefields improves habitat attractiveness by enhancing food resource accessibility. In Europe, the proportion of ricefields flooded during winter varies considerably between countries (0.17 to 62%), owing to differences in policy initiatives such as Agri-Environment Schemes. Promoting such schemes more widely across the European rice production area could make a big difference in terms of waterfowl habitat quality at the scale of their wintering range.

Keywords: Agricultural wetlands, Post-harvest management, Ricefields, Satellite images, Waterfowl, Winter.

1. Introduction

Historically, conservation biology was largely oriented to preserving wilderness in remaining natural environments (e.g. Leopold, 1949). Since the 1980s, however, there has been growing interest in the improvement of anthropized landscape matrices, such as agricultural lands, as these represent a growing proportion of the environment in areas with intensive agriculture (Balmford et al., 2012). The two approaches have now been shown to be complementary in mitigating erosion of biodiversity and biotic interactions, and many studies have commented on the respective roles of natural and artificial wetlands for waterbird conservation (e.g. Fasola and Ruiz, 1996; Elphick, 2000; Toral and Figuerola, 2010 versus Tourenq et al., 2001a; Bellio et al., 2009; Taylor and Schultz, 2010; Guadagnin et al. 2012). Such questions have been recurrently raised around the Mediterranean region, one of the first 25 Global Biodiversity Hotspots (Myers et al., 2000) but also one of the regions where natural habitats have been transformed by human activities for the longest period. In the Mediterranean region an estimated 80-90% of former natural wetlands have disappeared (Finlayson et al., 1992), and ca. 23% of the remaining wetlands are artificial (e.g. ricefields, salt pans, irrigation reservoirs; Perennou et al., 2012).

Ricefields are one of the most important of these artificial habitats, and currently represent 15% of the world's wetlands (Lawler, 2001). Around the Mediterranean, in the European Union, rice is cultivated on a total of ca. 460,000 ha, the top producers being Italy (53%), Spain (24%), Portugal (7%), Greece (6%) and France (4%) (FAOSTAT, 2012).

Although the expansion of ricefields is sometimes at the expense of natural wetlands, these fields have proven to be of general interest to a wide variety of waterbirds worldwide (see Elphick et al., 2010a), notably in Europe (Longoni, 2010). According to Toral and Figuerola (2010), ricefields represent one third of the suitable waterbird habitat in southern Europe (Italy, Spain, Greece, and Portugal).

The role of ricefields as winter diurnal roosts and feeding grounds for ducks is widely recognized in North America (Eadie et al., 2008), and more recently in Japan (Kurechi, 2007), where such habitats are managed in a waterfowl-friendly way. In Europe, ducks mainly gather during the day on natural or semi-natural deep wetlands (day-roosts), and only move at night towards distinct shallow water foraging grounds, including ricefields (well studied in the Camargue, France, see Tamisier and Dehorter, 1999). Due to such nocturnal behaviour, the use of ricefields by European ducks is difficult to quantify (Tourenq et al., 2001a), and is virtually unstudied in some regions. Thus, it is still unclear if ricefields can be considered valuable substitutes or complements to natural wetlands for wintering dabbling ducks in Europe.

Whether ricefields are attractive and provide abundant food resources to waterbirds may greatly depend on agricultural practices during the crop growing season (e.g. seeding practices, agro-chemical use and harvest method, Ibáñez et al., 2010) as well as during the post-harvest period (e.g. straw management such as crushing or burning, soil mechanical work such as mowing or disking, winter flooding and their combinations, Elphick et al., 2010b). In Europe, environment-friendly practices are supported by Agri-Environment Schemes (AES hereafter) contracted by farmers and implemented through the Common Agricultural Policy (CAP) (EC Directorate General for Agriculture and Rural Development, 2005). However, recommended practices can vary from one region to another as the final decision of which AES to implement is taken at the regional scale. Moreover, the European Community often lacks the data necessary to implement these recommendations, and scientific assessment of the efficiency of current schemes is also needed (e.g. Tourenq et al., 2001b; Ernoul et al., 2013).

One of the post-harvest management practices for which some European rice producers (mostly in Spain) receive financial support through AES is winter flooding of fields for

several months. Winter flooding is largely practiced to create bird habitat in the US under the North American Waterfowl Management Plan (NAWMP) (Eadie et al., 2008) and is implemented in two regions in Japan after regional decisions and non-governmental initiatives (Kurechi, 2007; Tajiri and Ohkawara, 2013). Previous studies showing how ricefield flooding can improve habitat quality for waterbirds have been restricted to those two countries. Some site-specific case studies exist in Europe (e.g. Tourenq et al., 2001a; Toral and Figuerola, 2010). However, no comprehensive study has been carried out in several sites in Europe to determine how such management is practiced at the flyway scale, and whether this can be a major driver of waterbird abundance at the regional scale. The extent to which this could potentially affect general population trends at the flyway scale in Europe has not yet been evaluated.

Local nocturnal surveys in the Camargue, southern France, have highlighted the great potential of flooded harvested ricefields to act as duck foraging grounds, since an average of 5 to 33 ducks/ha was recorded in flooded fields vs. 0.14 ducks/ha in dry paddies (C.A. Pernollet et al., unpublished data, see also Pirot, 1981). The aim of the present study was to go beyond this local information and assess whether winter flooding of European ricefields provides a suitable habitat for ducks, and thus translates into greater duck numbers at the regional scale. We first relied on a spatial analysis comparing five of the most important western European rice production areas in terms of habitat composition, and tried to establish the relative importance of natural wetlands and ricefields in determining the abundance of wintering ducks. Among ricefields a distinction was made between dry and winter-flooded fields, to accurately assess the effect of post-harvest management of ricefields, especially flooding, on duck abundance and species richness among the six dabbling duck species potentially using such habitats during winter. The second part of the study relied on a temporal analysis in two of the study regions, where winter flooding was introduced as an AES. There, the assessment

of the link between agricultural policies and duck populations was conducted by comparing the trends in duck numbers before and after AES implementation, to test whether this led to more positive trends during later years.

2. Material and methods

2.1. Study regions

The study was carried out in five major European rice growing regions in Spain, France and Italy (Fig. 1). These regions were selected because they all belong to the same duck flyway (see flyway delineations in Scott and Rose, 1996), their ricefields were established on former natural wetlands, and their landscape has remained relatively stable over the last decade due to strong anthropological control of the hydrological system.

Fig. 1. Map of the five study regions in western Europe (the size of dots represents the area cultivated in rice, expressed in ha).

In Italy, rice farming is concentrated in the inland plain of the Po Valley, where it has been practiced since the 15th century. Our study focused on the province of Vercelli in Piedmont ($45^{\circ}19'N$ $08^{\circ}25'E$, ca. 208 000 ha of which 72 000 ha are cultivated with rice, average 2002-2012) and the province of Pavia in Lombardy ($45^{\circ}11'N$ $09^{\circ}09'E$, ca. 300 000

ha of which 81,000 ha are ricefields, average 2002-2012). In northwest Italy the climate is continental temperate, with cold winters and warm summers allowing culture rotations such as rice-maize-soybean /wheat or rice in conjunction with poplars or forage pastures (Mañosa i Rifé, 1997).

In France, rice production is restricted to the Camargue Rhône Delta, in the south of the country (43°30'N, 04°30'E), where it was introduced in 1942. This region of about 145 000 ha comprises 60 000 ha of natural and semi-natural wetlands and about 18,000 ha of rice (details in Tamisier and Dehorter, 1999). The climate of the Camargue is typically Mediterranean. This, combined with saline soils, restricts agricultural crops to either rice monoculture or rice-wheat-alfalfa rotation (Barbier and Mouret, 1992). As in Italy, French ricefields are dried out at the end of the growing season to facilitate harvest (July-August in Italy, September-October in France) and are mostly ploughed or disked during the winter depending on weather conditions (Mañosa i Rifé, 1997). The small flooded area during winter is mostly inundated for waterfowl hunting purposes.

The last two study regions are located in Spain along the Mediterranean coast: the Ebro Delta (40°42'N 0°43'E), where 21 000 ha of the total 32 000 ha of the area are covered with ricefields (details in Curcó and Bigas, 2012), and Albufera de Valencia (39°27'N, 0°13'E) where ricefields represent ca. 15,000 ha of the total 21,000 ha (details in Oltra et al., 2001). Rice cultivation was introduced at a large scale to both areas around 1860 (Mañosa i Rifé, 1997). The climate and soil conditions make rice the only crop in the lowlands of the Ebro Delta and Albufera de Valencia. Ricefields there remain flooded for a longer period, i.e. harvest is conducted in water and fields are only dried by the end of January as part of the AES, even sometimes later in hunted ricefields. The AES “ricefield winter flooding” consists of maintaining the ricefield surface under flooding for at least 3.5 months in Albufera de Valencia (Law: RD 4/2001 and RD 708/2002) and at least 4 months in the Ebro Delta

(Council Regulation (EC) No 1257/1999). This practice was historically used mainly for hunting purposes in Spain (Ferrer, 1986), but this modern legislation increased the area of flooded ricefields and the time during which they are flooded. This measure was implemented by the European Union in 1998 to promote environment-friendly methods of agricultural production, and applied to these two Ramsar-designated wetlands. The AES “ricefield winter flooding” in both sites were applied as described until 2010 for Ebro Delta and 2012 for Albufera de Valencia but has been modified recently for reasons described in the Discussion.

Here we consider as “natural and semi-natural wetlands” all areas flooded by fresh or brackish water (temporary marshes, lagoons, ponds, hunted marshes), excluding salt pans (salines) and ricefields. In the Camargue, large remnants of the ancient natural wetland habitats can still be found, while in northwest Italy very little of the inland freshwater remains. However, in the Camargue, rice expanded mostly at the expense of freshwater and brackish marshes, and a total of 40 000 ha of natural habitats (33 000 ha wetlands) disappeared between 1942 and 1984 (Tamisier and Grillas, 1994). In the Ebro Delta, the progression of rice-farming has drastically changed overall habitat composition: at the beginning of the 20th century natural habitats still covered 28 000 ha (88% of the delta), then declined to 8,000 ha (25%) today (Mañosa i Rifé, 1997). In Albufera de Valencia, the conversion of wetlands to anthropized habitats (including ricefields) began in the 16th century and lasted until the 1940s (B. Dies personal communication). Very limited information is available concerning wetland transformation in the Italian study regions as regards wetland transformation (Perennou et al., 2012). More generally, in northern Italy ca. 60% of the wetlands were reclaimed for agriculture between 1938 and 1984 (Nivet and Frazier, 2004).

2.2. Databases

2.2.1. Duck numbers

Our study focused on the six most common European dabbling ducks, i.e. gadwall (*Anas strepera*), northern pintail (*A. acuta*, hereafter pintail), mallard (*A. platyrhynchos*), common teal (*A. crecca*, hereafter teal), Eurasian wigeon (*A. penelope*, hereafter wigeon) and northern shoveler (*A. clypeata*, hereafter shoveler). These species are known to use ricefields during winter whenever these are available within their range (Mateo et al., 2000; Elphick et al., 2010a).

The Ebro Delta is the second largest wintering ground for waterfowl in Spain, followed by Albufera de Valencia (Oltra et al., 2001; Martí and del Moral, 2003). The Camargue is the most important wintering area in France for 5 of the 6 studied dabbling duck species (i.e., all but shoveler, for which it is the second most important site at the national scale, Deceuninck et al., 2014). These three regions all exceed the criterion of international importance for several duck species (>1% of bird population size, Wetlands International, 2014). In northwest Italy, 15 000 ha of Vercelli ricefields are recognized as Important Bird Areas (IBAs, Heath and Evans, 2000); in the Pavia province, 30 941 ha are designated as SPA – Special Protection Areas (IT2080501, Risaie della Lomellina).

The duck data used in the analyses mainly came from the International Waterbird Censuses (IWC) carried out every year in mid-January throughout Europe and coordinated by Wetlands International (Wetlands International, 2012). For the Camargue we used the mid-January aerial duck surveys (method explained in Tamisier and Dehorter, 1999), which were more consistent in covering the same area from year to year than the IWC, which combine systematic aerial and non-systematic terrestrial data. National and local Wetlands International coordinators provided the duck data from their respective regions for the present analyses. It is important to note that counts were carried out in all regions whilst ducks gathered at their day-roosts, which generally were not ricefields. However, despite this, some ricefields were still included in the counts in some regions (14 000 ha in the Albufera, Oltra et

al., 2001; 22 723.9 ha in the Ebro Delta, Curcó and Bigas, 2012). Beside total duck abundance, expressed as the number of birds, we also compared species diversity between regions so as to determine if regions with more diverse habitats would also host a more diverse duck community. This was assessed through the Shannon-Weiner index which is based both on the number of species and their average relative abundance over the 2002-2012 period.

2.2.2. *Habitat data*

The surface areas of wetlands other than ricefields, of the total ricefields of the previous summer and of winter-flooded paddies were obtained or computed for each winter of the 2002-2012 period directly for each of the five study regions.

To extract the natural or semi-natural wetland area of Pavia (Lombardy) and Vercelli (Piedmont) provinces, two land cover maps were used, one for Lombardy (DUSAF2008, database cartografia.regione.lombardia.it/geoportale) and one for the Piedmont region (LCP2008, Land Cover Piemonte, Classificazione uso del suolo 2008). Both were produced from digital color orthophoto maps (2005-2007 for Lombardy and 2000-2005 and 2007 for Piedmont, respectively). Corine Land Cover codes corresponding to wetland habitats were selected and a calculation of their total area was done with ArcGis software. Natural and semi-natural wetlands are considered to have been stable in these regions over recent decades (G. Bogliani personal communication), therefore the value of the surface area obtained for these wetlands in each of these regions with the above method was applied to all years of the 2002-2012 period.

In the Camargue, natural and semi-natural wetland area was available for the years 2001, 2006 and 2010 (Observatoire des Zones Humides Méditerranéennes, 2014). From these data, missing annual values were extrapolated using linear regression, which was assumed

appropriate because of the gradual change of the Camargue wetland habitats over the last decades (Parc Naturel Regional de Camargue, 2013, annual rate of decline for period 1991-2001: 0.08%, Tour du Valat, 2009).

There is only one main wetland in Albufera de Valencia, a central lagoon covering 2,837 ha, with no change in area over the last 30 years (B. Dies personal communication). Owing to pollution from surrounding areas, this lagoon is hypertrophic and therefore provides little food for ducks (del Barrio et al., 2012). In the Ebro Delta, the decennial natural and semi-natural wetland area from Curcó (2004) was used as a reference for 1990, the value extracted by Observatoire des Zones Humides Méditerranéennes (2014) for 2005, and that given by Curcó and Bigas (2012) for year 2011. Missing annual values were computed from a linear regression between those dates, following the same procedure as in the Camargue.

The annual area of cultivated rice was extracted from databases of the national agriculture services: the Ente Nazionale Risi in Italy (<http://www.enterisi.it>), France AgriMer in France (<http://www.franceagrimer.fr>), and Ministerio de Agricultura, Alimentación y Medio Ambiente in Spain (<http://www.magrama.gob.es>).

A two step multi-temporal remote sensing approach with Landsat imageries (TM, ETM and OLI) was used to obtain the mean area of winter-flooded ricefields at each study site. Note that owing to the use of remote sensing, it was not possible to distinguish fields intentionally flooded by man from fields flooded by heavy rainfall. First, for each period of the annual rice cultivation cycle, at least 3 Landsat multispectral images were used to delineate and map the ricefields. These 3 Landsat acquisition dates corresponded to the main phases of crop production: (a) one image when the fields were devoid of any vegetation during winter (October to March), (b) one image when the fields were flooded after setting the young seedlings (end of spring and beginning of summer), and (c) one image when rice plants were mature, before harvest (July to September) (Fig. 2a, b, c and resulting map d).

This multi-temporal approach enabled us firstly to avoid confusion between ricefields and other aquatic habitats (e.g. marshes, lagoons, sea, etc.), and secondly to separate rice from other crops. We used two functions of the Spatial Analyst Tool of Arcgis. The function Reclass/Reclassify was used for identifying the ricefields that were flooded in winter for each image. Once rice crops were mapped for a given site and a given year, function Math Algebra/Raster Calculator was used to calculate the total flooded area for all the used images.

From this, the MNDWI (Modified Normalized Difference Water Index) was used to map open water areas (Hanquiu, 2006). The MNDWI enhanced open water features by efficiently suppressing built-up land noise as well as vegetation and soil noise (Fig. 2e and f). The calculation of this index is based on the Green band (G) and the ShortWave InfraRed band (SWIR) of Landsat:

$$MNDWI = 1 - (SWIR / G) / 1 + (SWIR / G)$$

The resulting water area map was then overlaid with the ricefield map produced during the previous step, and the GIS intersection between the two shapefiles was calculated (Fig. 2g and h). This figure represented the flooded area within all ricefields at a given site for a given date. The proportion of winter flooded ricefields was computed for each site each November, December and January whenever satellite images were available. The mean of these values (one to three, depending on available satellite images) was then used in the analyses. In practice, an area of flooded ricefields was available for 2 years of the 2002-2012 period in Albufera de Valencia (2002, 2003), 3 years in the Camargue (2002, 2003, 2006), Vercelli (2002, 2003, 2012), and Pavia (2002, 2003, 2012), and 5 years in the Ebro Delta (2002, 2003, 2007, 2010, 2011). Due to the limited number of satellite images available in Albufera de Valencia, missing annual data were complemented by information on winter flooded ricefields provided by the Dirección General de Innovación Agraria de la Consejería de Agricultura, Pesca y Alimentación of the Valencian community

(<http://www.agricultura.gva.es/>) for the winters from 2003 to 2011 (except winter 2007) based on the CAP farmers declaration. The Albufera was the only region where we had access to such information. Because flooding policy has remained stable in each of the five regions during the last decade, we computed the mean proportional area of ricefields that was flooded over all available annual data in each region, and applied this mean number to all years of our study period (2002-2012).

Fig. 2. Ricefield mapping derived from a multi-temporal Landsat analysis for year 2003: a) Non-vegetated fields (10 March 2003), b) Artificially flooded fields for rice cultivation (22 May 2003), c) Mature fields before harvest (9 August 2003), d) Ricefield delineation map derived from the 3 acquisition dates using an automatic remote sensing classification, e) and f) Extraction of water surface areas using the MNDWI (29 December 2002), g) and h) Extraction of the flooded ricefields for one acquisition date during the winter season (here, December) of the 2003 time period. The mapping technique is illustrated here with images of Albufera de Valencia.

2.3. Statistical analyses

2.3.1. Habitat features and duck abundance

All statistical tests described in this section were performed using R version 2.15.3 (R Core Team 2013).

The mean landscape features and the annual total duck numbers were firstly compared between the five study regions using an ANOVA with repeated measures on log-transformed proportions of wetlands / rice in the total area and log-transformed duck numbers, respectively, to meet normality criteria.

The potential relationship between duck abundance and habitat features was then analyzed using Generalized Linear Mixed-effects Models (GLMMs) with a negative binomial distribution (data overdispersed : package glmmADMB, function glmmadmb). In the GLMMs, dry rice, natural and semi-natural wetlands, flooded rice as well as total wetland (i.e. natural & semi-natural wetlands + flooded ricefields) and total rice (i.e. dry ricefields + flooded ricefields) areas were used as continuous predictor variables, while Site (5 modalities for the 5 study regions) and Year (to account for variation between years) were included as random factors. We tested the effect of total wetland area and its components (i.e. natural wetland area + flooded ricefield area) in separate models, to assess if duck abundance depended on wetland availability in general (i.e. total wetland area), or was more dependent on the availability of some wetland types (i.e. natural or artificial). We repeated the same method for the ricefield areas (i.e. dry ricefields + flooded ricefields), called total rice area.

All predictors were z-transformed (in order to have means equal to 0 and standard deviations equal to 1) prior to the analyses. The Akaike's Information Criterion (AIC) was used to compare the set of possible models and to rank them (Burnham and Anderson, 2002). After ranking models according to their respective AIC, the principle of parsimony was used to find the best trade off between biases related with the use of a simple model versus the loss of performance of a more general model.

The best model is the only one to be presented in details in the results section.

2.3.2 *Effect of flooding regime on the number of ducks*

To test whether regional duck population trends were related to the AES “Winter Flooding” application, we compared the trends in the numbers of ducks at the Ebro Delta and Albufera de Valencia before and after winter flooding was introduced. The spatial images were insufficient to compare the proportion of rice actually flooded before and after the implementation of the measure. Hence, two periods of similar duration (with the date of AES application chosen as the change point) were considered at each site: 1989-1999 (Ebro) and 1989-2001 (Albufera) were the periods before the AES, and 1999-2010 (Ebro) and 2001-2010 (Albufera) were the post-AES implementation periods. The most recent data (i.e. 2011-2012) were removed from the analysis as flooding politics changed again in the Ebro Delta after winter 2010, with parts of the ricefields currently kept dry as a measure against the spread of the exotic Apple Snail *Pomacea insularum* (Curcó and Bigas, 2014). Duck population trends were calculated using TRIM, a freeware widely used in Europe to implement Poisson regressions to analyze time-series of counts, especially for waterbirds (Pannekoek and van Strien, 2001). The time effects model with imputed indices was used, considering serial correlation and overdispersion (e.g. Wretenberg et al., 2007) to estimate the overall trends and their 95% confidence intervals over the whole study period (1989-2010) for each of the two regions. This procedure was then used with years 1999 (Ebro) and 2001 (Albufera) as change points in linear trend models. Finally, to test if any increase in duck numbers was explained by a global trend at the flyway scale, the analysis was performed for the Camargue, which was considered a control site, using 2000 (the mid-point between AES implementation at Ebro and Albufera) as the change point, i.e. pre-AES years: 1989-2000, post-AES years: 2000-2010.

3. Results

3.1 Habitat features and duck abundance

Fig. 3. Mean wetland habitat composition and abundance of wintering dabbling ducks (triangles, from January censuses) in five major European rice production regions (black: natural and semi-natural wetlands, grey: flooded ricefields, white: dry ricefields). Average values over the 2002-2012 period, vertical bars for the numbers of ducks indicate standard error.

Mean wetland percentage cover differed greatly among the five regions (ANOVA: $F_{4,49} = 12648$, $P < 0.001$), with the proportion of natural and semi-natural wetlands versus ricefields highest in the Camargue, intermediate in the Ebro Delta, and lowest in the Albufera and Italy (Fig. 3). The two Italian provinces were almost completely covered with ricefields (only 3% of natural and semi-natural wetlands in Vercelli). The mean proportion of ricefields that were flooded during winter was 62% on average in the Ebro Delta and Albufera de Valencia. The figure was 9% on average in Camargue. The other extremes were the two Po Valley provinces in Italy with only 0.17% (Vercelli) and 0.28% (Pavia) of the ricefields being flooded during winter.

Major differences in mean total duck numbers were also observed between the five study regions (ANOVA: $F_{4, 49} = 209$, $P < 0.001$): the Camargue and the Ebro Delta had the greatest numbers while the two Italian provinces, despite being the largest rice farming areas in Europe, had very few ducks (Table 1). The Albufera de Valencia and the Italian study regions have similar natural and semi-natural wetland areas, but the Albufera had both more flooded ricefields and more ducks (Fig. 3, Table 1).

Table 1

Abundance of six dabbling duck species $\pm$ SE (January censuses) in five major European rice production regions, and mean relative percentage of each species in the duck community of each region ($\pm$ SE, in parentheses). Average values over the 2002-2012 period.

Region	Duck species					
	<i>A. platyrhynchos</i>	<i>A. crecca</i>	<i>A. acuta</i>	<i>A. strepera</i>	<i>A. penelope</i>	<i>A. clypeata</i>
Camargue	43 130 $\pm$ 3,039 (40 $\pm$ 2)	32 670 $\pm$ 4,386 (29 $\pm$ 3)	931 $\pm$ 471 (1 $\pm$ 0.2)	15 860 $\pm$ 7,168 (14 $\pm$ 1)	9,790 $\pm$ 1,140 (9 $\pm$ 1)	8,290 $\pm$ 847 (8 $\pm$ 1)
Ebro	53 202 $\pm$ 3,951 (55 $\pm$ 3)	21 417 $\pm$ 2,837 (21 $\pm$ 2)	2,867 $\pm$ 701 (3 $\pm$ 0.4)	3,540 $\pm$ 387 (3 $\pm$ 0.3)	3,055 $\pm$ 590 (3 $\pm$ 1)	14 968 $\pm$ 2,272 (15 $\pm$ 2)
Albufera	15 820 $\pm$ 1,548 (71 $\pm$ 3)	1,591 $\pm$ 382 (7 $\pm$ 1)	504 $\pm$ 114 (2 $\pm$ 0.4)	100 $\pm$ 17 (0.4 $\pm$ 0.04)	209 $\pm$ 77 (1 $\pm$ 0.4)	4,498 $\pm$ 898 (19 $\pm$ 3)
Pavia	11 651 $\pm$ 824 (90 $\pm$ 1)	1,122 $\pm$ 123 (9 $\pm$ 1)	6 $\pm$ 3 (0.05 $\pm$ 0.02)	37 $\pm$ 11 (0.3 $\pm$ 0.1)	58 $\pm$ 27 (0.4 $\pm$ 0.2)	16 $\pm$ 5 (0.1 $\pm$ 0.1)
Vercelli	2,379 $\pm$ 493 (92 $\pm$ 2)	145 $\pm$ 34 (7 $\pm$ 2)	1 $\pm$ 0.5 (0.05 $\pm$ 0.03)	4 $\pm$ 4 (0.2 $\pm$ 0.2)	2 $\pm$ 1 (0.2 $\pm$ 0.1)	12 $\pm$ 4 (0.6 $\pm$ 0.2)

Two models (Δ AIC scores < 2) explained differences in mean duck numbers better than the other models (Table 2). The first model was considered as the best one as it was the simplest. This model contained site-specific areas of the two wetland habitat types (ducks~flooded rice+natural & semi-natural wetlands). The mean number of ducks at a site was positively related with the area of flooded rice (Table 3, Fig. 4) and with the area of natural & semi-natural wetlands.

Table 2

Set of all candidate GLMMs testing the relationship between the environmental variables (NatWet: natural & semi-natural wetlands, FloodRice: flooded rice, DryRice: dry rice and TotWet: natural & semi-natural wetland + flooded rice, TotRice: dry rice + flooded rice) and the mean annual numbers of dabbling ducks in five major European rice production regions over the 2002-2012 period. Significance of the predictor variables is represented by * as followed: °: Tendency, * : $P < 0.05$, ** : $P < 0.01$, *** $P < 0.001$.

		AIC	ΔAIC
Ducks	NatWet***+FloodRice***	1177.97	0
	NatWet**+FloodRice*+DryRice	1179.87	1.90
	TotWet*+DryRice°	1180.66	2.69
	TotWet**	1180.90	2.93
	NatWet+DryRice*	1181.77	3.80
	DryRice*	1181.83	3.86
	TotRice*	1182.21	4.24
	FloodRice+DryRice	1182.51	4.54
	NatWet+TotRice°	1182.55	4.58
	NatWet	1183.07	5.10
	FloodRice	1183.08	5.11

Table 3

Model-averaged parameter estimates, standard-errors, z values and P values of the predictor variables of the best GLMM (i.e. lowest AIC) testing the relationship between environmental variables (areas of natural & semi-natural wetlands, winter flooded ricefields) and the mean annual numbers of dabbling ducks in five major European rice production regions over the 2002-2012 period.

Fixed effects	Estimate	s.e	z value	Pr(> z)
(Intercept)	10.06	0.26	39.52	< 2e-16***
Flooded rice	1.01	0.25	4.01	6.0e-05***
Natural & semi-natural wetlands	1.07	0.25	4.23	2.3e-05***

Fig. 4. Annual abundance of six dabbling ducks species (black dots) (January census) and mean area of winter-flooded ricefields (left) in five major European rice production regions (grey bars) over the 2002-2012 period. Note that scales differ between regions.

The Italian sites had scarce natural and semi-natural wetlands, and simultaneously mostly hosted granivorous ducks (mallard, teal and pintail). Herbivores (gadwall, wigeon) were more abundant in Camargue, and to a lesser extent in the Ebro Delta. Shovelers, which usually have more zooplankton in their diet, were more abundant in the Ebro Delta (Table 1). The Shannon-Weiner diversity indices (H) were greater for the Camargue (1.45) and the Ebro Delta (1.28), intermediate at Albufera de Valencia (0.91), while values as low as 0.36 (Pavia) and 0.27 (Vercelli) were recorded in the two Italian regions.

3.2 Effect of winter ricefield flooding on the number of ducks

Over the 1989-2010 period, the numbers of wintering dabbling ducks in the Ebro Delta, Albufera de Valencia and the Camargue all increased significantly, at approximately similar rates, although profound changes occurred in the Spanish regions over the period considered (Table 4, Fig. 5). However, while such a positive trend was already apparent before the years 2000 in the Camargue, the numbers of wintering ducks in the two Spanish regions were declining. Only after the implementation of AES did the Spanish trends increase, especially so at Albufera, then becoming positive as in the Camargue (Table 4, Fig. 5).

Table 4

Annual population rate of change (in percentage) with 95% confidence intervals (CI) and trend interpretation for six dabbling ducks over two time periods (Pre and Post Winter flooding AES) in three rice production regions of southwestern Europe. The Camargue was considered to be a control region. Trend analysis performed with TRIM. All nine trends were significant $P < 0.01$.

Region	Pre Winter Flooding AES	Post Winter Flooding AES	Full period 1989-2010
Ebro Delta	-0.91 (-0.83 – -0.99) Moderate decline	+ 6.03 (5.97 – 6.09) Strong increase	+ 3.44 (3.42 – 3.46) Moderate increase
Albufera de Valencia	-5.33 (-5.27 – -5.37) Steep decline	+ 12.47(12.29 – 12.65) Strong increase	+ 1.10 (1.06 – 1.14) Moderate increase
Camargue	+ 0.72 (0.70 – 0.78) Moderate increase	+ 8.48 (8.56 – 8.64) Strong increase	+ 3.05 (3.03 – 3.07) Moderate increase

Fig. 5. Annual numbers of wintering dabbling ducks in the Camargue (open circles), the Ebro Delta (black diamonds) and Albufera de Valencia (grey triangles) over the 1989–2010 period. The two dotted lines indicate the years of the ricefield winter flooding AES implementation in the Ebro Delta (1999) and the Albufera (2001).

4. Discussion

This study demonstrates the benefits that can be expected from flooding fields post harvest in European rice growing regions: wintering ducks were generally more abundant where flooded ricefields were widespread, and site-specific trends in duck numbers became more positive after implementation of winter flooding as an AES.

Most of the world's rice is grown under flooded conditions (86%, Chang and Luh, 1991), but the practice of flooding the fields after harvest is more variable, and mostly promoted for environmental conservation, hunting purposes, or straw disposal (e.g. in North America, Eadie et al., 2008; in Japan, Kurechi, 2007; Tajiri and Ohkawara, 2013; worldwide, Elphick et al., 2010b). The present comparative study stemmed from the observation that most studies on the importance of this practice at the regional scale were from Japan or North American regions. Conversely, although knowing that the extent to which European ricefields get flooded in winter is largely dependent on national agricultural policies (through rice AES), the way this is practiced at the flyway scale in Europe and the consequences for duck numbers remained unexplored. This led us to expect clear differences in terms of landscapes between countries and regions, and possible translation into contrasting numbers of wintering ducks.

The number of wintering ducks was positively related to the area of natural and semi-natural wetlands. This can be explained biologically since ducks search for such habitats as their diurnal roosting sites (e.g. large ponds and lakes) and also rely on these as nocturnal foraging grounds to some extent (e.g. shallow vegetated wetlands, see for example Tamisier and Dehorter, 1999 for the Camargue). In accordance with this, duck abundance was negatively correlated to the area of dry rice (negative effect size of the dry rice variable when considered in the models, results not shown). Dry ricefields do constitute a valuable habitat to some birds such as e.g. raptors and granivorous passerines (Elphick, 2004). For species like ducks, however, the lack of water prevents any efficient use of the potential food resources

(e.g. Guillemain et al., 1999), and ducks do not rest on completely dry land during the day either, so the development of rice areas without flooding represents a lost opportunity. Converting a natural wetland into a dry ricefield can hence also be considered as habitat loss for ducks .

Conversely, the number of wintering ducks increased with the area of flooded ricefields. Harvested ricefields have abundant waste grains, weed seeds and invertebrates (Stafford et al., 2010), which are made accessible to ducks by the addition or the retention of water in the fields after the rice crop season, hence likely explaining the above relationship. Earlier studies in Japan and the US have demonstrated increases in local duck numbers with increased local winter rice flooded areas (e.g. Day and Colwell, 1998; Shimada et al. 2000; Tajiri and Ohkawara, 2013), or recorded larger numbers of non-breeding ducks in flooded than unflooded fields of the same area (Elphick and Oring 1998; 2003). Studies at a broader geographic scale are however far less numerous: in Europe only Toral and Figuerola (2010) demonstrated a positive relationship between European waterbird population trends and an index of rice field use during the autumn in Spain, highlighting how the provision of ricefields at key migration sites can enhance whole populations. To our knowledge, the present study is the first to consider how the post-harvest management of such fields, through their flooding, can promote duck numbers among scattered winter quarters within the ducks non-breeding range in Europe.

Flooded fields improve the attractiveness of winter quarters by increasing global wetland area, sometimes compensating to some extent for the lack of such natural wetlands (cf. the two Italian provinces). Wetlands in the broad sense, i.e. either natural or artificial (flooded ricefields) hence seemed to jointly promote large numbers of wintering ducks. However, the best model in our analysis was not among those comprising the variable “total wetlands” (i.e. sum of natural & semi-natural wetland + flooded rice areas), but rather had

each variable (natural & semi-natural wetland area and flooded rice area) considered separately (Table 2). Thus, a certain area of flooded ricefields was not strictly equivalent to the same area of natural wetland. Both present almost equivalent effect size, indicating that they are both important and complementary. Indeed, it is possible that these two habitat types do not play the same role: in Camargue, for instance, natural wetlands typically provide nocturnal foraging areas and day roosts to wintering ducks (Tamisier and Dehorter, 1999), while flooded ricefields are mostly used as nocturnal feeding grounds (Pirot et al., 1981; Mesléard et al., 1995), but are probably too frequently disturbed by humans or predators to represent valuable day-roosts. Some earlier studies have found lower bird numbers, species richness and species evenness in rice fields than in neighbouring wetlands, but these were based on diurnal censuses (Tourenq et al., 2001a; Bellio et al., 2009; Taylor and Schultz, 2010; Guadagnin et al., 2012). Such surveys hence completely overlooked the use of rice fields by ducks foraging at night (McNeil et al., 1992). Actually, the present results suggest that the number of ducks at day-roosts (mostly large lakes or marshes, where they were censused during IWC or aerial surveys) also depends on the availability of suitable nocturnal foraging grounds, which includes flooded ricefields.

Beyond total duck numbers, there was also a greater diversity of dabbling duck species where natural wetland area was greater and/or the local habitat matrix contained large shares of natural and artificial wetlands simultaneously (that is, Camargue > Ebro Delta > Albufera > Pavia > Vercelli). In Italy, where dry ricefields are the main habitat, the duck community was simple and mostly composed of granivorous species (mallard, teal and pintail). Conversely in the Camargue, which still has a diversity of wetland types, other species like herbivorous gadwall and wigeon were more numerous. Simultaneously conserving natural wetlands and improving adjacent agricultural wetlands by appropriate post-harvest management hence

creates a heterogeneous landscape mosaic particularly attractive and beneficial to a varied waterfowl community (see also King et al., 2010). The comparison of Albufera de Valencia and the two provinces of Italy provides some insight about the extent to which flooding ricefields can provide a complement to natural wetlands: such natural and semi-natural wetlands are similarly few in all three studied areas, but ricefield flooding in the Spanish region led to much higher numbers of ducks and higher species diversity, likely because the Albufera lagoon already provided an ideal day roost and the flooding of fields made vast areas of nocturnal foraging grounds accessible to the birds.

In the Camargue, most ducks concentrating at large roosts during daylight hours disperse at dusk into a variety of shallow wetlands, 78% of which are private properties (Brochet et al., 2009). While the large day-roosts have long been identified and protected in one way or another, the provision of more nocturnal foraging grounds and the protection of some of these have now been identified as priorities for conservation (Brochet et al., 2009). The present study suggests that the simple flooding of harvested ricefields may be a valuable technique to provide such nocturnal habitats, likely translating into more abundant and varied wintering duck communities. If some flooded ricefields become completely free from human disturbance, these may even potentially turn into suitable day-roosts as observed in North America (Rave and Cordes, 1993).

We recognize that the relationship between duck numbers and area of flooded ricefields described above is based only on a correlative analysis. However, the changes in habitat management policy in the Ebro Delta and Albufera de Valencia, through the introduction of rice winter flooding AES, also provided a test of this hypothetical relationship. The trends in duck numbers in these regions were negative before the 2000s, while ducks were increasing only a few hundred kilometers to the north in the same flyway, in the

Camargue, reflecting the gradual increases in dabbling duck numbers generally observed throughout their flyway over the last decades (Wetlands International, 2014). Temporal autocorrelation analyses between these three times series (not shown) also suggest that AES implementation has now led the Spanish sites to follow the general European trend, whereas they were disconnected beforehand. The implementation of a new AES promoting overwinter flooding induced a complete change of the situation, with the Spanish regions then following a trend broadly similar to that of the Camargue, and consistent with the more general pattern at the flyway scale (Wetlands International, 2014). This result combined with the spatial analyses above jointly suggested that flooding existing ricefields is genuinely beneficial to wintering ducks, likely because this makes existing food resources within the rice stubble accessible to the birds.

Winter flooding of agricultural fields thus seems effective to provide European ducks with suitable habitat, but issues remain regarding preferential timing, depth, and duration of winter floods (see also Twedt and Nelms, 1999). Elphick and Oring (1998, 2003) observed that American dabbling duck numbers were greatest at winter flooding depths from 14 to 22 cm, and advised shallow average depths (10-20 cm), to guarantee access to available invertebrates and seed resources also to other waterbirds. Timing and duration of flooding should be adjusted among regions so as to match the birds' main autumn migration period (Elphick et al., 2010b). If fields are flooded too early, spilled grain and weed seeds may decompose or be depleted by other organisms before the arrival of migratory birds (Nelms and Twedt, 1996; Greer et al., 2009). When carefully practiced, flooding of ricefields may translate into greater local residence time of birds during winter, as observed in Spain (in the Ebro Delta, Ferrer, 1986 versus Oltra et al., 2001) or changes in the general distribution of wintering birds, as observed in California, USA (Fleskes et al., 2005). Lastly, artificially

flooded ricefields may function as a buffer during critical drought periods (Fasola and Ruiz, 1996; Tourenq et al., 2001a; Kloskowski et al., 2009), thus providing a more predictable habitat to waterbirds than some temporary natural wetlands (Márquez-Ferrando et al., 2014).

Besides the expected benefits of winter flooding of ricefields in terms of bird habitat provisioning, this practice could also bring agronomic benefits to farmers. Unlike stubble from other crops, the silica content of rice straw confers unsuitable characteristics for several uses, and rice straw disposal is a problematic issue. Burning is a common practice, e.g. in the Camargue, but causes problems of air pollution (Monier et al., 2009). Flooding of rice stubbles was introduced to California after the implementation of the California Rice Straw Burning Act (AB 1378) of 1991 which imposed a strong reduction in burning. Flooding in itself helps rice straw decomposition, which is further promoted by the trampling of waterbirds using the fields (Bird et al., 2000; van Groenigen et al., 2003). The agronomic benefits of flooding ricefields have been studied at length in North America (Manley et al., 2005), and are also being revealed in Europe (e.g. in the Camargue, Brogi et al., unpublished data).

Given the likely benefits of flooding ricefields during winter in terms of both biodiversity and agronomy, it makes sense that this practice has been supported via AES in northern Spain. Up to now, winter flooding in France and Italy (Modena and Ferrara provinces in Emilia-Romagna region) is however only promoted at a small scale by local hunting groups within some private properties (Mathevet and Mesléard, 2002; R. Tinarelli, and A. Brangi, personal communications). In Italy, Agri-Environment Schemes in Emilia-Romagna, Lombardy and Piedmont may promote winter flooding in the coming years because this has been recommended as a conservation measure in Special Protected Areas (R.

Tinarelli personal communication). There are however hurdles to the general introduction of winter flooding in European ricefields. This would for example be easier in Italy where fields are flooded by gravity than in France, where water has to be pumped from the Rhône river and energetic costs are currently too high to encourage flooding without financial compensation. Some opposition has arisen in Italy, which was in part due to the fact that some of the irrigation channels are dried for maintenance during the winter and, therefore, only a fraction of rice growers could benefit from the contribution. Invasive alien species in such artificially-created wetlands may also become an issue, and in the Ebro Delta many ricefields have actually been kept dry or flooded with sea water since 2010 as a measure against the spread of the exotic Apple Snail *Pomacea insularum* (Curcó and Bigas, 2014), although ducks can help to control this pest (Green and Elmberg, 2014). The proposed new rural development Act of the region (Pla de desenvolupament rural de Catalunya (PDR) (2014-2020) PDR 2014-2020, 2015) proposes drying harvested ricefields during winter in areas highly invaded by the Apple Snail and keeping flooding the non-affected fields.

In any case, economics are the main driving factor of these and other agricultural practices; in Spain, the financial crisis and associated political decisions likely induced the end of the financial AES winter flooding help to rice farmers in Albufera de Valencia since 2012. The proposed new rural development Act of the region (Programa de Desarrollo Rural de la Comunitat Valenciana PDR CV 2014-2020, 2015), only considers to keep flooded the lowlands ricefield until mid-January. In France as well as in Spain, it is the rice industry in general that could be affected by economic changes, especially since the CAP 2015 plans some changes to the financial support to the cultivation of this crop. As a matter of fact, changes in the agricultural landscape have already been observed (reduction of ca. 25 % of the rice in the Camargue in 2013 and replacement by dry crops such as wheat or vegetables,

C.A. Pernollet, unpub. data). In the early 1980s, the rice area in France already declined to only 4,000 because of reduced financial incentives (Mañosa i Rifé, 1997). The decoupling of the direct payments applied in the 2003 CAP have proven that they could have negative consequences on biodiversity but could be offset by strengthening AES (Brady et al., 2009).

4.1 Conservation and policy implications

The European Commission often lacks the factual data necessary to implement an AES, and scientific assessment of the efficiency of current schemes is also urgently needed (e.g. Tourenq et al., 2001b; Ernoul et al., 2013). This study shows that the flooding of rice stubble after harvest is effective in providing attractive habitat to dabbling ducks in Europe. It is easier to flood one hectare of ricefield than (re)create one hectare of natural wetland. There may be some technical hurdles to the implementation of this practice in some rice growing areas, but the environmental as well as agronomic benefits that can be expected suggest this should be promoted (and financially supported where necessary) throughout the wintering range of European waterfowl. Finally, passive flooding through rainwater retention is a low-cost procedure that could be employed in areas where flooding costs are too high (e.g. in Portugal, Lourenzo and Piersma, 2009; in Japan, Shimada et al., 2000).

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